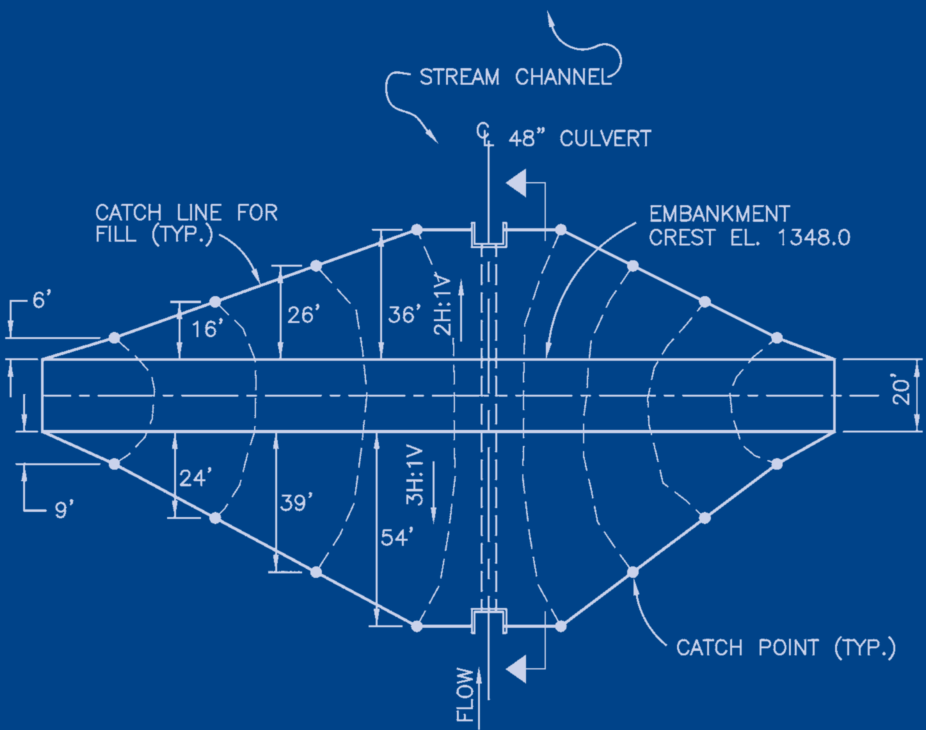
SECOND EDITION



Principles of Applied Civil Engineering Design

PRODUCING DRAWINGS, SPECIFICATIONS, AND COST ESTIMATES FOR HEAVY CIVIL PROJECTS

Ying-Kit Choi, Ph.D., P.E.

ASCE PRESS

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Preparation of Construction Specifications for Civil Projects, **by the Committee on Specifications of the Construction Institute** (ASCE Technical Report, 2013). Provides a ready, convenient resource for the recommended principles and approaches used for specification production in civil-engineered projects.

Public-Private Partnerships: Case Studies on Infrastructure Development**, by Sidney M. Levy** (ASCE Press, 2011). Demystifies public-private partnerships as an innovative solution to the challenges of designing, financing, building, and operating major infrastructure projects.

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Library of Congress Cataloging-in-Publication Data

Names: Choi, Ying-Kit.
Title: Principles of applied civil engineering design : producing drawings, specifications, and cost estimates for heavy civil projects / Ying-Kit Choi, Ph.D., P.E.
Description: Second edition. | Reston, Virginia : American Society of Civil Engineers, [2017] | Includes bibliographical references and index.
Identifiers: LCCN 2017008517 | ISBN 9780784414736 (hardbound : alk. paper) | ISBN 9780784480557 (PDF) | ISBN 9780784480564 (ePUB)
Subjects: LCSH: Civil engineering. | Construction contracts.
Classification: LCC TA147 .C44 2017 | DDC 624–dc23 LC record available at https://lccn.loc.gov/2017008517

Published by American Society of Civil Engineers
1801 Alexander Bell Drive
Reston, Virginia 20191-4382
www.asce.org/bookstore | ascelibrary.org

Errata: Errata, if any, can be found at https://doi.org/10.1061/9780784414736.

ISBN 978-0-7844-1473-6 (print)
ISBN 978-0-7844-8055-7 (PDF)
ISBN 978-0-7844-8056-4 (ePUB)
Manufactured in the United States of America.

24 23 22 21 20 19 18 17 1 2 3 4 5

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PART 2—CONSTRUCTION DRAWINGS

Preface to the First Edition

In 1984, I was hired by a nationally recognized civil and geotechnical consulting firm in Massachusetts. Three engineering degrees, all in civil engineering, and two years of teaching civil engineering at one of the best civil engineering universities in this country convinced me that I was ready for any assignment. My first task was to perform an engineer's cost estimate for an excavation to construct a new subway station in Boston. That provided the first indication that I was ill-prepared for the commercial consulting world. To complete this assignment, I had to estimate unit prices for dewatering, braced excavation, cofferdam protection, and miscellaneous earthwork items, and I had to estimate quantities based on the plan layout of the design. I had never heard of RS Means, whose construction cost data would be the basis for the unit price estimate. I was not familiar with the so-called bid schedule, which is the basis on which a contractor submits a bid and is paid for his or her work. Needless to say, that was quite an eye-opening experience for me, and after asking many questions and making many mistakes, I completed the assignment in excess of the allowed budget and beyond the assigned time.

After many small assignments in traditional foundation investigation projects in that first year, I found myself as a project engineer for a fast-track dam rehabilitation project located in Virginia. The position required me to prepare construction plans and specifications in fewer than three months. Before that assignment, I had never prepared construction drawings, nor had I ever written any technical specifications. There was a lot of quick learning on my own during this mad-paced assignment. I quickly discovered that the only resources available to me were the more experienced designers in the company and whatever examples of similar projects I could find in other project files. Ironically, even though life during this design assignment could be described as extremely unpleasant, I soon discovered near its end that I actually enjoyed sitting behind a drafting table creating construction drawings. The feedback that I received from management at the end of that assignment was that I should be more efficient in doing design work.

That was the beginning of a long tenure of a learning experience in civil engineering designs for me. During that tenure, my emphasis was in civil and geotechnical design and construction engineering. As I developed into a senior designer, I discovered that mentoring junior staff designers and working with computer-aided drafting (CAD) drafters would have been more efficient if there had been a design reference that I could have used as a teaching tool. The dream of writing a book on applied civil engineering design developed into reality when I decided to be self-employed, without the day-to-day responsibilities of project management, marketing, and proposal writing typical of most senior professionals at such a point in their careers. When the book proposal and manuscript were submitted to the American Society of Civil Engineers (ASCE) for review, the feedback from all of the reviewers was overwhelmingly favorable and supportive, demonstrating the need for such a reference in the civil engineering design profession.

The primary target audience for this book is young civil engineers and civil engineering students who want to learn how to prepare final design documents. My ultimate hope is that applied civil engineering design can be taught in a civil engineering curriculum so that young professionals will not have to learn on the job. This book is a teaching tool, and I firmly believe that abstract concepts and principles should be taught with examples and illustrations, which are plentiful in this book. Most of the examples and illustrations used in this book draw heavily from my own design experience and projects. While most of the design principles represent standard and conventional practice, there are also many design philosophy and design approaches that are my opinion. Although the philosophy and approaches are merely one man's opinion, they have worked well for me in my design career.

Besides young engineers, this book will benefit those involved with the design process—namely, the more senior design reviewers, drafters, cost estimators, and specification writers. Civil engineering design requires teamwork, and each team member has a unique role and set of responsibilities. I attempt to define the roles and responsibilities of separate design team members so that each will perform within his or her assignment. Throughout my design career, I was appalled that some design projects were not always staffed appropriately, and the results were usually cost overruns, delays, construction problems, and claims. I believe that some of these problems are caused by management's lack of understanding of the design process. With a better understanding of minimum qualifications and clear definitions of roles and responsibilities, I wish to educate the managers and decision makers as well.

This book will be valuable to contractors, particularly for their young project managers and project site engineers, many of whom are new graduates and are inexperienced in reading and interpreting construction drawings and technical specifications. Like young civil designers, these contractor personnel will have to learn on the job, with a steep learning curve. Although experience learned on the job is an essential part of one's development into a good construction manager, this book provides the developing site engineer a valuable insight into the basic principles from a designer's point of view. It also provides a background for them to effectively communicate with the designer during construction, prepare record drawings, prepare change orders and submittals, and estimate construction costs and quantities.

This book may also be helpful to owners of civil engineering projects. Whereas it is the responsibility of the design engineer to provide all necessary technical services from the inception of a project to its completion, the owner still plays a significant role. His or her responsibilities include funding and financing design and construction; applying for necessary permits and interacting with regulatory agencies; managing the performance of the engineer; establishing project design criteria and requirements; participating in the development of the construction bid schedule for measurement and payment; and managing the financial aspect and performance of the contractor during construction, including progress payments, change orders, and claims.

The vital interaction of a project owner, engineer, and contractor makes it necessary for an owner to understand the key decisions and recommendations provided by his or her engineer and the construction issues affecting the cost of the project. Of particular interest to the owners are the following topics: adequate funding of characterization of a project site and the construction cost implications of an inadequately characterized site; effective scheduling of the engineering design and preparation of the plans and specifications to allow the engineer adequate time to prepare a complete set of documents for bidding; cost implications of fair and risk-sharing approaches in contract specifications; and the strategy of bid schedule item preparation to minimize potential claims during construction.

This book is organized into four parts. Part 1 discusses the need for and scope of the book, the data that are needed for design of a civil engineering project, and how the construction drawings, specifications, and cost estimate fit into the overall scheme of a set of bid documents. Part 2 deals with the details and mechanics to prepare a set of construction drawings for a civil design project. Drawing production techniques are introduced and illustrated with examples. The use of computers and CAD is discussed. Part 3 deals with the preparation of technical specifications, with emphasis on using the Construction Specifications Institute (CSI) format. Bid schedule and measurement and payment provisions are particularly emphasized. Part 4 deals with preparation of an engineer's cost estimate, including estimating quantities and developing unit and lump sum prices. The use of various allowances and contingencies is also discussed for different levels of the design. In Parts 2, 3, and 4, the discussions of the interrelations among drawings, specifications, and cost estimates illustrate that these three documents and processes must be part of a coherent and coordinated set of documents intended to effect the successful construction of a civil engineering project.

Preface to the Second Edition

The design principles and methodology to produce civil design documents have been used for many decades by the civil engineering profession and have not changed since the first edition of this book was published in 2004. For example, the use of two-dimensional principal views, such as plans, sections, and details, in construction drawings remains the graphical medium through which the engineer communicates with the contractor, even though the methods and tools to produce the drawings have rapidly changed in the past 15 to 20 years. Written technical specifications for material and equipment requirements, installation procedures, and testing requirements still work closely hand in hand with the drawings, even though the presentation formats and technical resources have undergone many changes and updates. Nevertheless, a second edition of this book is needed for the following reasons:

- Technology, such as high-speed computers, data storage and transmittal on the Internet, new software, global positioning system (GPS), and geographic information system (GIS), has improved the data acquisition and the tools for civil design, so there is a need to update the methods and tools that are used to produce civil design documents.
- The first edition has no exercise problems, which are traditionally used in many college texts of other subjects. Because one of the main target readers is civil engineering students, the addition of some exercise problems in certain chapters will be useful as a teaching tool.
- The first edition of this book contains numerous references to documents published by various organizations such as the Engineers Joint Contract Documents Committee (EJCDC), the Construction Specifications Institute (CSI), and RS Means cost data. Some of these documents are now outdated.
- More examples and illustrations are needed to explain certain key design issues, such as constructability, loss prevention, design quality control, and changed conditions.
- The author has been teaching the subject matter for continuing education in a civil design training course. Based on the feedback to the author, some topics (e.g., permits, borrow investigation, design submittals, contractor selection process, bidding strategy, alternative pricing methods, and factors affecting pricing estimate) require more in-depth treatment.

In this new edition, the same four parts are used for Introduction, Construction Drawings, Technical Specifications, and Cost Estimating, and the book is based on the same 25 chapters. Chapter 2 undergoes the most changes and reorganization to include engineering design documents, the design submittal process, and various procurement methods to select a construction contractor besides competitive bidding. In the first edition, an appendix was used to illustrate how to present reference data in the technical specifications based on the 1995 CSI *MasterFormat*. That appendix is no longer necessary because CSI assigned specific sections in Division 00 to present available information under both 2004 and 2014 *MasterFormat*. The List of Resources provided at the back of the first edition is not included in the new edition because the Internet now provides the readers a much more rapid and updated source of information for professional organizations, government agencies, product manufacturers, and other references cited in the book.

The most notable change is the addition of exercise problems to Chapters 3, 7, 8, 9, 15, 16, 18, 19, and 22. The exercise problems not only provide hands-on experience to practice the design principles being discussed in the text, but they also allow the opportunity for further teaching. For example, among the exercise problems on establishing catch points and catch lines for excavations and earthfill in Chapter 9 are problems involving sloping excavations and sloping fills; the solutions to those problems include step-by-step illustrations of how to establish the catch points and catch lines of these more complicated geometries. Chapter 3 contains numerous exercise problems on how knowledge in engineering geology is used to characterize project sites, on construction methods, and on borrow investigation; the solutions to these problems all contain new information that is not in the main text. The author encourages the readers to review the solutions to all of the exercise problems for more learning experience, even for those who are not actually attempting to solve those problems.

When the first edition was written, the applicable CSI format was the 1995 *MasterFormat*, which was the basis for Chapters 18 and 20, as well as for illustrating the construction pricing method using the RS Means Cost Data. The 1995 *MasterFormat* has since been replaced by 2004 *MasterFormat* and 2014 *MasterFormat*. Under the current format, the 16 divisions are expanded to 48 divisions to allow the building industry to adopt new products and new construction methods and processes. For heavy civil construction, the most significant effect of the format change is the shifting of much of the work in the old Division 2 (Site Construction) to Division 31 (Earthwork Methods), Division 32 (Bases, Ballasts, and Paving), and Division 33 (Utilities). Even though much of the design and construction profession has adopted the new format, some owners and engineers still maintain and use the old format. The new edition uses the new format as the basis for assigning the divisions and sections in preparing technical specifications and pricing estimate, but at the same time the author does not discourage the discontinuation of the usage of the old format.

Acknowledgments

The author is deeply grateful to the following friends and professional colleagues who contributed to the review of this book. All of these individuals were practicing professionals with busy schedules, and yet they graciously provided the critical review on the manuscript prior to submission to ASCE. Alton P. Davis, Jr., whom the author considers his mentor, reviewed the entire draft manuscript and provided many valuable comments and suggestions. Gregg Batchelder-Adams, a former colleague and an excellent civil and geotechnical designer, reviewed Parts 1 and 2 of the draft manuscript. Ken White, a construction manager and former contractor, reviewed Part 3 of the draft manuscript. Roy Watts, a former contractor and a professional cost estimator, reviewed Part 4 of the draft manuscript. Michael Boulter, one of the most talented CAD drafters the author has known, expertly prepared all of the figures in the main text. Mr. Boulter passed away in 2013. All of the new figures added to the second edition were prepared by Warren Hofer, who is an excellent CAD designer and a former colleague. The assistance of these individuals is graciously acknowledged.

The preparation and production of the manuscript would not have been possible without the emotional support of the author's wife, LeEtta. Her constant encouragement, love, and understanding are affectionately acknowledged.

PART 1

Introduction

CHAPTER 1

Objectives and Approach

1.1 Applied Civil Engineering Design

Applied civil engineering design is a multidisciplinary process involving detailed analysis, judgment, and experience aimed at producing construction drawings, technical specifications, cost estimates, and bid schedules required to allow contractors to bid and construct heavy civil projects. Civil engineering encompasses such disciplines as structural engineering, geotechnical engineering, water resources engineering, environmental engineering, transportation engineering, and many related subspecialties. The emphasis of this book is on heavy civil construction projects, also known as infrastructure. It is interesting that there is no precise definition of *heavy civil construction.* Ringwald (1993) listed several characteristics of heavy construction projects, as follows:

- Equipment cost, expressed as a percentage of total project cost, is about 10 times higher in heavy construction than in building construction.
- Heavy construction projects tend to spread out horizontally, as compared with the vertical nature of a building.
- Heavy construction is usually performed for a public owner, whereas building work is usually performed for private as well as other owners.
- Heavy construction documents are prepared by engineers, whereas building documents are prepared by architects.
- Heavy construction is much more weather-sensitive and allows far fewer working days per construction season than building construction.

These characteristics provide an applicable description of the types of construction projects intended for this book. Examples of heavy civil construction projects, many of which are public works, include roads and highways, dams, levees, canals, foundation excavations for buildings, tunnels, bridges, airports, pipelines, drainage and flood control facilities, and urban development. A *civil engineering designer* is a specialized and experienced professional engineer who is licensed and capable of producing construction documents for these projects.

1.2 Purpose and Need

University civil engineering curricula, even at the graduate level, do not currently provide the necessary training or skills for a civil engineer to practice design immediately upon graduation from a bachelor's or master's degree program. Frequently, the design skills of a civil designer are gained through many years of design practice and mentoring under a senior professional, combined with experiences gained through field construction observations. Certainly, the basic technical background and courses in engineering graphics, computer-aided drafting (CAD), surveying, engineering contracts, and mathematics that one learns in a typical engineering curriculum are important in building these design skills. However, contrary to other design disciplines, such as mechanical, electrical, or architectural design, the production of civil engineering design documents is not taught in academia, nor are there readily available guidelines for young practicing civil engineers to gain these vital skills. Most universities offer no practical or applied civil engineering design courses, and no other references on this critical subject are currently available.

Professional organizations such as the American Society of Civil Engineers, the American Council of Engineering Companies, the Association of State Dam Safety Officials, and the CSI offer many continuing education courses to practicing civil engineers on a variety of technical and nontechnical subjects that are not taught at colleges and universities. Some of these continuing education courses are related to various subject matters of civil design, such as CSI formatting, design review of construction drawings and specifications, construction safety, and environmental permits, but there is not a comprehensive training course in continuing education on civil design. Businesses that produce CAD software and construction cost databases offer training seminars, but the primary intention of those seminars is to promote those products, rather than teaching the general principles of civil design.

It is important to point out that this book should be considered a pioneering publication on a subject that has been practiced by the profession for many years. There are numerous books that touch on portions of the subject matter, but none tie all the parts together. For example, there are many books written on engineering graphics and drafting, but the emphasis of those books is on mechanical or architectural drawing, not civil engineering layout drawing. There are many books written on engineering contracts and specifications, but typically, the emphasis is on contracts and construction administration-related matters, not technical specifications. There are many books written on engineering surveys, but not on the application of survey techniques to civil design and project layout control. Finally, there are many books written on estimating quantities or pricing construction work, but most of these books are for buildings instead of heavy civil construction, and they do not include a compilation of the entire cost-estimating process, that is, establishing a bid schedule, estimating unit price and lump sum prices, quantity takeoffs, and writing measurement and payment clauses in the specifications.

1.3 Objectives and Instructional Approach

There are three main objectives in this book:

1. Provide beginning and practicing civil engineering design professionals with a technical reference to prepare construction drawings, technical specifications, bid schedules, and engineer's construction cost estimates with consistent methodology, style, and format.
2. Provide recommended guidelines and design approaches and design philosophy to prepare quality construction documents, with emphasis on loss prevention; constructability; risk sharing; fairness; and avoidance of claims, disputes, and litigation during construction.
3. Provide a starting point for a civil engineering curriculum on which an engineering course on applied civil engineering design can be based.

This book serves the dual roles of a technical reference and of a textbook on a design discipline that has been practiced for a long time yet not traditionally taught in a civil engineering curriculum. As a technical reference, this book contains the information and industry guidelines needed for practicing civil design engineers to produce construction documents for bidding and construction. At the same time, this book relies on the traditional academic knowledge of mathematics, geology, geotechnical engineering, engineering graphics, surveying, engineering contracts, and structural engineering to provide the technical basis for the investigations and designs. The instructional methods to teach the general design principles and methods are based on the following approach:

- The application of traditional engineering graphics and CAD techniques to civil design layouts;
- The consolidation of three main components of final design—construction drawings, technical specifications, and cost estimating—under one cover and into a coordinated and interrelated set of documents that can serve as a starting reference for young professionals;
- The frequent use of common heavy earthwork and infrastructure projects, such as dams, drainage and flood control projects, and highway projects, as examples and illustrations;
- The discussion of technical specification writing using the standard CSI format and guidelines, which are the industry standard for preparing these documents;

- The inclusion of enough teaching materials, including exercise problems, that can be used to form the basis for a one-semester course for senior civil engineering students or a graduate course in civil engineering applied design practices, or for a continuing education training course in civil design for practicing civil engineers.

Because this book is also intended to be a teaching tool, numerous examples and figures are used to illustrate key points and guiding principles. General rules and guidelines are explained using specific examples. Essentially all of the specific examples used are all actual cases and from actual projects, thus allowing the readers to use real-life situations to learn general principles. Exercise problems are included in certain chapters to provide hands-on opportunities to practice key concepts and design methods. General design philosophy and design approaches are introduced as guiding principles to produce a set of quality construction documents that are coherent, well-coordinated, easily understood by the contractor, and contractually fair to all three concerned parties (the owner, the engineer, and the contractor) for heavy civil construction projects.

1.4 Use of Design Guidelines

This book introduces the conventional methods, styles, and formats for producing construction drawings and technical specifications. None of them are new, and many of them are not currently standardized. Many design firms and public agencies have their own drafting standards and specification formats and styles that they have developed through many years of use and refinement. It is not expected that these entities will replace their standards or formats with the guidelines and recommendations given in this book. That is not the intention of this book. Nor is it the intention of this book to standardize drafting of civil drawings (e.g., line weights, lettering style and heights, hatchings, and symbols). Rather, design guidelines and recommendations on the preparation of drawings and specifications are introduced in this book for the following reasons:

- To show students and young engineers some of the available tools and methods used to produce these documents. Young designers can use them as a starting point in their work, or they can use them to understand specific standards that they need to follow in their own firms or agencies.
- To show readers who are not engaged in design (e.g., contractors, cost estimators, and owners) how to understand and interpret construction documents.
- To show CAD drafters of other disciplines (e.g., architectural, mechanical, and structural engineering) the basic information and styles typically needed for developing civil drawings.

- To use them as a starting point for dialogue, future improvements, and possibly some form of standardization. The CSI already has taken an important step in standardizing the preparation of technical specifications and architectural drawings; perhaps similar effort should be extended in graphical civil engineering design.

For the current practitioners of civil design, particularly those who are directly involved with production of the drawings and specifications, they are expected to use their own judgment and experience to decide what is and is not acceptable. To a student who is learning how to draw a plan or cross section, whether by hand or on the computer, it is important that he or she start out with some basic techniques and fundamental skills that can be used as stepping stones for his or her future professional development.

1.5 Organization of This Book

This book is organized into four parts and 25 chapters. The purpose of Part 1 (Introduction) is to introduce design and construction documents, and how the products of the civil design process—namely, site characterization data, construction drawings, technical specifications, and the engineer's cost estimate—are used for design and construction of heavy civil projects. The principles, processes, and techniques of producing construction drawings and technical specifications are the subject matters of Part 2 (Construction Drawings) and Part 3 (Technical Specifications), respectively. There are a total of 17 chapters in Parts 2 and 3, and these chapters form the core of this book. Part 4 (Cost Estimating) deals with the cost forecast, funding, and payment aspects, and how the financing and cost of construction are closely related to the quality and care in site characterization efforts and production of the construction documents.

The topics and chapters in all four parts are carefully chosen to cover as much of the design process and spectrum as possible, assuming that the readers have little to no background in design and construction. In Chapter 2, three types of design and construction documents are discussed: engineering design documents, bid documents, and construction documents. It is important for a designer to distinguish the difference between designs that will not be used for construction from designs that will ultimately become part of the construction documents. Site characterization in Chapter 3 is unique for heavy civil construction because the information obtained from relevant site investigations has direct bearings on the quality of the construction drawings and specifications. Throughout this book, it is emphasized that adequate site characterization is absolutely essential for a successful design and to avoid claims, disputes, and litigation during construction.

Many of the 10 chapters in Part 2 cover the best practice of producing quality construction drawings, from basic and minimum information that should be in the drawings to graphical techniques to produce two-dimensional principal views for a designer to communicate graphically with the contractor. Specific attention should be paid to the roles and responsibilities for various design team members (that is, designer, checker, drafter, and technical reviewer) during the production and quality control of construction drawings. Even though most civil design in the United States continues to be prepared in U.S. customary units, design in the metric system is introduced in Chapter 10 for those who may have the opportunity to practice metric design within or outside the United States. The production of construction drawings is now universally done in CAD, which is the subject matter of Chapter 11. CAD software in this book is portrayed as a modern-day tool only, and it should not replace the traditional principles of sound engineering design, good judgment, and experience. Chapter 12 is a discussion on the practice of certifying construction drawings by professional engineers, which is done at the end of final design and also at the end of construction. Many of the target readers of this book are young engineers who start out as staff engineers in the organization and will not be senior enough to stamp drawings, but eventually they will advance in their careers and become senior designers.

Similar to Part 2, many of the seven chapters in Part 3 cover the best practice of producing quality technical specifications, from avoiding many of the common problem areas to good narrative and writing skills for a designer to communicate with the contractor. Chapter 18 introduces the CSI format, which is commonly (but not universally) used for technical specifications in the United States and Canada. Chapter 19 covers the process of preparation of the bid schedule and the related measurement and payment clauses, which are incorporated into the specifications package for bidding and construction payment purposes. The method of presenting reference data in the specification package, such as field investigation data for site characterization, is discussed in Chapter 20.

In Part 4, the methods and practice of estimating quantities and prices are presented in Chapters 22 and 23, respectively. Cost allowances and cost contingencies during design and during construction of heavy civil projects are discussed in Chapter 24. The final process in design, discussed in the final chapter of this book, can be taken as the bidding and award of the construction contract to the successful bidder. The award of the construction contract is the end of the design phase and the beginning of the construction phase.

CHAPTER 2

Design and Construction Documents

2.1 Types of Documents

One of the key objectives of this book is the production of engineering design documents that will be first used for bidding to solicit a contractor for construction, and then subsequently used as technical requirements to construct the project. The process considered in this chapter and throughout this book is for the conventional design-bid-build construction procurement arrangement that has been used successfully for many years for heavy civil projects. For a design-bid-build project, the engineering design documents are prepared by the engineer under contract with the owner. A contractor is selected through a bidding process, and the contractor then enters into a construction contract directly with the owner. Recently, the design-build procurement arrangement has been used for construction, including some heavy civil projects such as highways. For a design-build project, the contractor is usually under contract with the owner both to produce the design documents and to perform the construction, and the engineer is usually under subcontract with the contractor to produce the design. There are some advantages to the design-build approach, such as cost savings to the owner and savings in construction duration. Although some of the bid documents and bid processes in the design-bid-build arrangement are still applicable for the design-build method, no further reference will be made on the subject of design-build in this book.

This chapter presents an overview of the three main types of design and construction documents for heavy civil construction projects:

- Engineering design documents—These documents include those produced during planning and conceptual studies, final design documents such as construction drawings and technical specifications, and various reports.
- Bid documents—These documents include an invitation to bid, contractual and administrative documents that are nontechnical, draft or final design drawings and technical specifications, reference data from site investigations, and the bid schedule.

- Construction documents—These documents are used for construction of the project after the bidding phase is completed and after a construction contract has been awarded, and include the general and supplemental conditions, final construction drawings and technical specifications, and the payment schedule.

Note that the drawings and specifications are common to all phases of the project, namely, the design phase, the bidding (or solicitation) phase, and the construction phase. This chapter presents details of each type of document in each of the three phases, but with an emphasis on the engineering products (that is, the drawings and specifications) and how they fit in and evolve as the project progresses from the beginning to the end. The intention of this chapter is to provide a big picture overview of the roles of the engineering products before the principles and techniques to produce these products are introduced in Parts 2 and 3.

2.2 Engineering Design Documents

The engineering design process usually involves various levels, with each subsequent level more involved and detailed than the previous one, culminating in the so-called final design. For heavy civil projects, there may be concurrent site investigations to obtain relevant data for design at each level of design. Details of various design levels are discussed in Section 4.2, and details of various levels of site investigation are discussed in Section 3.9. Broadly speaking, engineering design documents can be divided into two categories:

Documents not for construction—All designs before final design (e.g., during planning level or conceptual level design) are considered "studies," and the products of these studies include design drawings, design reports, data reports, and engineer's cost estimates. These design documents are intended to evaluate technical feasibility and cost feasibility of various alternatives and options to meet project goals and objectives, and to provide a basis for funding the project. Note that there are no technical specification documents necessary for design studies; all technical requirements are included in the design drawings or described in the design reports.

As discussed in more detail in Section 4.2, the design drawings in planning-level or conceptual-level designs are not prepared with the same details as final design drawings because construction of these project features is not necessary. In fact, the designer should refrain from putting excessive details (e.g., rebar sizes, fastener sizes, or detailed survey controls) on these drawings. Design drawings in these early design studies should contain only enough details to illustrate the concept and constructability, and to give a reliable construction cost estimate.

Documents for construction—These documents are produced during final design and include construction drawings and technical specifications, design reports, bid schedule, and engineer's cost estimates. Some of these documents are intended to be used by the contractor, construction manager, and inspector for bidding and construction, but some documents are prepared only for the owner of the project. Typically, the preparation of final design engineering documents is done in several progress submittals to the owner or project reviewers and regulators. These milestone design completion stages can be expressed in terms of *percent completion*. There are no fixed rules about what percent completions are appropriate, and sometimes the number of intermediate design submittals depends on the project schedule and the review requirements. For example, there may not be adequate time for progress submittals for a fast-track project or for emergency repairs. In any case, under normal circumstances, the following are some guidelines on milestone design submittals:

- Early submittal: 30–35% completion,
- Intermediate submittal: 50–65% completion,
- Substantially complete draft submittal: 90–95% completion, and
- Final submittal: 100% completion.

The submittal contents (so-called "deliverables" in the consulting industry) are different for different milestone design submittals. Table 2-1 contains guidelines of final design submittals for construction drawings, technical specifications, cost estimates, engineering calculations, and design reports. These guidelines provide the designer with priorities and dedication of design resources to produce various design documents. In many cases, the actual deliverables in a design project are specified in the design contract between the owner and the engineer.

It should be noted that the design drawings and technical specifications at 100% design completion are not necessarily the documents used in construction. As discussed in Section 13.1, drawings and specifications may change during the bidding phase, and the updated documents with those changes (so-called "conformed documents") are actually used in construction.

Whereas the drawing and specifications are used by the contractor and the construction inspection and management team, the design report is prepared by the engineer for the owner. The design report should include the project goals and objectives, design criteria, design basis and requirements (technical and nontechnical), descriptions of the project design features, engineering assumptions and calculations, designer's operating criteria of the new project features, key construction considerations and construction schedule, and documentation of the construction cost estimate. Even though the construction cost estimate is usually part of the design report, the cost estimate summary and backup calculations are usually confidential, and therefore this information is removed from the report as a

Table 2-1. Final Design Submittal Requirements

Percent Completion	Construction Drawings	Technical Specifications	Cost Estimate	Engineering Calculations	Design Report
30–35%	Plan of existing conditions Construction survey and project features controls Plan and typical sections of critical project features Critical details to support proposed concept	Partially completed Division 1 sections, Part 1–Part 3 Partially completed Part 1 only of other divisions and sections	Preliminary bid schedule Construction cost estimate with proper design and construction contingencies (optional)	Key calculations to support feasibility of critical design features	Report outline Technical memorandums (TMs) of data collection, including geotechnical investigations and borrow investigations Design criteria and TMs, including design flood, static, and seismic loads
60–65%	All partially completed site drawings, including existing conditions, survey, borrow, contractor staging, and stockpiles Partially completed civil plan, sections, profiles, and details of all critical project features Partially completed structural and mechanical plans, sections, and profiles of all critical project features, including key dimensions	Substantially completed Division 1 sections Partial completion of other divisions and sections, Part 1–Part 3 Partially completed measurement and payment clauses to match bid schedule	Substantially completed bid schedule Construction cost estimate with proper design and construction contingencies	All engineering calculations to support all design features completed Checking of calculations in progress	Partially completed report, including sections on design criteria, descriptions of key design features, basis and assumptions of design, and methodology used in design analysis Include all supporting TM and backup calculations

90–95%	All substantially completed drawings, all sheets: general site drawings, civil drawings, structural drawings with reinforcement details, and mechanical and electrical drawings	All substantially completed divisions and sections, including measurement and payment clauses	Update of 60–65% bid schedule and cost estimate	All engineering calculations to support all design features completed Checking of all calculations completed and properly documented	Substantially completed report in its entirety, including all section text, appendixes, and technical memorandums
100%	All drawings completed, stamped, and signed	All divisions and sections completed, stamped, and signed	Update of 90–95% bid schedule and cost estimate No design contingency is allowed	All engineering calculations checked and properly documented	Final report, stamped and signed, with all appendixes and backup calculations

stand-alone document. It is important that the bidders and the eventual contractor do not have access to the engineering design report and the cost estimate.

2.3 Construction Contract Documents

Construction documents are used for bidding and construction of projects. During bidding, the construction documents are part of the bidding documents; after the contract is awarded, these construction documents, which are the contract scope of work and technical requirements, become part of the contract documents. The administrative components of the contract documents are the general conditions and supplemental conditions, and the technical components are the construction drawings and specifications. The administrative documents (so-called “boilerplate” documents) are typically prepared and furnished by the project owner and can be reviewed by the engineer for consistency and coordination. The technical requirements are prepared by the engineer during final design. Preparation of construction drawings and specifications are the primary subject matter of Parts 2 and 3, respectively, of this book. The administrative and technical components of the contract documents are interrelated, and it is important to understand the general relationship between the two components before proceeding with preparation of the technical documents. For this reason, an overview and background on contract documents are given in this chapter; however, an in-depth treatment of the administrative documents is beyond the scope of this book.

An understanding of the process of competitive bidding is also important in learning how to prepare a bid schedule and the related measurement and payment provisions. During final design, the engineer discusses with the owner the bidding strategy and prepares payment arrangements for the construction. Preparation of a schedule for bidding, measurement and payment provisions, bid quantities, and estimated construction costs are the primary subject matter of Part 4 of this book.

Bid Documents

Bid documents are information furnished to the bidders during the bidding period. These documents typically include an invitation to bid, instructions to bidders, bid forms, general conditions, supplemental conditions, construction drawings, technical specifications, and amendments. All contractual, administrative, and technical requirements are contained in these documents. These documents define the duties and responsibilities of all parties involved, namely, the owner, the contractor, and the engineer. For federal construction, the contractual documents are contained in the construction contract clauses of the Federal Acquisition Regulations (FAR), but they contain similar types of information as the documents for private-sector construction. The following are brief descriptions of these documents. Detailed descriptions are available in many publications for construction management (Fisk 1992; Knutsen et al. 2008).

- *Invitation to Bid*—This document is used in advertising to solicit bidders for construction work, and it includes some of the information used in the bid advertisement (see Section 2.4).
- *Instructions to Bidders*—This document contains procedures for bidding, basis and criteria that will be used for bid evaluation, and guidance to bidders for other relevant information contained in the bid documents.
- *Bid Forms*—This document is used by the bidders to submit their bid prices and to document the basis contained in their bids. In many cases, a *bid schedule* is attached as part of the bid forms. The bid schedule (see Section 19.2) contains all of the payment items, quantities estimated by the engineers, measurement units, and owner-defined allowances for specific items.
- *General Conditions and Supplemental Conditions*—The general conditions and supplemental conditions are provided to bidders during bidding because they will become part of the legal contract documents after award of the contract.
- *Construction Drawings and Technical Specifications*—Drawings and technical specifications contain all of the technical requirements to construct the project. It should be noted that the technical specification package should also include reference data collected during design and investigations (see Chapter 20).
- *Amendments*—Bid amendments are owner-initiated changes or new information furnished to the bidders during the bidding period. After the contract is awarded, the bid amendments become part of the contract documents.

Construction Contract Documents

A heavy civil construction contract typically contains the following documents: agreement, general conditions, supplemental conditions, amendments, pricing schedule, construction drawings, and technical specifications. The pricing schedule is based on the successful bidder's prices entered into the bid schedule. All of these documents are considered legal documents, and the contents of these documents should be carefully compiled (or conformed) to avoid disputes, ambiguities, conflicts, and unnecessary information. Generally, the agreement, general conditions, and supplemental conditions are *contract forms* furnished by the owner, and the bid schedule, construction drawings, and technical specifications are prepared by the engineer. Together, they define how construction work will be performed and completed, how the contractor will be paid, the project schedule, bonding and insurance requirements, construction management and inspection, change orders, claims procedures and timing, and actions for breach of contract.

The agreement, signed by the owner and the contractor, is the legal document that takes precedence over all the other documents in a construction contract. It makes reference to all other pertinent documents and is usually a standard form that varies for different owners.

The general conditions of an engineering construction contract define the duties and responsibilities of the owner, contractor, and engineer. They address all issues related to the administration and management of the contract and include such items as bonding and insurance; procedures for changes in work scope, schedule, and prices; warranty and guarantee; payment procedure and method; and dispute resolution. It is not the intention of this book to examine and scrutinize the contents of the general conditions, except in instances in which they affect the drawings, specifications, and engineer's cost estimate. Like the agreement, the general conditions are contained in standard documents that normally do not significantly change from project to project for a particular owner. Any changes to the general conditions are contained in the supplemental conditions.

The supplemental conditions (also called *special provisions*) should be considered an extension of the general conditions and are used to address site-specific requirements and unique characteristics for each construction project. In other words, any deviations from the general conditions should be handled in the supplemental conditions. Examples of items contained in supplemental conditions include specific bonding and insurance requirements, specialty items of work to be performed by qualified subcontractors, liquidated damages, project permits, local laws and regulations, site restrictions, coordination with other work on site, and site safety.

It is important for the engineer to understand all of the requirements in the general conditions and supplemental conditions so that they are consistent with the construction drawings and specifications. To avoid costly changes caused by conflicts and inconsistencies among these documents, coordination of the contract forms and the technical documents should be done before bidding and contract award.

For the resolution of conflicts and inconsistencies among various contract documents, the contract usually contains a definition of the hierarchy of these documents. With some exceptions, the typical hierarchy of contract documents, in order of decreasing precedence, is (1) agreement, (2) general conditions, (3) supplemental conditions, (4) amendments, (5) technical specifications, and (6) construction drawings. From a design standpoint, the fact that the technical specifications take precedence over the construction drawings is highly significant. Some of the implications of this hierarchy between drawings and specifications are discussed in Section 14.4.

Engineers Joint Contract Documents Committee Documents

There are numerous variations of bid documents and contract forms among different government agencies and among private-sector owners. Most engineering firms also have their own versions of the documents that they use for their clients. Because these documents are legal documents, any problems that arise out of a dispute in these documents may be subject to interpretation in a court of law. In an attempt to provide standard construction documents to the engineering industry, a group known as the Engineers Joint Contract Documents Committee (EJCDC) was organized. The EJCDC consists of the National Society of Professional Engineers, American Council of Engineering Companies (formerly American Consulting Engineers Council), American Society of Civil Engineers, Construction Specifications Institute, and Associated General Contractors of America.

EJCDC documents include bid forms, instructions to bidders, general conditions, and agreements between the owner and contractor. Some of these publications are used as guidelines, and some can be used in contract documents without changes. All of these documents are the products of many years of study, research, legal interpretations, and court decisions, and they are endorsed by most engineering professions and contractors. The contractors' endorsements suggest that these documents represent not only the interests of the owner and the engineering profession, but also the interests of the construction industry as well.

EJCDC documents are available through its website www.ejcdc.org, or through the member organizations, such as the American Society of Civil Engineers, http://www.asce.org/contractdocuments/.

2.4 Contractor Selection Processes

There are several methods to select a contractor for heavy civil construction under the design-bid-build procurement arrangement; competitive bidding is the most common. Other methods include the best value method and sole-source negotiation.

Competitive Bidding Method

In competitive bidding, the bidder with the lowest responsive bid is selected as the contractor. Typically, the owner, or his or her representatives or agents, manages the bidding process. Briefly, the competitive bidding process consists of the following steps:

Advertising—A construction project is advertised to solicit interest or bids from interested contractors. The advertisement generally contains information on the owner, project location, general scope of work, minimum qualifications, and a range of construction costs. The cost range indicates the size of the project, which provides a means for the bidder to determine whether he or she can be bonded to perform the work as well as the resource capability. The cost range also prevents a small contractor from bidding on a large project. The advertisement also indicates where bid documents are made available to prime contractors, subcontractors, material suppliers, manufacturers, and distributors.

Prebid meeting—A meeting with prospective bidders is conducted at the beginning of the bidding period. The purpose of this meeting is to explain the work scope and other administrative requirements to the bidders; it usually includes a visit to the project site. Some owners make this meeting mandatory, but others, such as the federal government, do not. Questions raised by bidders during this meeting and the answers to those questions are generally recorded and distributed to everyone on the plan holder's list as an amendment to the bid documents.

Issuance of bid amendments—Additional information provided to the bidders during bidding are called *amendments* or *addenda*, and they are considered legal parts of the bid documents. Amendments may include answers to bidders' questions, design changes, changes in bidding period or construction period, new field information, or other added requirements (e.g., permits). To allow bidders adequate time to respond and adjust their bids where appropriate, it is generally a fair practice to extend the bidding period when a bid amendment is issued close to the bid opening deadline. It is important that a record is made of all those receiving the addenda, either through the use of certified mail, records of fax transmission, and electronic mail. Failure of a bidder to acknowledge receipt of a bid amendment can be grounds to disqualify that bidder.

Bid opening—Bid opening occurs at, or shortly after, the bid submittal deadline. Bid opening can be open or closed to the public, depending on the owner of the project. In general, all bids received are summarized in a form called a *bid tab* using the format of the bid schedule (see Chapter 25). The bidder that submits the lowest bid price is declared the "apparent low bidder." It should be noted that any changes in the design and any changes to the work requirements after the bid opening are considered "scope changes" and should be properly handled through formal "change orders."

Bid evaluation—The owner, with assistance from the engineer, generally evaluates the low bid and other bids to determine (a) whether the apparent low bidder has adequately responded to the work requirements in his or her bid; (b) whether any unbalanced bidding (see Chapter 25) has taken place; or (c) whether there are other omissions of bid submittal information. When it is necessary to obtain the basis for, and confirmation of, any items in question, the owner may request a bid verification from the apparent low bidder. One of the reasons for bid verification is to check whether a bidder has responded adequately to the work requirements. For example, if the work requires the contractor to process on-site materials to manufacture a clean filter aggregate, but the bidder submits a price to import the material from an off-site commercial source, then that bidder is considered to be nonresponsive. In some cases, the owner will meet with the apparent low bidder to better understand the bid and negotiate changes before award of the contract. This bid verification meeting is also called "bid hearing."

Contractor selection—If the owner is satisfied with the bid, the apparent low bidder is selected as the contractor. A construction contract is established between the low bidder and the owner. For the engineer, the bidding process ends here, and construction management begins. Construction management is beyond the scope of this book.

Best Value Method

In competitive bidding, the low bidder is usually awarded the construction contract. From time to time, depending on the circumstances and the type of work, the contractor that is the lowest bidder is not necessarily the best-qualified contractor, in terms of capability, experience, and resources. The best value method in contractor selection considers the bid price as well as the qualifications and has become more popular in contractor selection, especially among federal agencies. To evaluate the contractor's qualifications, the bidders are required to answer a series of questions related to the contractor's experience and records, especially on specific aspects of the construction that will be performed. For example, if the project being bid is to stabilize a landslide with posttensioned rock anchors in a clay shale foundation, then the contractor's team experience and personnel with installing posttensioning rock anchors in a weak shale is very important. When evaluating the bids, both the bid price and the qualifications are assigned weights and points, but the formula to weigh the price and qualifications varies from owner to owner. Sometimes, the successful bidder does not necessarily have the lowest price. This method is best used for specialized heavy civil construction and is not needed for the so-called "curb and gutter" work.

Sole-Source Negotiation Method

In the sole-source negotiation method, the owner identifies a particular contractor and negotiates the price of the construction until an agreement is reached. This is the least price competitive, as the contractor will have little to no incentive to bid low prices without any competition. This method is rarely used in private-sector construction, but it is used from time to time by federal agencies to meet small-business or minority-business goals. This procurement method has several potential problems, such as the following:

- The small or minority contractor is not necessarily the best qualified to do the work. Not only will the quality of work suffer, but also there is an increased likelihood for claims, disputes, and delays.
- The contractor has limited bonding capability and can only perform small projects.
- The owner pays a much higher price for comparable work than when using a large contractor procured competitively.

Not much can be done about the higher price, but the owner can do some up-front research and inquiry on available small and minority contractors to screen out unqualified bidders before identifying one for negotiation.

2.5 Permits for Construction

Project permits are typically included as part of the construction contract documents. In most heavy civil construction, project permits should be obtained by the owner before beginning construction. Most of these permits are issued by regulatory agencies for environmental control, and stipulations are included in the permits as conditions for construction. The contractor is required to abide by the conditions set forth in the permits the same way that he or she should conform to the plans and specifications.

Permitting issues on the federal level are based on federal environmental laws to ensure that

1. There are no impacts to federally listed threatened or endangered species as required by Section 7 of the Endangered Species Act. The Endangered Species Act is a federal law passed by Congress in 1973 and administered by the U.S. Fish and Wildlife Service and the National Oceanic and Atmospheric Administration. Compliance with the Endangered Species Act is typically addressed by the local ecological services unit of the U.S. Fish and Wildlife Service.
2. There are no impacts to cultural resources in accordance with Section 106 of the National Historic Preservation Act. The National Historic Preservation Act is a federal law that was passed by Congress in 1966. The act requires federal agencies to evaluate the impact of federally funded or permitted projects on historical properties such as buildings or archaeological sites. Compliance with the National Historic Preservation Act is typically addressed at the state level by the state historic preservation office.
3. There are no impacts to jurisdictional wetlands in accordance with Section 404(b) of the Clean Water Act. The Clean Water Act is a federal law passed by Congress in 1972. This is the primary federal law governing water pollution and is administered by the Environmental Protection Agency in cooperation with state governments. Wetlands impacts are typically addressed by the local office of the U.S. Army Corps of Engineers.

The 404 Clean Water Permit issued by the U.S. Army Corps of Engineers is required if construction will take place in or near regulated land such as wetlands and waterways. This federal permit is named after Section 404(b) of the Clean Water Act. Stipulations contained in the 404 Clean Water Permit may include limits on turbidity of construction water (e.g., dewatering discharge or runoff) discharged into streams, limits of wetlands that can be disturbed or filled, and protection of aquatic and riparian vegetation and fisheries. These conditions must be enforced during construction, and the owner will usually pay fines associated with noncompliance. In some cases, failure to comply with these conditions will result in a construction *stop work order* by the regulatory agency.

When work is performed on federal land, a special-use permit is usually issued by the federal agency that owns the land, with additional stipulations regarding allowable access, schedule and disturbance, and reclamation of disturbed areas.

Because of the consequences of a permit violation, all owner-acquired permits should be made part of the bid documents and construction contract documents so that appropriate actions and costs are included in contractors' bids. Owner-acquired permits that are added after bid opening are regarded as scope change, and the contractor is entitled to adjustments to the contract prices or time to abide by the requirements of the added permits.

It is important to point out that this discussion excludes the permits that the contractor is required to obtain during construction. Those permits are the sole responsibility of the contractor and are required for such things as hauling on, and access to and from, local and state highways; blasting; quarry development; and disposal of dewatering and hazardous wastes.

CHAPTER 3

Characterization of Project Site

3.1 Importance of Adequate Site Characterization

This chapter describes the key characteristics of a heavy civil project site that are important for design, and how to obtain information about those characteristics. Central to characterizing a site for a civil design project is the definition of the existing conditions that are relevant to that particular project. Most of the effort in characterizing a site involves understanding what is in the ground and describing the topography of the ground surface and surface features. Some heavy civil projects are located in environmentally sensitive areas that will require a thorough environmental survey in order to comply with environmental laws and to acquire the necessary permits.

Civil design starts in the field with field investigations to explore the site and ends in the field with construction. Contrary to architectural, mechanical, electrical, and structural designs, the design of heavy civil projects is intimately tied to the field conditions before construction and during construction. Site characterization establishes a baseline field condition for a project site, which is important for design and construction in the following respects:

1. Changes in site grades are compared with the existing ground surface to determine the limits of excavations and the fill quantities in earthwork design;
2. Geotechnical design for new foundations, excavations, earthfill, dewatering, drainage, and other earthwork features is controlled by geology and subsurface conditions, including groundwater conditions;
3. Large earthwork projects usually involve owner-furnished borrow sources (see Section 3.4 on borrow investigations), which are investigated to determine suitability, quantities, and costs;
4. Many times, knowing how the project site has been developed and used in the past will provide useful information for feasibility, planning, and permitting;
5. Environmental surveys are important for designs to mitigate potential environmental issues and for success in procuring environmental permits from regulatory agencies; and

6. Information obtained from topographic surveys is used to create the base map for design drawings, to establish design and construction controls, and to determine such levels of effort as clearing, demolition, reclamation, and construction access.

Site characterization work is usually planned and performed by specialists in their own disciplines, such as geologists, geotechnical engineers, land surveyors, and environmental scientists. Data are collected and then used for design. Sometimes, civil designers are involved in the project only after completion of site characterization work, which is not recommended. Without input from the designers during site characterization, it is possible that key information may be missed. At that point, three scenarios are possible:

1. The designer recognizes what is missing, and the missing information is obtained with additional field work;
2. The designer recognizes what is missing, but has decided that the missing information will be obtained during construction instead of during design; or
3. The designer does not recognize that key information is missing, and the design is completed without that key information.

All three of these scenarios are problematic. For Scenario 1, the interruption of design to collect additional data will result in delay in the design schedule and additional costs for the field work. Nevertheless, the design will be completed with no design problem. For Scenario 2, the procrastination of obtaining the missing key design data until construction will likely result in a variety of design and construction problems, ranging from design errors to contractor claims for changed conditions. For Scenario 3, a serious design error may occur without the key missing information, and the error will need to be corrected during construction. When a design is changed during construction, a change order will be needed to address the changes, with increased costs and schedule delays. All of the issues discussed in these three scenarios will be explained in detail in the remainder of this book. There are numerous examples and illustrations in Parts 2, 3, and 4 of this book, where the main reason for the problems in the production of construction drawings, technical specifications, and cost estimates is because of inadequate site characterization. Carrying unknown site conditions into construction is a potential liability for the designer, and inadequate site characterization may be considered a design error.

Two general guiding principles are recommended in this discussion:

1. Designers should be involved to provide input to site characterization field work so that adequate data are collected for design at the beginning of the project.
2. To the extent possible, investigations for site characterization should be completed during design and should not be delayed until construction.

The results of the various site characterization investigations are summarized in various reports or technical memoranda that are submitted to the owner and provide data and the basis for the design work (see Section 2.2). During construction, these field and laboratory data should also be furnished to the contractors for evaluation and planning of means and methods, and this information also serves as a baseline and the basis for their bids. The Construction Specifications Institute (CSI) has provided an orderly way to present these reference data, as discussed in Chapter 20.

3.2 Geologic Investigation

The importance of geology in heavy civil projects is well-established (Legget and Karrow 1983). Because of the existing information that is readily available, most projects in developed urban settings do not require a geologic investigation, and a literature search may be all that is required. However, when a project is located in an undeveloped area, a geologic investigation is vital to the understanding of geotechnical and foundation issues that are relevant to the project. A geologic investigation may include geologic reconnaissance, a literature search, aerial photography, detailed structural geology mapping, trenching, and laboratory testing. The level of investigation would depend on the size of the project, the complexity of the geology, and the design's dependence on geologic factors, such as fault activity and seismicity estimates. In a seismically active region and for projects that impose large risks to public safety (e.g., dams and nuclear power plants), a deterministic seismotectonic assessment or a probabilistic seismic hazard assessment (PSHA) usually is required to determine the seismic design loading conditions. In recent years, the PSHA is preferred over the deterministic approach in assessing seismic loading conditions because many of the public agencies have adopted the application of risk analysis for public safety (USBR 2011a).

Engineering geology is the discipline of applying knowledge of geology to engineering problems. In some cases, understanding the geologic setting for a particular project can identify potential problems. For example, the subsurface condition in a glacial till setting is highly variable, with significant amounts of cobbles and boulders that may affect the feasibility of some types of foundations. Young lacustrine deposits such as fine-grained silts and clays yield low strength and large settlements. Some windblown deposits are collapsible upon wetting and are highly erodible by flowing water. The existence of soluble minerals such as gypsum and carbonates in rock formations may lead to the development of sinkholes, subsidence, and excessive foundation leakage under water-retention structures. In the western United States, high-plasticity claystones and clay shale are prevalent, and these materials frequently give rise to foundation swelling problems and slope stability problems.

Understanding the geologic setting frequently provides guidance in planning a subsurface investigation. For example, a particular drilling or sampling method is preferred over others because of the presence of boulders and cobbles at one site or the presence of sands and gravels at another site. Or when the beddings and joints in foundation bedrock are near vertical, an inclined core hole is preferred over a vertical core hole in order to intercept more rock discontinuities. A borrow investigation (see Section 3.4) to explore sources of clean granular aggregates will focus within the alluvial floodplain where sedimentary clean sand and gravel were deposited.

One of the objectives of a geologic reconnaissance is to identify geologic hazards for further study and evaluation. Geologic hazards that may affect the performance of civil engineering projects include earthquakes, landslides, rockfalls, and ground subsidence. The effects of large earthquakes on a structure include large ground motions, ground liquefaction of saturated granular soils, and fault offsets in the case of active faults. Contrary to earthquake hazards, which occur in seismically active areas, landslides can occur anywhere in topographically steep areas. Active landslides can be mitigated, but this work is usually very costly. Rockfalls are common hazards along highways that are adjacent to steep rock cuts, and mitigating this hazard by the highway departments is always a continuing maintenance activity. Ground subsidence and sinkholes occur when underground voids collapse. Underground voids can be natural or created by human activities. Natural underground voids occur in limestone areas (e.g., Florida and Kentucky). In some states with old abandoned underground coal mines (e.g., in Wyoming, Colorado, and West Virginia), local or large-scale ground subsidence can occur from the collapse of these mines.

3.3 Subsurface Investigation

Subsurface investigation is used to obtain geotechnical information for foundations and earthwork design, to evaluate the constructability of excavations and backfill, and to estimate groundwater problems and mitigation methods. When a project requires the use of on-site fill materials, a borrow investigation should be performed to evaluate the suitability and quantity of materials that are available (see Section 3.4). Subsurface investigation includes drilling boreholes and excavating test pits, field and laboratory testing, field monitoring of groundwater levels and groundwater quality, and geophysical investigation. The technical reasons for an adequate subsurface investigation and the methods of subsurface investigation (e.g., Hvorslev 1949; Clayton et al. 1982; Winterkorn and Fang 1975; Terzaghi et al. 1996; Head 1980a) are not discussed in this book. Also not discussed are geotechnical analyses, such as determination of bearing capacity, settlements, shear strength, and groundwater modeling. Only issues pertaining to constructability, construction problems, site safety, construction document preparation, and cost estimates related to subsurface conditions are discussed herein.

In addition to foundation analysis and the selection of the type of foundation, many design- and construction-related issues must be evaluated by the geotechnical designer, such as:

How is the earthwork constructed?—A geotechnical designer should have an understanding of how the specified earthwork will be constructed. Such understanding includes the construction equipment, sequence of placement, constructability constraints, and the installation procedure, and this understanding is valuable in the preparation of construction drawings, technical specifications, and even construction cost estimates. Without a clear understanding of how the earthwork is constructed, the designer may not provide adequate instructions to the contractor to meet the design intent, even though the contractor is responsible for the means and method of the construction. Two examples are used to illustrate this discussion:

- Constructing a Sloping Chimney Drain—Chimney drains are frequently used in embankment dam design to filter and collect internal seepage in a dam (e.g., Cedergren 1997; FEMA 2011; USBR 2011b). For example, an inclined clean filter sand is required adjacent to the clay core of an embankment dam for seepage control. It is understood by the designer that both the drain and the clay core will be placed concurrently in horizontal lifts. It is of paramount importance that the clay core material does not contaminate the clean sand. This requirement can be simply stated in the specifications, and the contractor will protect the sand from being contaminated. The contractor's effort may or may not be successful, depending on the experience and method he or she is using. An experienced designer will choose a more proactive approach to minimize the potential contamination of the sand chimney by adding two requirements in the specifications: (1) the drain sand in the chimney should be maintained at least 12 in. above the surrounding clay core material; and (2) the lift surfaces of the clay core material adjacent to the chimney drain should be sloped away from the chimney drain.
- Processing Clay Shale Bedrock for Clay Fill—The contractor is required to process a highly weathered clay shale bedrock into a clay fill for use in a highway embankment. This construction method is based on a material behavior known as *slaking*, whereby a plastic shale bedrock rapidly deteriorates into a soil-like material upon cycles of wetting and drying. Not all contractors are familiar with this method, and sometimes even a test fill is not successful to produce a satisfactory product. An experienced designer will provide the additional guidelines to the contractor so that the test fill will produce a satisfactory material: (1) after the shale is excavated and stockpiled in the borrow area, water should be added to the stockpile to hydrate the rock; (2) a minimum *tempering* time is needed for the rock to absorb the water on a clay-particle level; and (3) the fill should be thoroughly mixed and broken down with a disk.

Can a design from a previous project be reused?—A common error made by inexperienced designers using precedents to justify their design is to ignore the special circumstances and foundation conditions that are unique to that particular site. A design that had worked in a previous project may not be appropriate for the current project because of different foundation conditions. For example, a clean filter sand drainage blanket may be effective for seepage collection of a silty and clayey foundation subgrade, but is not effective for a silty sand foundation. Instead, a two-stage filter sand and gravel drainage blanket would be more appropriate. The requirement of a two-stage drainage system would have been apparent if a seepage analysis was performed with properly assigned permeabilities for the drains and foundations.

What excavation method is appropriate?—Many designers maintain that selection of an excavation method is not their concern because means and methods are the responsibility of the contractor. To a certain extent, this is correct. Construction documents should be prepared to allow a contractor the freedom and flexibility to use whatever method and equipment he or she deems appropriate for a given site. This approach of not specifying the means and method of construction usually results in the most cost-effective construction method (see Section 15.5). However, when a designer or a cost estimator is required to estimate the cost of excavation, it becomes necessary to assume a specific method of excavation as the basis of the cost. The cost of excavation varies greatly for different types of soil materials, different soil densities or stiffnesses, and different degrees of saturation. Earth excavation methods, such as backhoe excavation, would be inappropriate for hard bedrock. Soft rock or highly weathered rock can be excavated by a hydraulic excavator or ripper, but hard rock requires blasting. Because of bearing pressure limitations, only certain construction equipment and excavation methods can be used for very soft subgrades. Without adequate subsurface investigation, the excavation cost cannot be estimated reliably both by the designer and by the contractor, and the consequence is usually a construction claim for differing site conditions or excessively high bids to account for unknown conditions and risk.

Is the site safe for construction?—Site safety is a construction issue (see Section 15.12). It is discussed here in relation to design of earthwork. Most civil drawings depict a maximum slope inclination for temporary excavation, and the contractor is also required to abide by the appropriate Occupational Safety and Health Administration (OSHA) regulations on temporary excavated slopes (OSHA 2011, 2015). A stable temporary excavated slope depends on many factors, including type of soils, location of groundwater, duration of exposure, and external loads. A designer should call out any special excavation requirements based on known ground conditions, such as bracings, dewatering, and restricting the depth of cuts, and there should be provisions in the contract documents to compensate the contractor for these requirements. Without adequate subsurface investigation, the contractor may not adequately anticipate safety requirements during bidding and performing the site work.

How is the site dewatered?—The issue of construction dewatering should be addressed during design, in groundwater investigations, specifying requirements, and estimating its cost. Except under some special circumstances, selection and design of a dewatering scheme is the responsibility of the contractor. With the information obtained from subsurface investigation, a designer prepares the appropriate dewatering specifications and requirements, and the appropriate cost of dewatering is estimated accordingly. With that same information, a contractor also prepares his or her dewatering bid cost. For example, pumping from sump pits may be adequate for excavating into a clay foundation, but well points may be required for excavations into more pervious sandy or silty foundations below the groundwater table. It is almost impossible to bid on dewatering or to provide an engineer's cost estimate of dewatering with inadequate groundwater information and inadequate understanding of the subsurface materials.

How accurate are the excavation and backfill quantities?—An inadequately investigated foundation usually results in quantity overrun or underrun for excavation and backfill. For example, an unexpectedly shallow bedrock will require less earth excavation, more rock excavation, and a deeper subgrade to reach an acceptable foundation, or it will require overexcavation and replacement with structural backfill. Almost all contract documents have allowances for a contractor to renegotiate his or her unit prices for earthwork items that are significantly different than the bid quantities (see Section 22.5). Most of the time, the owner ends up paying higher unit prices for renegotiated work items during construction.

So, from a civil design standpoint, what subsurface information is required to characterize a site? The following is a partial list of relevant subsurface data, in addition to other requirements for engineering design of the structures:

- Subsurface conditions to the design limits of excavation. In general, the exploration should not terminate above the depth of excavation, unless the excavation is in bedrock. If bedrock is shallow and above the limits of excavation, it may not be necessary to explore all the way to that limit, depending on the conditions of the rock. If the bedrock is weathered to highly weathered, then the depth of weathering is important to determine the location of competent foundation or depth of excavation.
- Laboratory index tests to supplement the field descriptions of the various materials encountered in boreholes or test pits, such as natural water contents, gradation, and plasticity.
- The effort of excavation should be characterized using quantifiable indices, such as the standard penetration blow counts from boreholes. Soft foundation subgrade could require special excavation provisions, such as low-tire-pressure equipment or support mats. Hard or stiff foundation subgrade may require a ripper or other special tools and will affect the production rate of the excavation equipment. Unconfined compressive strength is a useful index to evaluate the method of excavation in bedrock. Soft rock, such as a weakly cemented sandstone or a claystone, may be excavated using a hydraulic hoe ram or backhoe. Hard rock, such as a competent granite or sandstone, requires blasting. Useful information for tunnel excavation includes coring rates during drilling, joint frequency and spacing, hardness, and unconfined compressive

strength. A contractor bidding on a project involving rock excavation would need most or all of these data to estimate effectively the actual cost and method of excavation.

- Groundwater conditions at the limits of excavation. Groundwater conditions observed during borehole drilling and test pit excavation should be recorded. Water levels monitored with observation wells are also useful to characterize the long-term stabilized conditions. Any changes in surface features, such as water levels in adjacent streams, irrigation canals, or lakes, should be noted in the monitoring data for any correlation of groundwater level with these features.
- Locations of buried utilities and buried structures.
- When the use of sheet piles, foundation piles, or piers is anticipated, the ground conditions should be known to at least the bottom of the piles. The ability to drive piles into the ground without sustaining damage should be demonstrated in the design, or there should be provision made for a test pile program. Critical to the installation of driven piles is the presence of cobbles and boulders that should be made known in the documents. The presence of cobbles and boulders increases the chances of damaging piles during driving and introduces questions on what refusal criteria are considered adequate for acceptance.

The results of subsurface investigations are summarized in a geotechnical investigation report, which contains all the field and laboratory data, descriptions and evaluations of the subsurface conditions, evaluations of suitable foundations and construction considerations, and geotechnical recommendations. It is important to note that the geotechnical investigation report is written by the geotechnical engineer to the owner of the project, and not to the contractor. There are portions of the report that should not be disclosed to the contractor, namely, all of the geotechnical evaluations and recommendations by the engineer. The contractor is expected to perform his or her own evaluations and conclusions of the foundation conditions based on the subsurface conditions as depicted in the field logs and laboratory data and develop his or her own methods of construction. Therefore, it is not appropriate for the engineer or the owner to furnish the contractor with the geotechnical investigation report in its entirety. During preparation of the reference data in the technical specifications (see Section 20.2), only the following geotechnical data should be furnished to the contractor:

- Field drilling logs and test pit logs;
- Field test results such as standard penetration test blow counts, field permeability, test fills, and test blasts;
- Instrumentation installation logs such as monitoring wells and piezometers;
- Groundwater conditions encountered during the investigations and any subsequent water levels from monitoring wells; and
- Laboratory test results, including soil and rock testing, concrete or grout mix designs, and corrosiveness testing.

3.4 Borrow Investigation

A borrow investigation is performed to explore earth and rock materials that are suitable for construction. Borrow materials may include various classes of earthfill (such as clay, sand, gravel, structural fill, and topsoil), rockfill, and riprap. The borrow area is usually an owner-designated material source that is made available to the contractor for economic reasons. When suitable materials are available close to the worksite, the material costs can be significantly lower than imported materials from commercial sources. For economic reasons, a borrow source should be close to the worksite in order to reduce the haul cost.

All of the available methods of subsurface investigation discussed in Section 3.3 are suitable for borrow investigation. A large borrow investigation program may involve a geologic reconnaissance, drilling boreholes, excavating test pits, test blasting (for producing riprap), and test fills. A small borrow investigation program may merely be just test pit excavation. Regardless of the size and scope of the borrow investigation, a properly performed borrow investigation should yield the following information for design and construction:

- Types of materials available in the borrow area, including index and engineering properties.
- Locations where the materials are encountered in the borrow area, including areal limits in a topographic map, and depths.
- Groundwater conditions.
- Estimated quantities available for construction for each type of materials. The estimated available quantity should be at least twice the required quantity to account for uncertainty in the ground, wastes, and quantity changes during construction.
- Feasibility of processed materials (such as a filter sand or concrete aggregate) or manufactured materials (such as riprap). Test blast or test fill programs may be required to demonstrate the constructability and technical suitability, not only for design purposes, but also for the purpose of bidding and construction planning and cost estimating.

During preparation of technical specifications, the specified borrow materials should be based on results of the borrow investigation. The purpose of the material specifications of borrow materials is for quality control and borrow development, not for rejection of materials. This distinction is important during construction. An owner-furnished material, such as a borrow material, should not be rejected unless it does not meet the key specified specifications; in that case, the borrow investigation has failed to identify a suitable material, and the specifications do not reflect the results of the borrow investigation. It is considered a design error to specify borrow materials that cannot be furnished by the owner in the designated borrow area, and it is grounds for a differing site condition. When the contractor cannot use the specified borrow materials that are the basis of his or her bid, then the materials will need to be imported from alternative sources, such as commercial pits, resulting in an increase in construction cost.

3.5 Prior Site Use Investigation

A seemingly undeveloped land may have been used or disturbed by humans in the past. Encountering buried surprises during heavy civil construction may have serious effects on the project, which may include changed conditions, work stoppage, and even cancellation of the project. Therefore, site characterization efforts should include investigation of prior use of the site. The reasons for investigating the prior usage of a project site are threefold:

1. To clear the site for any potential cultural or archaeological resources that are of value;
2. To investigate the potential of environmental contamination and hazardous waste; and
3. To identify any buried structures that would affect the design and construction of the project.

In the United States, cultural and archaeological features may be related to Native Americans, early American settlers, or the Civil War. To most untrained eyes, the significance of most of these features is not obvious and therefore is often overlooked in a site survey or a field visit. For example, a circular pile of rocks may be an ancient fire ring used by Native Americans. Or a plain-looking trench on a hillside in an eastern state may be a Civil War trench with great historical value.

During the emergency reservoir drawdown of Lake Ilo Dam in Killdeer, North Dakota, for dam safety modifications, numerous arrowheads known as “Folsom points” that were 10,000 years old were encountered all around the exposed reservoir floor. In an early planning phase of a heavy civil project, it is important to perform a screening-level study by archaeologists to determine whether the project site has any potential of archaeological or cultural significance. Most states now have an agency known as a state historical preservation office (SHPO) that provides guidelines and assistance, and this office should first be consulted at the beginning of the data collection phase of most heavy civil projects involving seemingly undeveloped land. In the case of Lake Ilo Dam, the presence of 10,000-year-old artifacts triggered an environmental impact statement and mitigation efforts that cost millions of dollars before the construction of the dam safety modifications.

Investigation of site contamination from prior usage requires field reconnaissance; sampling; testing; and knowledge and expertise in inorganic and organic chemistry, toxicology, and biology. These studies should be performed by specialists. A contaminated site, if discovered during design, should be adequately mitigated before redevelopment for a heavy civil project and before authorizing the construction contractor to proceed. If mitigation is not feasible, then a different site would be needed.

Investigation for buried structures (e.g., tanks, pipes, or old foundations) requires a search for previous construction records, drilling boreholes, and test pit excavations. Where it is not feasible to use boreholes or test pits, geophysical methods such as ground penetration radar (GPR) (Spangler and Handy 1982) may be used to identify buried objects. In some cases, GPR can be used to optimize other investigation programs such as trenching and test pits.

Sites that will be developed above abandoned underground mines should be investigated for collapse potential that may result in ground subsidence and sinkholes. Most state geological surveys have compiled maps of underground mines that can be used for screening purposes.

3.6 Topographic Survey

A *topographic survey* is the applied engineering discipline to characterize and map the existing ground surface, to locate and determine land boundaries, to determine the configuration (relief) of the surface of the ground, to document locations of field investigations, and to locate and describe the natural and artificial features on the ground. In heavy civil design projects, the product of topographic survey is a map of existing conditions that is used as a starting base map for civil design (see Section 3.7). The characterization of topographic relief defines the existing grade that determines the extent of cuts and fills in earthwork design. Methods of topographic survey include transit-tape, transit-stadia, cross-sectioning, total station, global positioning system (GPS), photogrammetry, and light detection and ranging (LIDAR) (ASCE 1999; Anderson and Mikhail 1997; Brinker 1969; Shan and Toth 2009; NOAA 2012). With the advance of electronics, satellites, and lasers in recent years, topographic survey techniques have been developed into an efficient and accurate operation, and the most commonly used methods for topographic survey are total station, photogrammetry, GPS, and LIDAR. By measuring the distance light travels to the ground and back, LIDAR can digitally strip away tree canopy from wooded areas to produce bare-earth topography. Topographic surveys for design and for preparing construction documents should be performed by a licensed surveyor.

Depending on the intended use of the topographic maps, it might be necessary to survey all of the natural and artificial features on the ground. Natural features include vegetation, streams and drainage features, rock outcrops, landslide scarps, fault zones, and lakes. The surveyed limits and nature of vegetation, such as trees, shrubs, wetland, and marshland, are needed for design and permitting. The limits of trees and shrubs are used to define the limits of clearing and grubbing work for site development. With the enactment of the National Environmental Policy Act (NEPA) and the Clean Water Act, the preservation of natural resources, such as wetland

and marshland, becomes an important consideration in the permitting, layout, and design of most heavy civil projects (see Sections 2.5 and 3.8). The definition and delineation of wetlands require the use of specialists (e.g., botanists and ecologists) who delineate these limits in the field before they are surveyed.

Areas that have been disturbed or developed may contain artificial and constructed features that should be included in a topographic survey. These features may include roads, trails, buildings, utilities (e.g., overhead or buried power lines and telephone lines), bridges and highway overpasses, water conveyance structures (e.g., ditches and canals), walls, fences, and property markers. The locations and descriptions of these features may be important in the early planning and design phases of a heavy civil project when determining conflicts, interference problems, site restrictions, demolition efforts, permanent and temporary easement requirements, property ownership, and permit requirements.

The starting point for a topographic survey is the establishment of vertical and horizontal controls. Controls can be tied to national, state, or county datum and grid systems, or they can be local, depending on the project requirements. Regardless of whether local, state, or national data are used, the basis on which the survey is performed should be clearly defined and stated in the scope of work before field work begins. Horizontal controls are provided by two or more monuments with known coordinates; similarly, vertical controls are provided by two or more benchmarks with known elevations. Frequently, the same two monuments or benchmarks contain both coordinate and elevation information.

In the United States, standard elevations and horizontal coordinates are still expressed in feet. In civil engineering and surveying practice, horizontal coordinates are expressed in terms of *northings* and *eastings*. Northings are distances measured in the north–south direction that increase from south to north. Eastings are distances measured in the east–west direction that increase from west to east. A point in plan view is represented by a northing coordinate, easting coordinate, and an elevation, similar to the x-, y-, and z-coordinates in mathematics. Fig. 3-1 shows an example of three points that are represented by this coordinate system.

The latest vertical control datum is the 1988 North American Vertical Datum (NAVD), which is also referred to as the National Geodetic Vertical Datum (NGVD). The primary horizontal control is normally the State Plane Coordinate System. Sometimes, survey controls are already established on site from previous work or from known benchmarks, and they should be used for all project survey work, so that the existing and new features can be compared in the same space. Before the availability of GPS in survey work, new survey controls had to be brought in from off site, sometimes from many miles away and at a high cost. Now, new survey controls can be installed at the site using GPS without the need to bring in any outside controls, albeit at the expense of reduced resolution and accuracy. Total stations using a real-time kinematic GPS system are accurate to about 20 mm (0.78 in.) horizontally and 30–40 mm (1.4 in.) vertically. In any case, when the cost of establishing survey controls becomes expensive, as compared with the rest of the

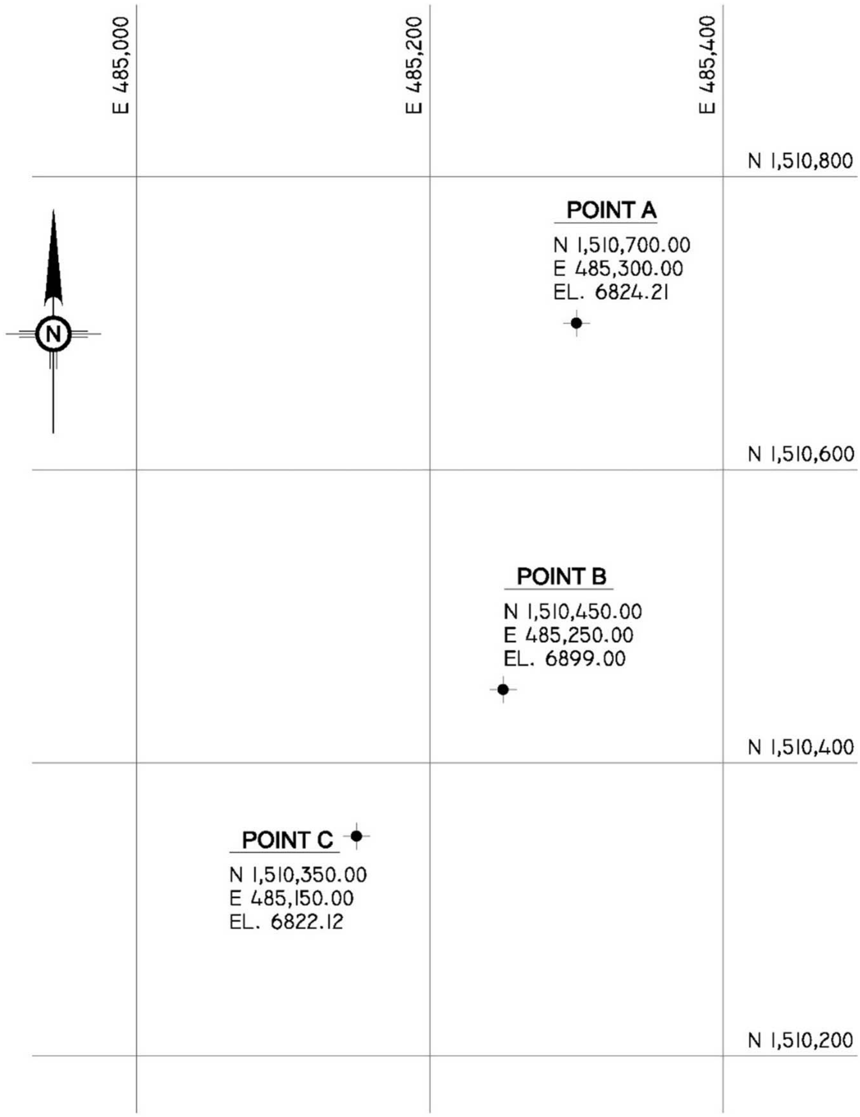

Fig. 3-1. Horizontal Coordinate System Representation

survey work and the size of the project, it would be justified to use an assumed local control for the work.

Local controls are based on an arbitrarily assigned vertical datum and coordinate system. When an existing point is present at the site, such as a structure corner, property marker, section corner, or fence corner, it can be used as a local control reference, with an assigned elevation designation such as 100.00 or 1,000.00 ft, depending on the local relief, and an assigned coordinate datum, such as N10,000.00 and E10,000.00. All the survey work and the topographic map will then be based on this locally assigned control system. When the local control references are preserved and not disturbed, it is possible to eventually tie this local control system to the national and state system in the future.

3.7 Topographic Map

The finished product of a topographic survey is the topographic map. Nowadays, all topographic maps that are used for design purposes are electronically digitized. A topographic map is the starting drawing of any civil design project. The importance of an accurate topographic map in civil design cannot be overemphasized, for the following reasons:

- The survey controls and benchmarks are the basis for design controls and construction controls;
- The topographic contours represent the existing ground surface, which is an important reference when designing excavations and earthfills as well as estimating earthwork quantities;
- The map provides a baseline condition for the contractor to plan and construct temporary facilities such as staging and stockpile areas, access roads, sediment and erosion controls, and water controls; and
- The limits of trees, shrubs, and wetlands are the basis for site clearing design or environmental protection.

Regardless of whether the map is simple or complicated, there are basic elements that should be shown on a topographic map (Fig. 3-2):

- Topographic contours and contour labels. Typically, every fifth contour line is labeled, and the labeled contour is called a *major contour*; a heavier line (see Section 7.7 for line weight) is commonly used to distinguish it from the remaining contours, which are called *intermediate contours*. In the example in Fig. 3-2, the major contours are elevations such as 2,155 ft, 2,160 ft, and 2,165 ft, and the intermediate contours are elevations such as 2,156 ft, 2,157 ft, and 2,158 ft. Note that in steep areas in Fig. 3-2, the intermediate contour lines are deliberately not drawn continuously across those areas because those lines would have been very close together.
- Locations of control monuments within the mapped area, and the vertical data and horizontal control system.
- A north arrow.
- A scale (written scale or graphic bar).
- All surveyed and known natural and artificial features, such as trees, waterways, utilities, buildings, roads, culverts, and known underground structures.
- The survey date and name of the surveyor company.

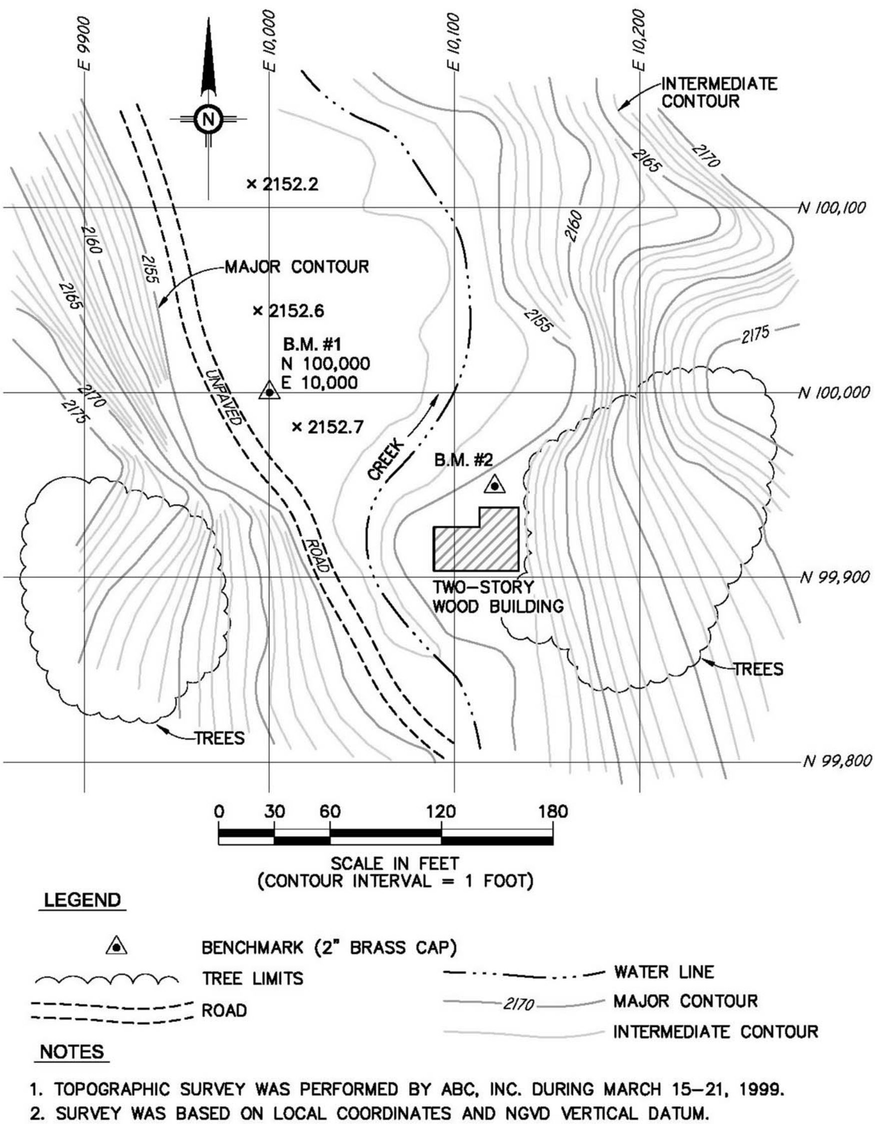

Fig. 3-2. Typical Topographic Base Map

- Legend of the features.
- Grid lines of northings and eastings of the horizontal control.
- Spot elevations for specific high and low points.

Selection of the contour interval of a base map, which is the vertical distance between adjacent contours, should be the responsibility of the civil designer. In general, the contour interval is selected based on the purpose of the map, relief of the project area, and required accuracy in the vertical direction. The contour interval should be specified as part of the survey scope requirements. A designer needs to balance the design requirements with the available design budget because survey cost increases with decreasing contour interval. The American Society of Civil Engineers has guidelines for selecting contour intervals for various projects (ASCE 1999). At critical points, such as peaks, low spots, steep slopes, stream inverts, culverts, and highway crossings, spot elevations should be surveyed and shown on the map. These critical points should be specified by the designer and then picked up by the surveyor during field work. It is important for the lead designer to perform a site visit to become familiar with site conditions so that he or she can reasonably evaluate the accuracy of the survey data submitted by the surveyor. It is a recommended practice for a civil designer to field check a topographic map before it is finalized by the surveyor. Any inaccuracies, omissions, and inconsistencies with the actual field conditions should be corrected before the map is finalized and used for design. The final topographic map should be stamped and signed by a licensed surveyor. Typically, a digital file of the map is submitted along with the certified paper copy.

Digital topographic maps can be used directly for civil design using one of many computer-aided drafting (CAD) software packages (e.g., AutoCAD 2016 or Microstation 2004). Regardless of what software is used, the contour lines of a digitized topographic map are *polylines*, which are continuous three-dimensional lines of straight-line segments and contain the northings, eastings, and elevations (x, y, and z) information. Survey data in an electronic file of a topographic map are usually organized in layers. Some of the typical layers are surveyed points, contour lines, utilities, buildings, natural features (e.g., streams or trees), roads, text, and lettering. Existing spatial data from geographic information systems (GIS) can be digitally imported into the drawings by means of shape files as separate layers. The establishment of individual layers can be specified as mapping scope requirements, but usually is left to the discretion of the surveyor or CAD operator. Each layer can be turned on or off electronically to yield a map containing different levels of information.

3.8 Environmental Investigations

Environmental investigations are performed to address potential biological, cultural, archaeological, wetland, and hazardous waste issues at project sites. As discussed in Section 2.5, many of these environmental investigations are mandated by federal laws, including the National Environmental Policy Act. NEPA requires federal agencies to prepare an environmental assessment (EA) or an environmental impact statement (EIS) on potential environmental effects of proposed federal agency actions. An EA is a concise public document that typically involves the preparation of a purpose and need statement, a description of alternatives to meet the purpose and need, and a summary of the expected environmental impacts. Environmental assessments require a public comment period, and public meetings can be used if necessary. Environmental assessments are concluded with either a “finding of no significant impact” (FONSI) or a "finding of significant impact" (FOSI). If the EA results in a FOSI, an EIS must be prepared. If it is clear from the beginning that the project will create significant environmental impacts, such as impacts to endangered species, the EA process can be bypassed and the NEPA compliance process can go directly to an EIS. If an EIS is required, it will result in a detailed public involvement process and written analysis of the significant and other environmental impacts associated with the project, as required by Section 102(2)(C) of the National Environmental Policy Act and Parts 1500 through 1508 of the Council on Environmental Quality Regulations for Implementing NEPA Procedures.

A preliminary environmental investigation may involve only a "paper study," when a large number of potential project sites are being considered at the early phase. Many states have published resources regarding threatened and endangered species and known wetlands. For example, in the state of Colorado, the following existing information can be used for screening-level environmental investigation:

- Colorado Natural Heritage Program data, which show known sensitive species within a particular USGS 1:24,000 quadrangle.
- Natural Diversity Information Source data, which show whether a particular project site intersects the designated range or area of a selected species.
- National Wetlands Inventory data, which show whether identified wetlands are present in a particular project site.
- Designated Critical Habitat data, which show critical habitat locations and boundaries for various identified biological species.

Detailed environmental investigations, if required, involve field surveys that are performed by specialists, usually following specific guidelines prescribed by regulating agencies. Results of these investigations are used to acquire project permits from various regulatory agencies. In the case of hazardous wastes, a mitigation plan must be implemented if the project site will be used for future development. Regardless of the nature of the environmental issues, it is important that these issues be addressed during planning and design phases, and not during construction. Encountering an environmental problem during construction can have serious consequences to the project, including shutting down the construction for mitigation.

3.9 Levels of Investigation

Except in emergency situations, heavy civil projects are typically completed in phases or levels, similar to most engineering projects. When a project is conceived, some site data are collected as the basis of preliminary evaluations of options and concepts. As the project proceeds to more advanced studies, more site data are collected for further analyses and designs. The following design levels are used to illustrate the level of efforts required in site characterization:

Feasibility and conceptual levels—At these levels, various concepts, options, or alternatives are being proposed and evaluated, and the advantages, disadvantages, constructability, and approximate project costs are identified for each option. No construction documents are needed at these levels because these study documents are not used for construction. It is also at these levels that fatal flaws are identified that would eliminate certain options from further consideration. If more than one site is being considered, then each site should be investigated on an equal basis for site selection evaluation. An adequate site investigation at this level is important. There is a misconception that an adequate site investigation is not needed at these early levels, but an adequate site investigation is not the same as a thorough investigation. A thorough investigation is performed to provide all the information required for final design. An adequate site investigation should be sufficient to provide enough information that the relative project cost and technical feasibility for each option can be reasonably estimated without leaving any significant issues unresolved that may later "kill" the project.

Final design level—At this level, a project site and a particular design concept have been selected for detailed design. It is at the final design level that construction documents are prepared, such as construction drawings and technical specifications. The site investigation at this level should yield the following information:

1. All required design parameters, additional geologic investigation, subsurface investigation, and field and laboratory testing.
2. Adequate topographic mapping so that an accurate design can be prepared and an accurate quantity estimate can be made. Typically, the coverage of the surveyed area and the contour interval are two important considerations at this level.
3. Construction issues such as methods of excavation, excavation subgrade conditions, stability of temporary excavation slopes, and dewatering requirements, to establish a basis for bidding.
4. Adequate design and test data for the contractor, if the design is performance-based (see Section 17.3 for a discussion of performance-based specifications).

Exercise Problems

3.1 Glacial till is characterized by the presence of numerous gravels, cobbles, and boulders in a matrix of silty sand or sandy silt. What design or construction problems are anticipated if the following work is planned in a glacial till foundation?
   a. Open-cut excavation adjacent to a stream.
   b. Driving sheet piles as a seepage cutoff wall.
   c. 150-ft-high water storage embankment dam.

3.2 Loess is a windblown deposit consisting of silt and fine sand with weak cementation among soil particles. What design or construction problems are anticipated if the following work is planned in a loess foundation?
   a. A two-story apartment building on shallow spread footings.
   b. An unlined earth canal.
3.3 Young marine clays are typically soft, plastic, and normally consolidated. What design or construction problems are anticipated if the following work is planned in a young marine clay deposit?
   a. A concrete-paved interstate highway embankment.
   b. A grain storage silo.
3.4 Understanding the geology at a project site frequently provides guidance in planning a subsurface investigation. What useful information is provided by the geology in planning a drilling and sampling program?
   a. Method of drilling in a glacial till foundation.
   b. Method of drilling and sampling in a saturated alluvial sand foundation.
   c. Method of drilling and sampling in a highly plastic clay shale foundation.
3.5 Understanding the geology at a borrow site frequently provides guidance in planning a borrow investigation for materials of construction. Which geologic setting is more favorable to yield the following borrow material?
   a. Clean filter sand: borrow from alluvial deposit or colluvial deposit?
   b. Riprap rock: borrow from a shale or granite bedrock?
   c. Low-permeability clay fill: borrow from coastal floodplain deposit or alluvial deposit?
3.6 Which compaction equipment should be specified for the following fill materials?
   a. Aggregate base course surfacing for a gravel county road.
   b. Roller-compacted concrete to construct a concrete gravity dam.
   c. Clay core for an embankment dam.
   d. Clean filter sand for a drain blanket.
3.7 What excavation equipment is likely to be used by a contractor for the following work?
   a. Stripping topsoil to prepare the staging area for construction.
   b. Grading a 100-acre open area for a housing development.
   c. Installing a new 24-in.-diameter sewer pipe along a residential street.
   d. Dredging a river to deepen the navigational channel.
   e. Repairing a broken sprinkler system line.
3.8 What hauling method is likely to be used by a contractor for the following work?
   a. Hauling borrow fill materials 2.4 miles from the borrow area to the placement area.
   b. Hauling topsoil 300 ft from the stockpile to the placement area.
   c. Hauling fill for site grading a 100-acre open area.
   d. Transporting freshly mixed roller-compacted concrete from the batch plant to the placement area.

3.9 Open-cut excavations less than 20 ft deep should comply with OSHA excavation safety requirements, based on the type of soil and the strength of the soil. Refer to OSHA Standard 1926 Subpart P Appendix B: Excavation Sloping and Benching. Based on OSHA, what maximum slope is allowed for the following soil?
   a. Stiff sandy clay.
   b. Soft to very soft silty clay.
   c. Dense, dry, gravelly sand.
   d. Loose, saturated, silty sand.

3.10 An owner-furnished borrow area is used to provide three types of materials for construction: topsoil for reclamation, clay fill for a natural impermeable liner, and a granular material as structural fill. During design, the engineer dug nine exploratory test pits in the flat borrow area (see plan view in Fig. 3P-1), and the simplified test pit logs are shown in Fig. 3P-2. Calculate the available quantity for each type of fill material, and evaluate whether the quantities are adequate for

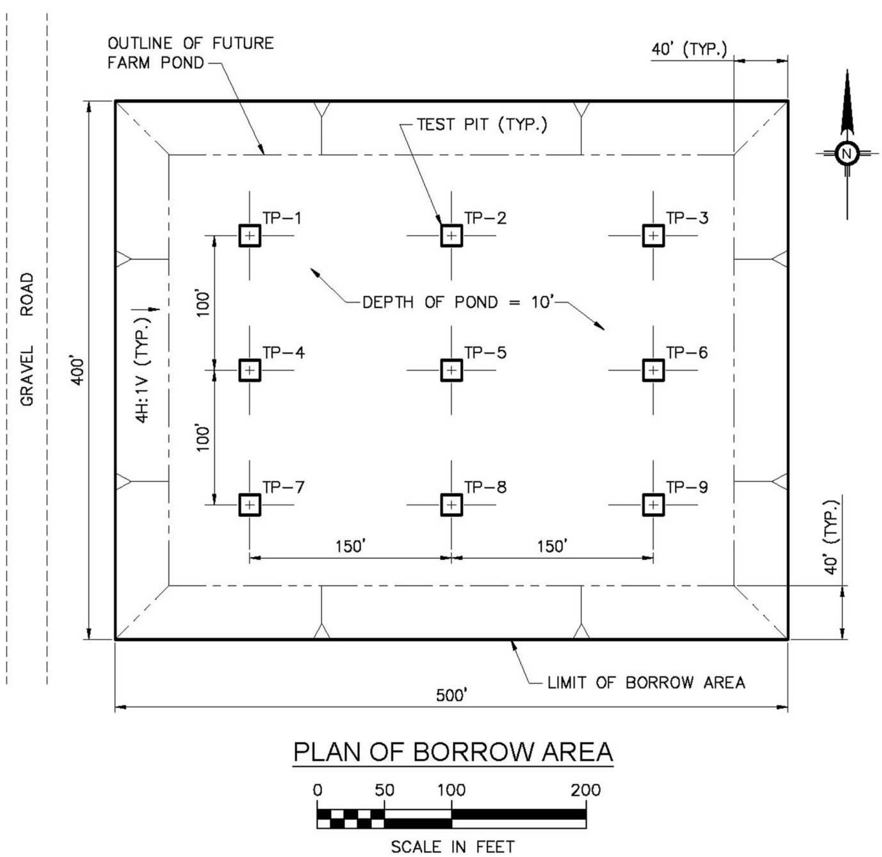

Fig. 3P-1. Plan of Borrow Area and Test Pits

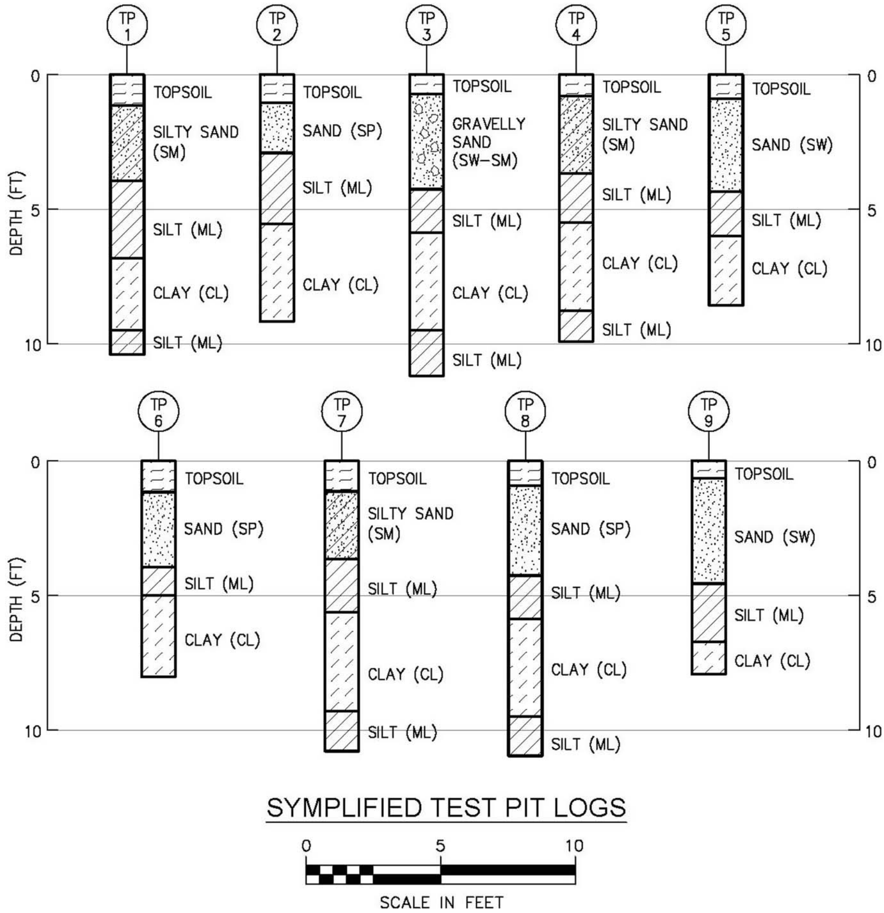

Fig. 3P-2. Simplified Test Pit Logs of Borrow Area

construction. The required quantities for the project are the following: topsoil = 2,000 cubic yards; clay fill = 12,000 cubic yards; and structural fill = 6,500 cubic yards. At the end of construction, the borrow area will be reclaimed as an unlined farm pond, with a maximum depth of 10 ft. The borrow excavation therefore should not exceed the limits of the future farm pond.

PART 2

Construction Drawings

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CHAPTER 4

Civil Design Drawings

4.1 Definition of Civil Drawings

Heavy civil projects, such as highways, dams, and pipelines, are constructed using documents consisting of drawings and specifications. The term *plans* is frequently used for construction drawings. Design drawings are graphical media that designers use to depict their concepts and communicate the design concept to the builder (contractor). A typical set of plans used in heavy civil construction projects may contain designs from different engineering disciplines. These multidisciplinary designs are divided into groups, such as *civil drawings, structural drawings, mechanical drawings, electrical drawings*, and *architectural drawings*. Although most of these groups can be distinguished readily from one another, the most ambiguous group is that of the civil drawings. For example, structural drawings are used for reinforced concrete and structural steel; mechanical drawings are used for mechanical equipment such as pumps, gates, pipes, and valves; and architectural drawings are used for buildings, room layouts, and elevators. The definition of a civil drawing requires some discussion.

No readily available definition of a civil drawing exists. In the absence of any guideline, the following definition is proposed. A civil drawing shows the graphical interrelation between structures and grades. The term *grade* is used to designate a surface. An *existing grade* denotes existing ground surface or contour before construction. An *excavation grade*, or *subgrade*, denotes a ground surface or contour created by excavation during construction, and that grade can be temporary or permanent. A *final grade* denotes the finished ground surface or contour after construction and can be created by excavation and/or backfilling. By this definition, the following drawings would fall into the category of civil drawings:

- Plan of existing conditions, showing topography and surrounding features and structures;
- Plan of survey control, showing baselines and centerlines, existing and new benchmarks, and coordinate grids;

- General plan of new structures, showing location and final grading around the new structures; and
- Sections, profiles, and details of new structures showing existing ground surface, limits of excavation, locations of backfill, and final grades.

This book addresses the preparation of civil design drawings as defined by these criteria.

Preparation of civil design drawings requires knowledge and training in engineering graphics, descriptive geometry, and topographic survey. Before the early 1980s, these drawings were done by hand by skilled drafters sitting at large drafting tables. The development of high-speed personal computers allows this design process to be performed using computer-aided drafting (CAD) software. Chapter 11 is devoted to civil design processes using CAD systems. Knowledge of CAD skills is helpful, but is not necessarily an essential skill to produce good civil design drawings. The essential skills to produce good civil design drawings require proper selection of scales, principal views, line types, and line weights that are independent of the tools to draw them. In addition, an understanding of construction methods and constructability, gained through construction field experience and observing construction in progress, is important in the production of a sound civil design.

4.2 Levels of Design Drawings

Heavy civil design projects are developed in phases, or levels. A typical chronological sequence of phase development includes the planning phase, the feasibility or conceptual phase, and the final design phase. Design drawings are developed during each phase. In general, the level of details contained in the drawings increases as the project advances to subsequent phases. The following is a set of general guidelines for developing drawings at various phases:

Planning-level drawings—Planning-level drawings are developed and used at the beginning of a project to illustrate a particular concept or idea being considered. Typically, more than one concept or idea is being considered at this time, and sometimes these concepts lack supporting analysis or precedence, and therefore may not have sound technical bases. In fact, at this level, only limited engineering analysis is performed for each design concept, and most of the time, design drawings are developed based on project requirements and constraints, engineering judgment and experience, precedence, and past projects. Although often considered easier to prepare than final design-level drawings, the preparation of planning-level drawings—without the support of analysis and other design data—requires considerable design experience and judgment on the part of the designer. Therefore, inexperienced and junior design staff should perform this work only when closely supervised by more experienced designers.

Planning-level drawings should be developed with an equal level of detail for all concepts being considered. If no construction cost estimate is required to support each concept, then only sketches are needed to illustrate each concept, and only few key dimensions are needed. If a construction cost estimate is required, then more key dimensions or elevations will be necessary to determine the quantities of materials needed. Planning-level concepts are typically evaluated and screened to a smaller number of concepts for further evaluation in the conceptual-level phase. All the technical requirements are called out in the drawings, and no separate technical specification document is needed. In most cases, only a general plan and a typical section are required to illustrate each concept. Planning-level drawings should be based on conservative assumptions because of limited site data and analysis to support the design.

An example of a planning-level drawing is shown in Fig. 4-1. The figure shows a typical cross section of a geomembrane liner concept for a new canal project. The section shows the liner being protected by an earth cover and a gravel cover. The hydraulic cross section (bottom width of the canal and the flow depth) has been determined based on project flow requirements; however, numerous design elements (the type of geomembrane material, thickness of the cover materials, and freeboard requirements) have not been determined at this time.

Conceptual-level drawings—Conceptual-level drawings for each project option are developed primarily to compare construction costs, to evaluate advantages and disadvantages, and to identify potential fatal flaws so that a preferred concept can be selected for final design. The evaluation criteria for various concepts may vary considerably from project to project and may include cost, schedule, risk, environmental, regulatory, operation and maintenance, and other nontechnical considerations. For many projects, construction cost estimates developed at this level are used as a basis for funding of the project, so it is important that the project cost is not underestimated. With this goal in mind, these drawings should be developed with sufficient details and dimensions to define all of the significant cost items associated with each concept. These drawings should not be used for construction, and not all the information needed for construction is necessary for conceptual-level drawings. No technical specification document is required at this level.

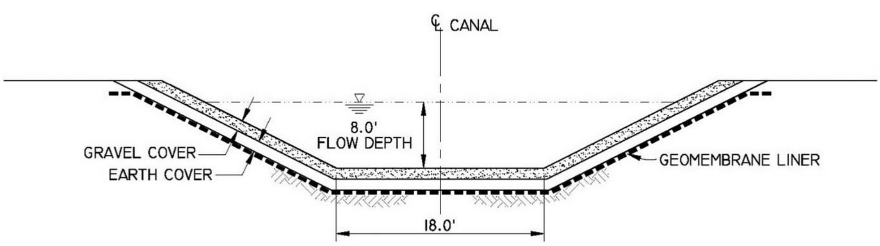


Fig. 4-1. Geomembrane Liner Concept for a Planning-Level Canal Design Project

A plan and a typical cross section supplemented with relevant details are required. In some cases, if a typical cross section does not adequately represent the concept, then other cross sections are required to obtain more accurate work quantities. Some engineering analysis may be required to support the design at this level, and the analysis performed at this level represents a refinement from the planning-level design. In general, with or without analysis to support the design at this level, the conceptual-level design should be conservative for the following reasons:

- The layouts, details, and sections developed are still inadequate to provide an accurate quantity estimate.
- Not all technical issues are addressed or anticipated until final design, when more detailed analyses are performed.
- The site may not be adequately investigated at this time to allow for consideration of all anticipated problems associated with subsurface conditions or other site constraints.

Fig. 4-2 is an example of a conceptual-level drawing, shown as a refinement from the example in Fig. 4-1 and illustrating the additional level of detail. The geomembrane-lined canal will be constructed using the cut-and-fill method. A 60-mil (1.5-mm)-thick high-density polyethylene (HDPE) liner was determined to be most suitable for this project. The proposed thicknesses of the earth cover and gravel cover are also shown on the section. The required freeboard will be 2 ft (0.6 m); therefore, the depth of the canal will be 10 ft (3 m). These dimensions will be used to determine the conceptual-design cost estimate for this option for comparison with other options; however, it should be noted that the design details, geotechnical information, and survey data at this level are still inadequate for construction.

Final design drawings—Final design drawings, or *construction drawings*, are used for construction. These drawings contain all of the information necessary for a contractor to bid and build a particular project. Most heavy civil projects require permits from various regulatory agencies (municipal, county, state, and federal); these drawings are used to support applications for these permits. Construction drawings are used in

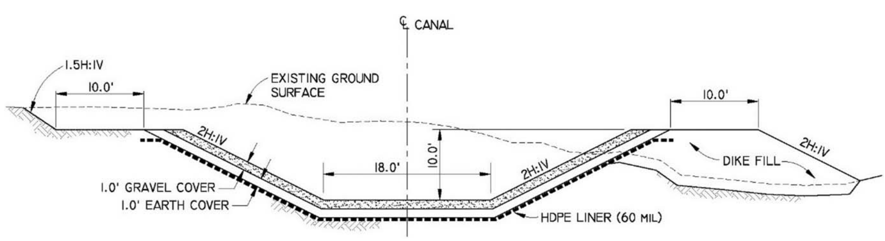


Fig. 4-2. HDPE Liner Concept for a Conceptual-Level Canal Design Project

conjunction with a set of technical specifications to define completely the spatial, material, installation, and quality requirements of a project. Construction drawings are also used during final design to obtain an accurate estimate of quantities for a construction cost estimate and for developing the bidding schedule.

Fig. 4-3 is an example of a construction drawing, shown as a refinement from the example in Fig. 4-2, and illustrating the level of detail necessary for construction. Additional details include anchoring at the top of the HDPE liner, curved transition at the slope break at the canal invert, stripping depth, permanent excavation slope, sloping on top of the service road and dike crest, and canal invert at the section shown. Note that all material requirements, including the HDPE liner and earthfill cover materials, are deliberately omitted from the drawings because these material requirements are now contained in the technical specifications and should not be repeated in the drawings. The layout of the canal is based on a topographic map along the canal alignment, and the existing topography (existing ground surface in the section) is used to design the cut-and-fill earthwork.

Occasionally, bid amendments are used to change design drawings during bidding. After the contract is awarded and before construction begins, these design changes can be incorporated into the drawing set, and the revised set of drawings is referred to as *conformed drawings* (see Section 13.1).

When a construction project is completed, the construction drawings are updated and modified to reflect all of the changes made during construction. The resultant drawings are called *record drawings*. Record drawings (see Section 13.2) have been commonly referred to as *as-built drawings*, but the current trend is to use the term *record drawings*.

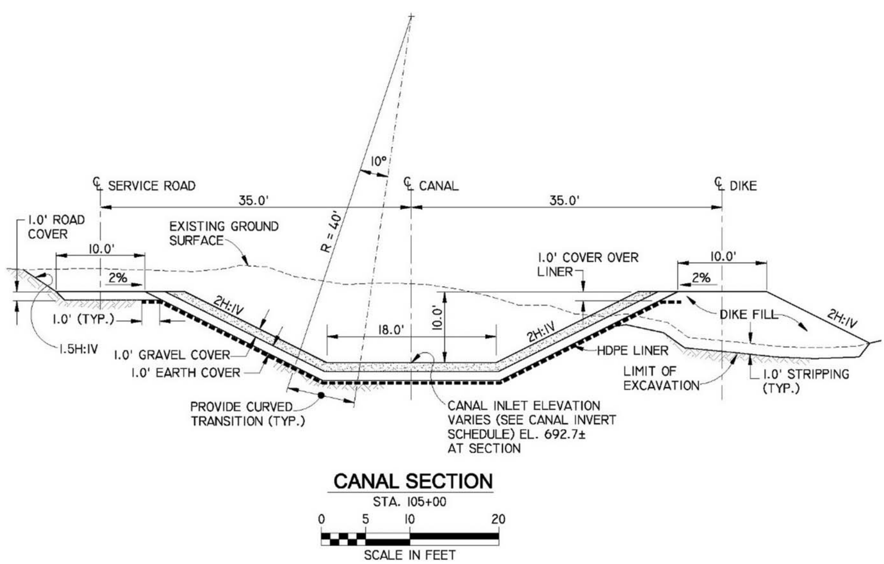


Fig. 4-3. HDPE Liner Section for a Canal Final Design Project

4.3 Drawing Information

Unless otherwise stated, the remaining treatment of civil drawings focuses on final design drawings (construction drawings). Construction drawings, when combined with technical specifications, provide all of the information given to the contractor to construct and build a project. Information contained in construction drawings and information contained in technical specifications are intended to complement each other, and duplication between these documents should be avoided.

Information on civil drawings is contained in various graphical views (see Chapter 7). In general, civil construction drawings contain the following information:

Location—Locations of existing conditions and new structures are shown in the drawings. Existing conditions include topography and surface features (e.g., vegetation, exposed structures, roads, and streams). Buried structures and utilities, if known during design, should also be shown or noted in the drawings. Subsurface conditions, including soil types, bedrock, and groundwater-level conditions, are also considered as existing conditions and should be shown using simplified borehole logs or test pit logs. All existing and new features shown in the drawings are located with the survey controls established for the project.

Dimensions—Dimensions of new structures or new facilities, including lengths, angles, elevations, and thicknesses, are shown in the drawings using a variety of graphical views, including plan views, cross sections, profiles, elevation views, and details.

Survey control and grades—Survey control and grades are shown in the drawings for construction survey of the new structures or new facilities. If existing benchmarks are located on site, they should be shown in the drawings. If off-site benchmarks are required for construction, their locations should be defined in the drawings. In fact, the survey basis of the project, whether it is based on local coordinates or state plane coordinates, local elevation or National Geodetic Vertical Datum (NGVD) elevation, should be clearly stated in the drawings. All construction grades (existing, excavation subgrades, final) should then be based on the specified project control. Other project references, such as baselines and centerlines, temporary survey points, permanent benchmarks, and existing structures not part of the work, should also be shown in the drawings.

Sequencing—Some construction projects require proper sequencing, and it may be possible to describe the narrative sequencing in the specifications. A graphical representation, supported by notes in the drawings, may be required to fully illustrate the sequencing requirements for a particular project. If the engineer assumes a particular construction sequence or erection procedure, this assumption should be shown in the drawing. During design, the designer should determine whether a particular sequence is mandatory or suggested. The contractor should follow a mandatory sequence with no variation, whereas for a suggested sequence, he or she is allowed to propose an alternative sequence for review and approval by the engineer.

Conflicts and interference—Conflicts and interference between new structures and existing facilities, or among various features of the new structure, frequently occur during construction. If anticipated during design, these problems should be shown in the drawings. Anticipated conflicts and interference not shown and not disclosed in the drawings or elsewhere in the construction documents will become grounds for change orders, claims, and disputes by the contractor.

Schedules and tables—Lists of design data that are used to define such things as structure locations, curve data, sizes, material lists, dimensions, and grades can be summarized in tables known as *schedules* in the drawings. These schedules may also include roadway centerline tangent and curve information; property line azimuths, lengths, and coordinates; and culvert sizes and invert elevations.

CHAPTER 5

Building a Set of Construction Drawings

5.1 Drawing Sheet Size

Drawing sheet size refers to outside-to-outside dimensions. In the United States, there are two standard drawing sheet sizes in the engineering design industry for full-size drawings: 24 × 36 in. (610 × 914 mm) and 22 × 34 in. (559 × 864 mm). The predominant size is the former. The architectural design profession uses a larger 36 × 48 in. (914 × 1,219 mm) sheet, but this size is rarely used in engineering design. Based on historical precedence, some private-sector owners and state and federal agencies use drawing sizes that are somewhat different from the standard sizes. For example, the standard sheet size for the U.S. Fish and Wildlife Service Division of Engineering construction drawings is 21.5 × 36 in. (546 × 914 mm), but the basis for this size is unknown.

The size of the drawings is selected at the beginning of the design. The selection may be based on client requirements or, in the absence of client requirements, the designer's general preference. Recently, designers and owners have used half-size drawings during reviews and submittals. Half-size drawings have the following advantages over full-size drawings:

- They are less bulky and can easily fit into briefcases and file cabinets.
- Because they do not require the blueprint process or a large-format copy machine, they can be copied easily and inexpensively in a conventional copy machine.
- They are preferred by contractors for ease of use in the field.

In a true half-size drawing, all the scales are reduced to exactly 50%, and therefore, dimensions can still be scaled where needed. For a 24 × 36 in. (610 × 914 mm) drawing, the half-size drawing sheet is 12 × 18 in. (305 × 457 mm). For a 22 × 34 in. (559 × 864 mm) drawing, the half-size drawing sheet is 11 × 17 in. (279 × 432 mm). Almost all conventional copy machines can provide 11 × 17 in. (279 × 432 mm) copies, but making 12 × 18 in. (305 × 457 mm) copies requires a special, large-format copy machine that is more expensive. For this reason, some designers select a 22 × 34 in. (559 × 864 mm) full-size drawing so that true half-size drawings can be easily copied.

For designers who prefer a 24 × 36 in. (610 × 914 mm) sheet that offers a larger drawing space, an approximate half-size drawing can be obtained by copying on an 11 × 17 in. (279 × 432 mm) sheet, except the scale is reduced to about 47% instead of 50%.

5.2 Drawing Title Block

After the drawing sheet size is selected, the drawing title block information is assembled. The title block format of a construction drawing is usually fixed for a particular design firm or government agency and should not be changed from project to project unless specifically requested by the client. Many different title blocks have been used, and standardization of the title block is not intended here. Most title blocks are located on the bottom or right side of the sheet. Regardless of the title block's location on the sheet, it should contain the following information:

Project identification. Project identification should include a brief title of the project and the project location (city, county, and state).

Sheet identification. Each sheet should be properly numbered and identified with the full title as listed on the cover sheet.

Revision number or block. Revision numbering is the designer's way to keep track of changes made to a particular drawing or to the entire set. Some designers prefer to use a numbering system that starts at Revision 0, and progresses to Revision 1, 2, etc., until the design is complete and ready for bidding and construction. Others prefer to use lettering (e.g., A, B, C). Either method is acceptable. The revision block is used to describe the reason for the revision, and the block contains the revision number, description of the revision, date of revision, and usually the principal designer's initials. There are many reasons to change a design during production, e.g., progress submittals for reviews or changes in design criteria and project requirements. Some designers prefer to switch revision designations (e.g., from lettering to numbering) when the design is complete and the project enters into the bidding and construction phase, with Revision 0 designated as "issue for bid" or "issue for construction," and Revision 1, 2, 3, etc., for later revisions during construction.

Date of submission. The date of submission for a particular submittal or revision is shown in full (month/day/year) and also in abbreviated form (month/year) in the revision block.

Designer and owner identifications. The logos, names, and addresses of the design firm and owner of the project should be shown in the title block.

Responsible personnel identification. The initials or signatures of responsible personnel are part of the title block. Different designing entities have different project personnel classifications and designations, and they also have different policies as to whose names or initials can be put in the drawings. In general, the following lead design personnel categories are contained in the title block:

- The *designer* is responsible for the technical content of a particular drawing or a particular engineering discipline. Depending on the complexity of the project, there may be more than one designer for a given set of drawings. For example, one person might be in charge of geotechnical design while another person is in charge of structural design. The designer may or may not be a licensed professional engineer, depending on the subject matter of the design. The designer is also responsible for back-checking drawings after they are drafted by the computer-aided design (CAD) drafter.
- The *principal designer* (called the *engineer of record*) is responsible for the overall technical aspect of the project. This person directs and coordinates the field work, analysis, and design. He or she also coordinates with the lead design engineers of other disciplines. The principal designer should be a licensed professional engineer.
- The *drafter* is responsible for drafting production of a particular drawing or of the entire set. Essentially all modern engineering design is prepared in CAD; when a designer prepares the design in CAD, he or she is also the drafter.
- The *reviewer* is the person who “checks” the drawings and design. A reviewer’s responsibility is to review the design for compliance with all technical requirements of the project, but the reviewer also performs an editorial review, including compliance with drafting requirements. The reviewer should be an experienced practitioner who has design experience and is technically qualified for the project. Fundamentally, the reviewer and the designer cannot be the same person in order for a design review to be meaningful and effective. The reviewer is involved only at milestone completion stages before the design documents (plans and specifications) are submitted to the client. It is important that the reviewer focuses primarily on critical issues (e.g., constructability, technical solutions, and compliance with design criteria).
- The *project manager* may be the person who “approves” the drawings. In the engineering consulting profession, the project manager is the person in charge of a particular project, whether administratively or technically, or both. Depending on his or her background and the size of the project, a project manager may also be the principal designer or the reviewer.

Engineer’s seal. To certify the design, construction drawings are stamped and signed by a licensed professional engineer, who is the engineer of record. There are no guidelines on the location of the engineer’s seal. In most cases, the seal is located at the bottom or the right side of the sheet. Some title blocks contain a square space that is reserved for the engineer’s seal. The engineer’s seal can either be “wet-ink” stamped or in digital format. Certifying construction drawings is discussed in Chapter 12.

Sometimes, a drawing scale is shown in title blocks to verify whether the drawing has been reduced in size. This practice may lead to confusion and is not recommended, as a drawing may contain more than one scale.

Fig. 5-1 shows an example of a title block at the bottom of the sheet. Alternatively, this layout can be rotated vertically and placed on the right side of the sheet.

Similar to many digital documents, the file name and the path of the file name of a CAD drawing are printed in the drawing for future retrieval. This information is usually shown outside the drawing borders, either at the bottom or along the left side of the drawing, and it should not be part of the title block.

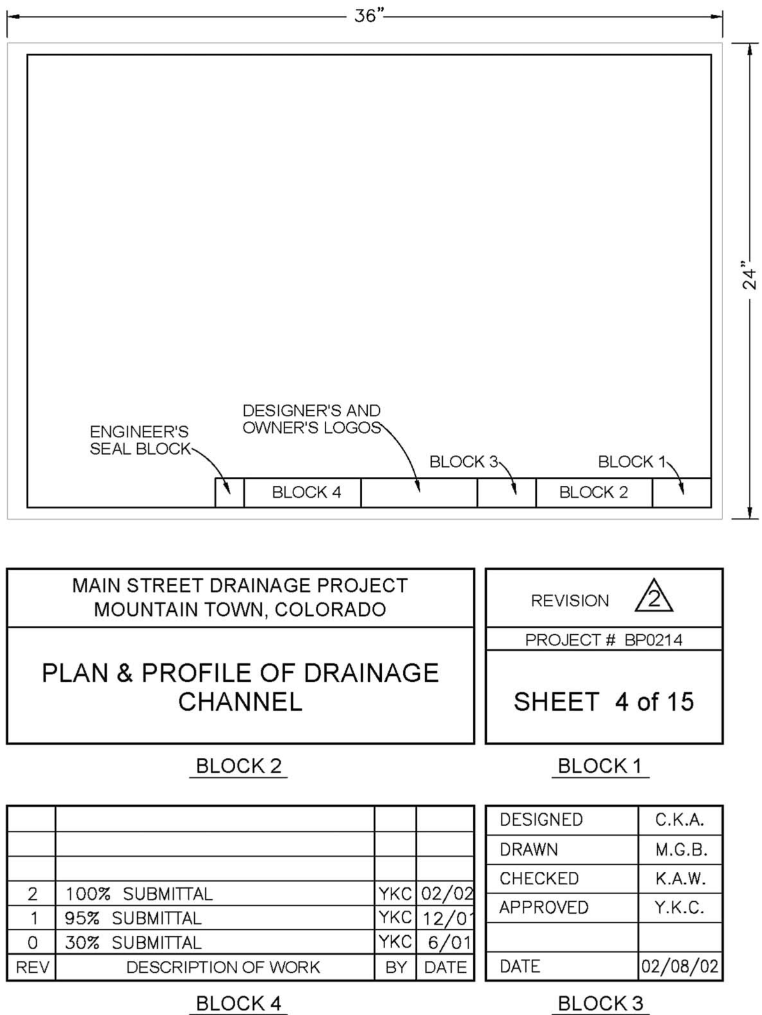


Fig. 5-1. Example Drawing Title Block

5.3 Sheet Organization

There should be a logical order to the organization of the construction drawing sheets, regardless of the size of the design package. When a logical order is followed, the organized manner allows the design team to divide up and produce the drawings according to various design disciplines, and the contractor benefits from the ease of obtaining needed construction information and passing the information down to his or her subcontractors and supervisors.

The following sequencing of drawings is commonly used and recommended:

1. Title sheet;
2. Abbreviations, legend, and general notes;
3. Existing conditions;
4. Subsurface conditions;
5. Group drawings (civil, structural, mechanical, etc.) for each group:
   a. General plan and sections,
   b. Detailed plan and sections,
   c. Sections and detail sheets, and
6. Miscellaneous detail sheets.

The principle of sheet organization is simple: the series of sheets should be organized from general to specific. After the title sheet and other general sheets that define the existing conditions, the remaining sheets should show the general structure layout and sections, followed by more specific layouts and details. In heavy civil construction, the general civil drawings precede drawings from other disciplines, which are organized into groups. Where the work does not seem to fit into any well-defined categories, these design features are grouped into the so-called miscellaneous details at the end of the package.

The following is a discussion of the general requirements and guidelines for preparing various parts of a set of construction drawings:

Title sheet. The title sheet, of course, is always the first sheet in the drawing package. It is also referred to as the *cover sheet.* The cover sheet contains the following information:

- Name of the project, usually in very large and bold letters at the top of the sheet.
- List of drawings contained in the package. For a large package with many sheets, the list of drawings cannot fit on the cover sheet and is usually located on another sheet immediately following the cover sheet.
- Location maps of the project in relation to highways, access roads, and nearby towns and cities.
- Signature of the engineer of record, regulatory agency, or the owner.

There is a lot of flexibility for the designer to organize the title sheet information. All of the signatures are usually on the right side of the sheet. Some clients and owners have their own standard title sheets, and those standard sheets are usually furnished to the designer.

Abbreviations, legend, and general notes. These sheets are used to define the abbreviations used in the drawings, graphic symbols and legends, and general notes that apply to the entire drawing set. When there are reinforced concrete structures in the design, there should also be a separate sheet for structural notes.

Existing conditions. Several drawings may be required to define the existing (preconstruction) conditions of the project site. Existing conditions that should be shown include a topographic map of the site, survey controls, subsurface conditions, utilities, borrow areas, staging and stockpile areas, and other information obtained from site characterization (see Chapter 3). Some designers prefer to present climatic and meteorological data of the site in a graphical manner in the drawings (see Section 20.2).

Subsurface conditions are generally presented in the drawings in terms of a plan of exploratory boreholes and test pits, and simplified graphic logs of boreholes and test pits can be used to summarize the results of these investigations. More specific results of subsurface conditions can be found in geotechnical reports or as reference data incorporated into the technical specifications (see Chapter 20).

Some projects are so large that multiple sheets are required to show the topography of the entire site. In such cases, key maps are required to show the relative locations of sheets, and match lines (see Section 7.7) are used to show the splices in the drawings.

Grouping of disciplines. Heavy civil construction projects typically include multidisciplinary work such as structural, mechanical, and electrical components. Design packages with these features are generally grouped into sheets of the same discipline. Therefore, after the civil drawings, one or more groups of drawings can follow. To represent drawings of different disciplines, some design firms use prefixes in the sheet numbers. The following is a common set of prefixes for disciplines encountered in heavy civil work:

- *G*: General drawings (e.g., cover sheet, list of drawings, abbreviations, legend, general notes, and existing site conditions);
- *C*: Civil drawings (e.g., general plans and sections, excavation plan and sections, and earthwork);
- *S*: Structure drawings (e.g., reinforced concrete, structural steel, and metalwork);
- *M*: Mechanical drawings (e.g., gates and valves, piping plan and details, and pumps);
- *E*: Electrical drawings (e.g., electrical site plan, wire diagram, conduit diagram, one-line diagram, and details); and
- *A*: Architectural features of buildings (e.g., floor plan, windows and doors, and finishes).

Sheet Number	Description
G1	COVER SHEET, LOCATION MAPS, LIST OF DRAWINGS
G2	GENERAL NOTES, ABBREVIATIONS, & LEGEND
G3	GENERAL SITE PLAN, BORROW AREAS, & STAGING AREA
G4	EXISTING PLAN OF DAM & SPILLWAY
G5	BOREHOLE LOGS & TEST PIT LOGS
G6	GENERAL PLAN OF DAM MODIFICATIONS
G7	RECLAMATION – PLAN & DETAILS
C1	PLAN OF EMBANKMENT MODIFICATIONS
C2	PLAN OF EXCAVATIONS
C3	EXCAVATION SECTIONS & DETAILS
C4	EMBANKMENT – SECTIONS & DETAILS, SHEET 1 OF 2
C5	EMBANKMENT – SECTIONS & DETAILS, SHEET 2 OF 2
C6	EMBANKMENT – INSTRUMENTATION SCHEDULE & DETAILS
S1	PLAN OF SPILLWAY MODIFICATIONS
S2	SPILLWAY PLAN & SECTIONS
S3	SPILLWAY – SECTIONS & DETAILS, SHEET 1 OF 2
S4	SPILLWAY – SECTIONS & DETAILS, SHEET 2 OF 2
S5	SPILLWAY REINFORCEMENT DETAILS
S6	PLAN OF OUTLET WORKS MODIFICATIONS
S7	OUTLET WORKS – SECTIONS & DETAILS
S8	OUTLET WORKS REINFORCEMENT DETAILS
M1	OUTLET WORKS GATE & VALVE DETAILS

Fig. 5-2. Example of List of Drawings

General plan and sections. The general plan or overall plan of the new feature should be a civil drawing showing the finished grades or contours. Section cuts from the general plan should show existing ground surface, limits of excavation, and fill limits. All required grades for the project should thus be shown on these sheets.

Detailed plan and sections. A more detailed layout plan and sections of structures may be required for better resolution. If a general plan and sections have already been used to show all required grades, then the detailed plan and sections can just show details pertaining to the structure itself, without the surrounding topographic information in order to simplify these drawings.

Miscellaneous detail sheets. Miscellaneous detail sheets are used for details that do not fit logically into any of the disciplines listed above. Typical details shown on miscellaneous detail sheets include standard fencing, instrumentation, small fabricated metalwork, survey monuments, and temporary or permanent signs. These sheets typically represent the last sheets in a drawing set.

Fig. 5-2 is an example of a list of drawings for a dam project, illustrating the sequencing of drawings from different groups and disciplines. It is important to point out that no two drawings should have the exact same title. In the example shown in Fig. 5-2, there are two sheets for *Embankment—Sections & Details* and two sheets for *Spillway—Sections & Details*; these two sheets are differentiated by adding “Sheet 1 of 2” and “Sheet 2 of 2.”

CHAPTER 6

Layout of a Civil Design Plan

6.1 Design Controls

The layout of a civil design plan requires a set of design control references that are used to determine the design alignment and dimensions, and to enable the construction surveyor to establish the lines and grades to build the project. Design controls for civil design work consist of benchmarks, coordinate grids, control points, project baselines, and centerlines of structures. To account for ease of layout during design and ease of survey during construction, the selection of locations of design controls should be considered carefully.

Control points—Control points may be primary survey benchmarks (see Section 3.6) established on site before construction, and/or additional control points to establish project baselines and centerlines. Primary survey benchmarks should contain information on elevation and coordinates (northings and eastings). Control points that are used to define a baseline or a centerline only require information on coordinates and stationing (see Section 6.2). They are established by the contractor during construction, and they may only be temporary working points. All control points should be located beyond the limits of excavation and backfill operations so that they will not be disturbed during the work. Control points for construction can be converted to permanent benchmarks for future survey and monitoring uses.

Baseline and centerline—A baseline is a linear or nonlinear reference to establish project stationing and from which offset distances are taken. A centerline is usually associated with a particular structure or design feature, such as an embankment, canal, pipe, or highway. A centerline can also be a baseline. At least two control points, or one control point plus a bearing, are required to establish a straight baseline or centerline. A baseline or centerline can also be a curve. Any changes in bearing of a baseline or centerline should be noted with either the new bearing or the deflection angle.

Fig. 6-1 is an example of a set of design controls for a dam raise project. Benchmark numbers 1 and 2 are used for primary survey controls. The benchmark designations, coordinates, elevations, and stations are shown in the figure. A baseline is established by these two benchmarks. This baseline is also the centerline of the existing dam crest. The dam is raised by placing fill upstream, and the centerline of the raised dam

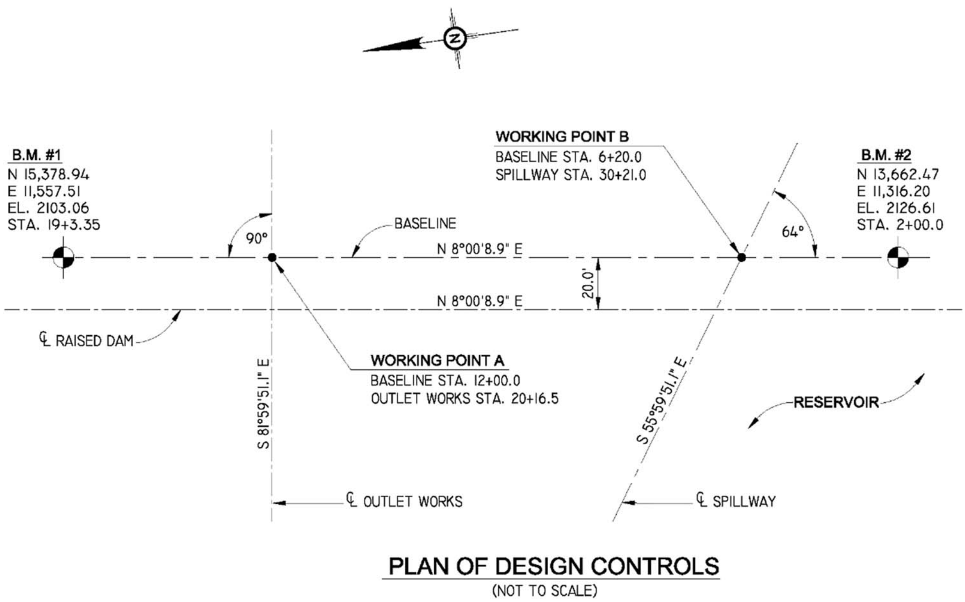


Fig. 6-1. Example of Design Controls for a Dam Raise Project

crest is parallel to the baseline and offset a distance of 20 ft (6.1 m) upstream of the original baseline. A new outlet works is constructed by a cut-and-cover method in the middle of the dam. The centerline of the outlet works is established by a bearing and Working Point "A." A new spillway is constructed in the right abutment of the dam. The centerline of the spillway is established by a bearing and Working Point "B."

6.2 Stationing and Offsets

In a civil design plan, any given point on the plan can be represented by the project coordinates (northings and eastings), which are cumbersome and should be reserved only for key control points. When the design controls include baselines and centerlines, any point on the plan can be referenced to these lines by means of stations and offsets.

Stations are distance labels along a baseline or centerline, similar to street addresses. The standard designation for stationing is $x + z$, where x is an integer including zero, and z is a two-digit number between 00 and 99. The integer x is used to express distance in hundreds of feet (or hundred of meters in the metric system). When the value of z is less than 10, it is still written with two digits (e.g., 02). For example, station $5 + 07.1$ is a point on the centerline that is 507.1 ft (154.56 m) from an arbitrary zero reference point (station $0 + 00$). When a point on the centerline falls behind the zero reference point, that point has a negative stationing.

Negative stationing is used by some designers, but this practice should be discouraged to avoid confusion associated with the negative sign. To avoid using negative stationing, station 0 + 00 should be well beyond the project limits. For example, the starting stationing for a project can be taken as 10 + 00 or 100 + 00, depending on the size of the project. Stationing is typically labeled at some regular interval along a baseline or centerline, such as every 100, 500, or 1,000 ft, depending on the length of the line.

When a project contains more than one baseline or centerline, different stationing may be required. When different stationings are used for a project, each stationing should be identified and differentiated. In the example in Fig. 6-1, three stationings are used:

1. Stationing for the baseline and centerline of the raised dam. The same stationing can be used for these two lines because they are parallel to each other. The stationing is called out in the drawings as "BASELINE STA."
2. Stationing for the outlet works structure. The stationing is called out in the drawings as "OUTLET WORKS STA."
3. Stationing for the spillway. The stationing is called out in the drawings as "SPILLWAY STA."

In addition, when more than one stationing is used for a project, it is advisable to use different numbering systems to make it easier to differentiate them. In Fig. 6-1, the dam baseline station is from 2 + 00 to 19 + 33.35. The outlet works station can be from 20 + 00 to 30 + 00, and the spillway station can be from 30 + 00 to 40 + 00. In this way, a station designation of 25 + 00 will imply that it is on the outlet works centerline, and a station designation of 15 + 02 will imply that it is on the dam baseline, even when the stationing prefix is not designated.

Offsets are distances measured perpendicular to the baseline or centerline. On the plan, the offset for a particular point can be dimensioned directly from the point to the line. Frequently, a table (also known as a *schedule*) is used in the drawings for a series of offset points on both sides of the centerline. To denote which side of the centerline a point falls on, a sign convention is sometimes used, with positive offset on one side and negative offset on the other. Positive offsets should be to the right, looking *up station*, that is, looking in the direction of increasing stationing. Alternatively, subscripts r and l are added to the offset to represent right and left, respectively, again looking up station.

6.3 Scale Selection

The selection of a proper scale for a civil design plan is controlled by the amount of paper space reserved for that plan. In general, the proper scale is selected to allow the maximum amount of information and details to be shown in the drawing space available. Because essentially all civil design drawings are now prepared in some form of computer-aided drafting (CAD) systems (see Chapter 11), this guideline requires some clarification. With CAD, any scale can be used for the drawing because the software allows the base map to be enlarged and zoomed to the necessary scale. The proper scale in a CAD drawing refers to the scale that will be plotted on a full-size drawing sheet, which will be read and interpreted for construction by the contractor.

In civil design, the *civil engineer's scale* is used. In the United States, where U.S. customary units are still commonly used in engineering design, the following scales, available from a standard civil engineer's scale, should be used: 10, 20, 30, 40, 50, and 60. Other scales (e.g., 15, 25, and 70) are not recommended because scaled distances cannot be readily obtained directly from the scale. When a 10-scale is used, it would mean that 1 in. = 10 ft; a 100-scale means that 1 in. = 100 ft.

For detailed structural or mechanical design, the *architect's scale* is used. In the United States, the following scales are available from a standard architect's scale in U.S. customary units:

3-scale (3 in. = 1 ft)
1.5-scale (1.5 in. = 1 ft)
1-scale (1 in. = 1 ft)
3/4-scale (3/4 in. = 1 ft)
1/2-scale (1/2 in. = 1 ft)
3/8-scale (3/8 in. = 1 ft)
1/4-scale (1/4 in. = 1 ft)
3/16-scale (3/16 in. = 1 ft)
3/32-scale (3/32 in. = 1 ft)

In all cases, the scale should be selected considering the complexity of the plan or detail and the legibility when half-size drawings are printed.

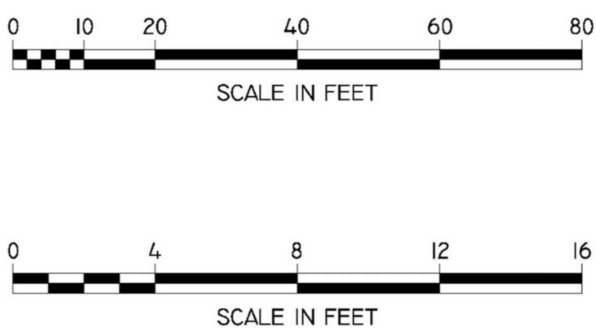


Fig. 6-2. Examples of Bar Scales

6.4 Scale Display

Bar scales with scale units should be used for all drawings. With the increased use of reduced drawings, a narrative description of the scale in the drawing (e.g., 1 in. = 200 ft, 1/2 in. = 1 ft) does not adequately convey that information because the drawing could have been photographically or electronically reduced to an unknown percentage of its original size. With a bar scale, the scale itself is proportionally reduced as the drawing is reduced, thus eliminating the ambiguity. Fig. 6-2 illustrates the use of bar scales.

CHAPTER 7

Graphical Representation of Civil Design

7.1 Graphical Practice

This chapter introduces the two-dimensional graphical views by which civil drawings are represented. Unlike drawing machine parts, three-dimensional views such as isometric or oblique views are too complicated for heavy civil construction, and they are not practical to show on construction drawings. Typical views include *plan views*, *sections*, *elevations*, *profiles*, and *details*. These two-dimensional views are used to represent a three-dimensional picture, such as that of an open excavation, earthfill structure, or site grading. The contractor uses these views to establish the survey controls for lines and grades required to build the structures. These graphical representations are also used to estimate payment quantities for completed work (see Chapter 22).

Graphical views are assembled using lines and *callouts*. Callouts are narratives that are used to describe different parts in a particular graphic view. Various line types, line weights, and lettering techniques in callouts are described and illustrated in this chapter. For civil design, definitions and meanings of various line types are based on traditional practices of engineering and architectural graphics, but they are explained specifically for civil design applications.

7.2 Plan View

The plan layout of a civil drawing is the most important view of all graphical representations; all other views are supplemental or auxiliary to the plan view. The plan view of a civil layout drawing, regardless of structure type, should contain the following information:

- A title.
- A bar scale.
- A north arrow, showing the orientation of the layout with respect to the compass direction.

- Base topographic contours, showing the existing contours both outside and inside the new structures. The existing contours under the new structures should be shown in dashed lines (see Section 9.7) because the new structures will alter the existing topography.
- Project coordinate grid lines, expressed in terms of northings and eastings. These grid lines should be labeled at regular intervals, such as every 100 ft (30.5 m), every 250 ft (76.2 m), or other convenient intervals, depending on the size of the project. Grid lines are sometimes shown as 2-in. (51-mm)-long lines on the borders, or cross-shaped tick marks in the interior of the plan.
- Stationing of centerlines of major features, such as a roadway, dam crest, or a pipeline. The stations should be labeled at regular intervals, such as every 50 ft (15.2 m) or every 100 ft (30.5 m), depending on the size of the project.
- Section cut lines, showing the locations where cross sections are being taken. The section cuts should include a "bubble" symbol (see Section 8.1) showing the section designation, the sheet number where the section is cut, and the sheet number where the section is shown.
- Centerlines and/or outlines of major buried features, such as pipes, manholes, or drain blankets.

An example of a typical plan view is shown in Fig. 7-1.

All exposed key elevations and slopes of the new structure should be called out on the plan. The exposed and buried limits of the structure should also be shown. The intersections of cuts or fills with existing ground contours are known as *catch points*. The linear trace of catch points is called a *catch line*, and both catch points and catch lines are established graphically. The catch line essentially becomes the outline of an earth cut or earth fill. Most computer-aided drafting (CAD) programs (see Chapter 11) have capabilities to establish these catch points and catch lines without manual operations. However, it is important that one should know the principles of manually establishing catch points, even though a computer would be used during production of the plan. The principles of establishing catch points and catch lines are explained in Section 9.2.

There are two methods to represent lines and grades. One method is to contour the entire feature; the second method is to use slopes and elevations without contours. Both methods accomplish the same goal, namely, telling the contractor what the geometry of the structure is. Figs. 7-2 and 7-3 illustrate the two methods of representing lines and grades of an excavated pond. Note that the method used in Fig. 7-2 requires significantly more lines to define the pond with new contours. Catch points are shown as black dots in Fig. 7-2. The same catch lines are used to define the outline of the pond in this example. Some designers prefer to use the second method, that is, using slopes and elevations, because it gives a cleaner drawing.

In general, the orientation of a feature on a plan is selected based on the best way to fit it on a drawing sheet rather than on compass orientation. For example, although it should be the first choice, it is not always necessary to orient a feature so

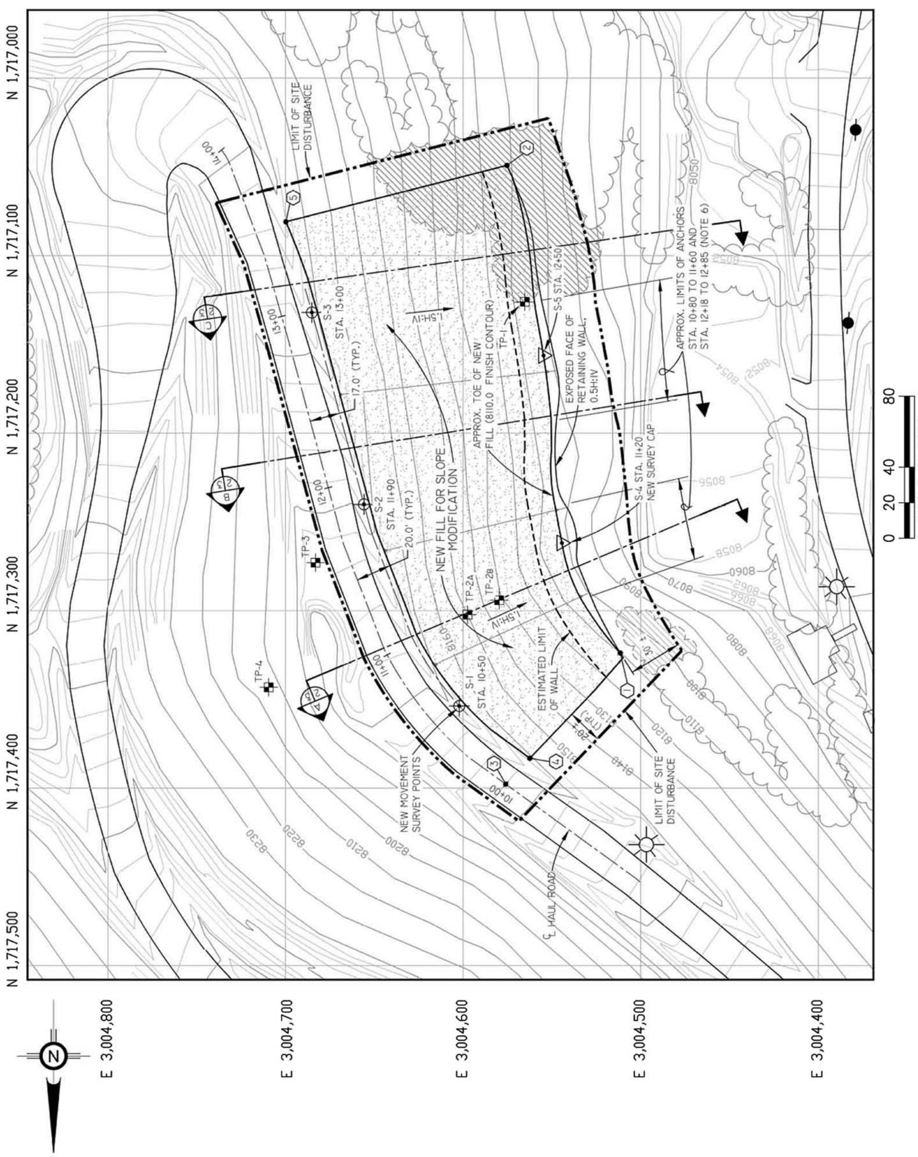


Fig. 7-1. Example of a Plan Layout

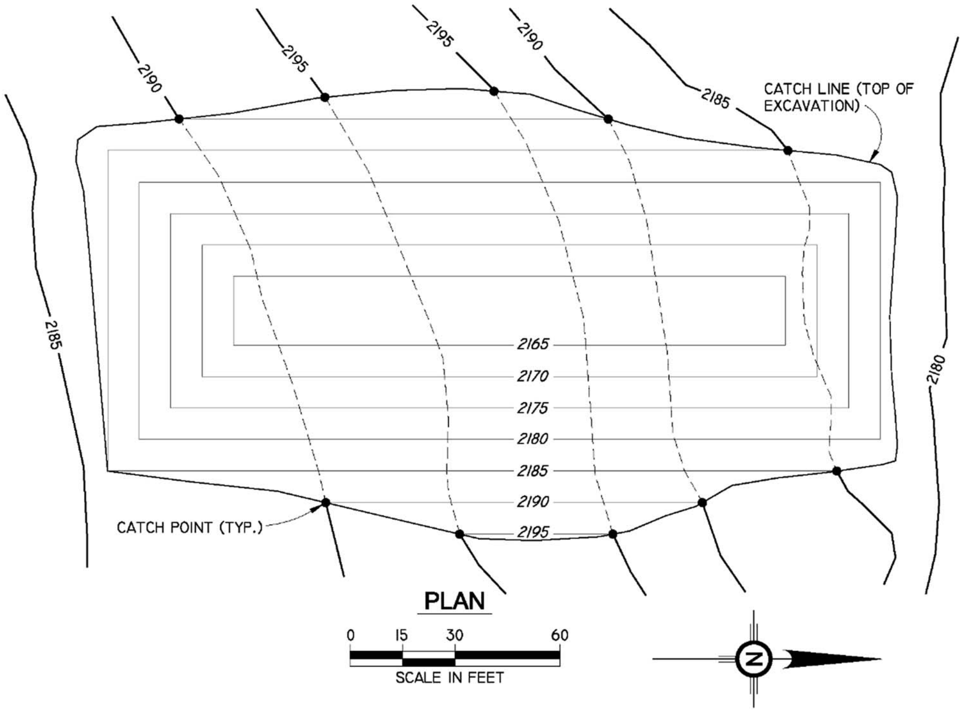


Fig. 7-2. Plan of Pond Excavation Shown Using New Contour Method

that the north direction points to the top of the drawing sheet (see Fig. 3-2). To avoid confusion, it is a good practice to be consistent in orientation for various portions of the plan view of the same feature in the drawing set. For example, if the front of a building is oriented to the left side of the drawing in one sheet, that same feature should not be oriented to the right side in another drawing sheet. Many state highway departments have guidelines on plan orientation for roadways. Generally, the plan of a roadway is oriented so that the station increases from left to right on the drawing sheet.

There is one particular type of feature for which the feature orientation on a plan view is controlled by the stream flow direction. Dams are usually located on a stream or across a drainage channel (although there are off-stream dams), and the plan view of a dam should be oriented on the drawing sheet so that the stream flows from the bottom to the top of the sheet. The reason for this preference is that abutments of a dam, by convention, are referred to in the dam engineering profession as the left and right abutments when one is facing downstream. When a dam plan is oriented this way, the left abutment is on the left side of the drawing and the right abutment is on the right side. Otherwise, one has to mentally or physically rotate the drawing in order to orient with reference to the abutments and the viewer's location. Fig. 7-4 illustrates the conventional orientation of a dam plan.

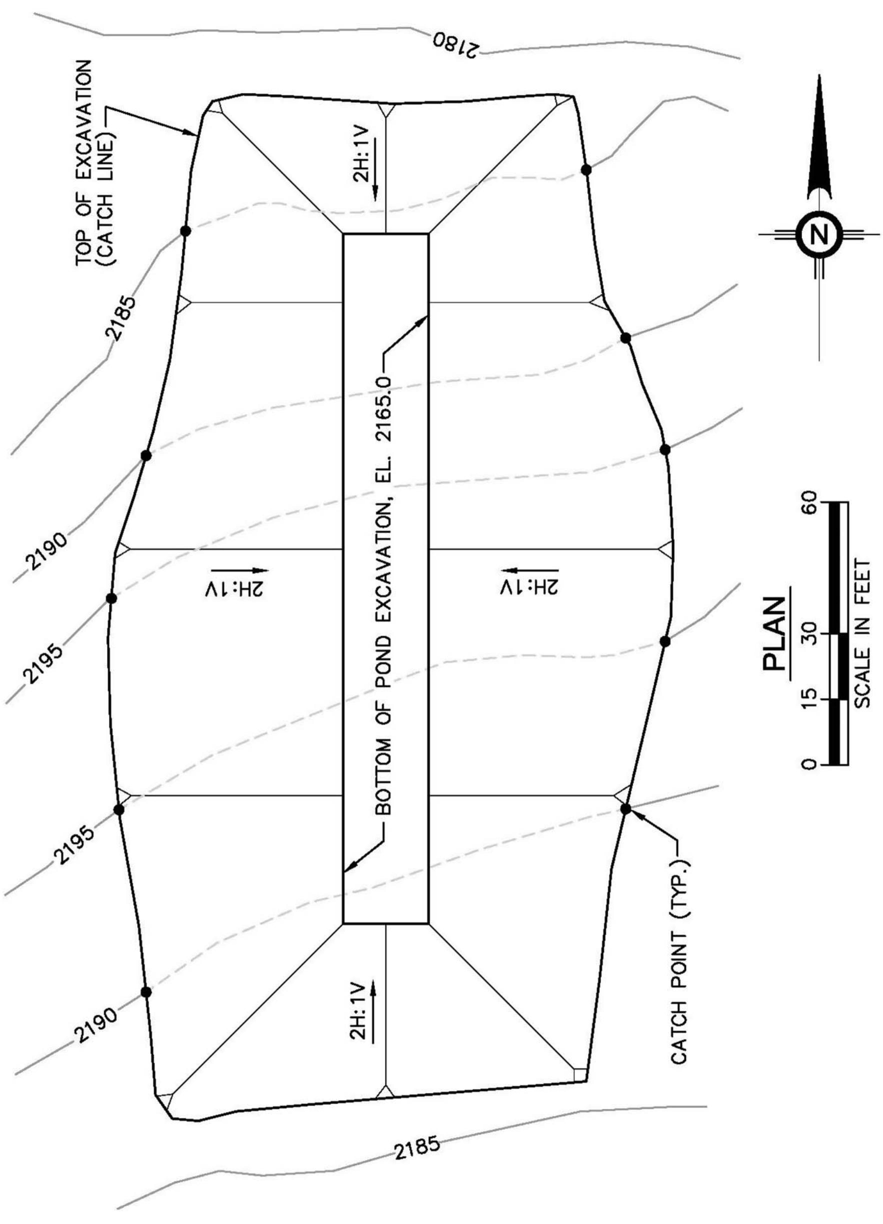


Fig. 7-3. Plan of Pond Excavation Shown Using Slopes and Elevation Method

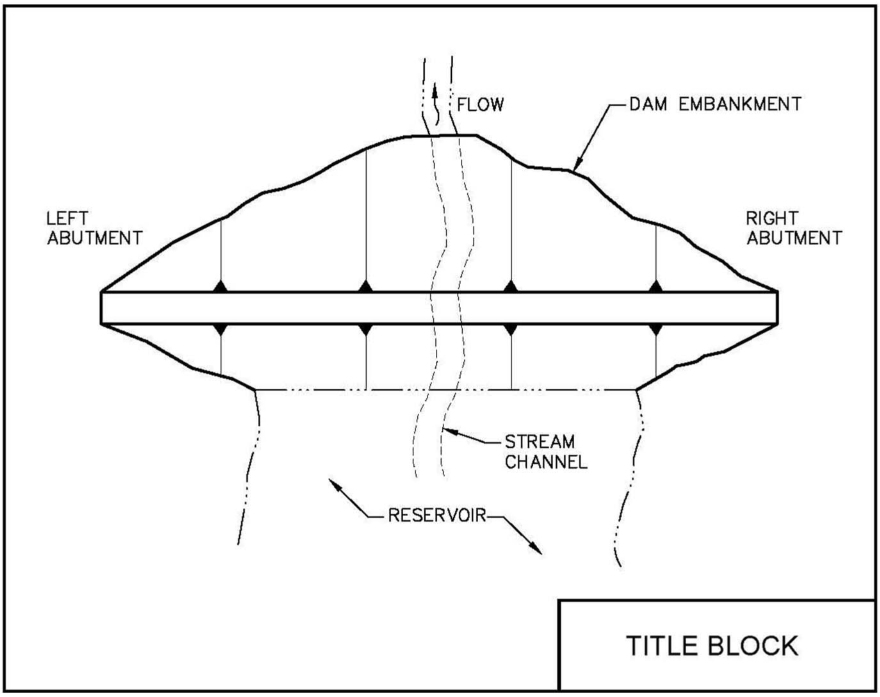


Fig. 7-4. Orientation of a Dam Plan

7.3 Section View

A section view is also called a *cross section.* A section shows the internal relationship among various components and features of a structure shown on the plan view. An adequate number of sections should be drawn to show all of the internal features in order to construct the structure. For a linear structure, such as a buried pipe or a highway, sometimes a single typical section (Fig. 7-5) may be sufficient to construct the entire pipeline. For other more complicated structures, more than one section may be required to show all of the design information and relationships of the project elements. Some clients or owners require sections at a certain interval, but those are usually for linear structures, such as highways, pipelines, or canals.

A section should contain, as a minimum, the following information:

- An elevation scale, preferably on both sides of the section, with the datum and units indicated on the scale. In some cases, an elevation scale is not necessary for a typical section if key elevations are not important (e.g., Fig. 7-5).
- A title and section bubble (see Fig. 8-5) that is referenced to the drawing sheet where the section is cut.
- A scale bar under the title. If no scale exaggeration is used, the same scale as the elevation scale is used here. However, if the section is exaggerated

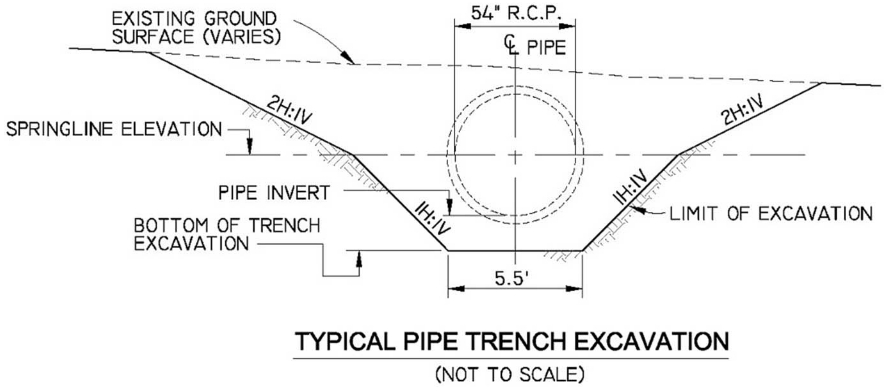


Fig. 7-5. Example of a Typical Pipe Section

(see Section 9.5), then both the vertical and horizontal bar scales should be indicated here.

- Existing ground surface as obtained from the base topographic map. This information is important because it is a reference for cut and fill. Without the existing ground surface in the section, it is impossible to show the excavation limits and the fill limits.
- Limit of excavation, which may also be the bottom of the structure. The excavation is between the existing ground surface and the limit of excavation. The limit of excavation (also known as *excavation neat line*) is an important design information that is also used by the contractor and owner for measurement and payment purposes. Excavation beyond this neat line is considered overexcavation, which requires special contract provisions for payment.
- Limits of earthfill. For purposes of material specifications and measurement and payment, each earthfill type should be assigned a name, such as structural fill, random fill, or embankment fill.
- Final grade (also called finish grade).

To minimize the number of sections required, the designer should carefully determine the appropriate section locations. The number of cross sections should be selected based on the following considerations:

- Each section should show the maximum design information. When changes occur from one location to another on the plan, additional sections are required to show these changes. These changes include different limits of excavation, different fill types, and different finished grades.
- Sections are required for quantity takeoff. Frequently, one section does not show a typical condition across the entire structure, and additional sections are required to define more accurately the quantities involved (see Section 22.3).

Sections can be labeled alphabetically (e.g., Sections A, B, and C). Because of potential confusion of the letters *I* and *O* with numbers, Sections I and O are generally not used. For a large design package, the 24 section designations are not enough for all of the required sections. However, it should be noted that a section is referenced not just by its designation, but also by the sheet number where the section is shown. For example, Section B on Sheet 4 is a different section from Section B on Sheet 7. In other words, there can be more than one section with the same designation in a drawing package; however, there should not be duplicate section designations on the same sheet.

Some designers prefer to label sections numerically instead of using letters. This approach allows unlimited sections to be used without repeating. In a large design package that includes general, civil, structural, and mechanical features, the sections should be numbered consecutively in each discipline. For example, sections in a civil package are numbered C1, C2, C3, etc., and sections in a structural package are numbered S1, S2, S3, etc. When sections are designated by numbers, details should be designated by letters instead of numbers to avoid confusion (see Section 7.6).

When a section is cut at a special location, such as a particular station, that station should be indicated under the section title. Fig. 7-6 is an example of a section view cut at a special location.

When a section shows several different types of materials, such as concrete, sand, gravel, and other types of earthfill, material symbols should be used to differentiate these materials and enhance the graphic quality of the drawing. Fig. 7-7 illustrates the use of graphic symbols to enhance the drawing. More discussion on effective use of shadings and hatchings is contained in Section 9.3.

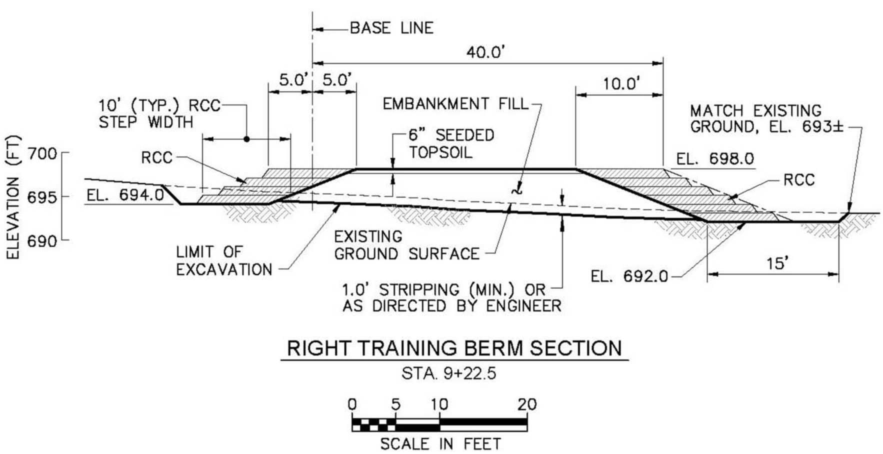


Fig. 7-6. Example of a Cross Section at a Specific Location

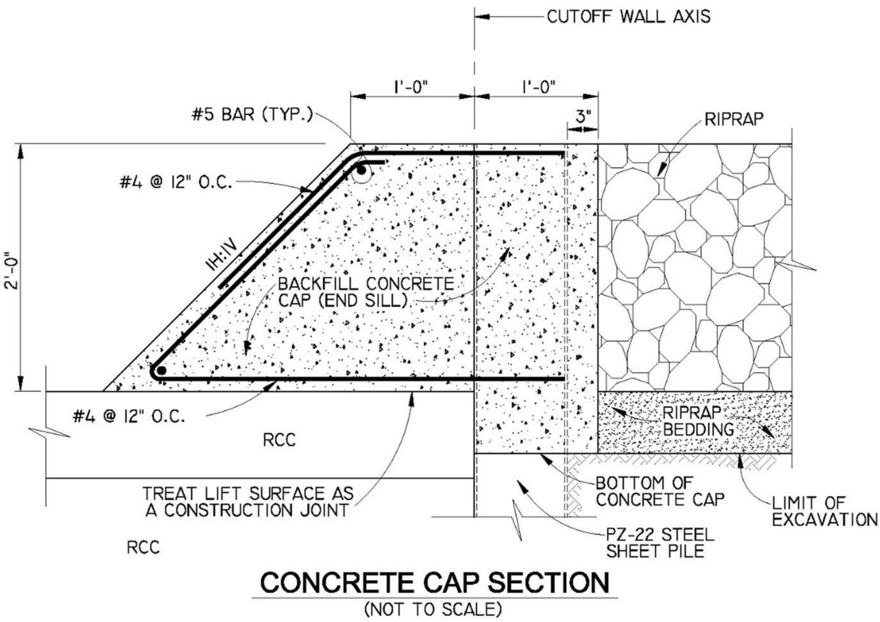


Fig. 7-7. Use of Graphic Symbols to Enhance a Drawing

7.4 Elevation View

Elevation view, as the name implies, shows the vertical relationship of various features of a structure. It is an external view of the side of a structure. When a structure is viewed from the outside, all of the external components that are exposed are projected onto the same plane. In a sense, the elevation view is similar to the plan view, except the plan is a view from above, whereas the elevation view is a view from the side. This view should not be confused with a cross section, which cuts through a structure. If a structure is nonsymmetrical, various elevation views (e.g., north elevation or east elevation) may be required to show all of the features. An elevation view can also be a profile, but an elevation view should not have exaggerated scales.

Elevation views are frequently used for concrete and mechanical structures, and they are not typically used for earthwork structures. Earthwork structures are typically simple enough that plans and cross sections are adequate to show all of the design requirements.

An elevation view should contain, as a minimum, the following information:

- A title and elevation bubble that is referenced to a plan or a section from which the elevation view is taken.
- A scale bar under the title. No scale exaggeration should be used for the elevation view.

Much flexibility and designer's discretion can be used in showing the elevation view. Options that have been used include the following:

- An elevation scale, with the datum and unit indicated on the scale. Whether an elevation scale is used or not, key elevations of the structure should be called out (e.g., bottom of excavation, top of concrete, and material boundaries).
- The compass orientation of each end of the structure may be helpful when various elevation views are taken for a nonsymmetrical structure.
- When an elevation view purposely shows an isolated structure for simplicity, it is not necessary to show the adjacent features around that structure. However, if the view is intended to show, for example, the structure foundation, then the existing ground surface and the finished ground surface should be shown in the view as well. The information on the foundation earthwork should be kept to a minimum and as simple as possible because the key foundation earthwork design should be shown on a separate cross section.

An example of an elevation view is shown in Fig. 7-8.

7.5 Profile View

A profile view is essentially a long cross section along an entire structure. The main reason for using a profile is to show the entire structure longitudinally in a view that includes all of the associated structures and interrelated controls. Examples of structures for which the profile view is useful in design drawings include canals, levees, highways, sheet pile walls, slurry trench walls, tunnels, spillways, outlet works, and pipelines.

Because the profile view is a cross section, all of the drawing requirements listed in Section 7.3 apply. In most cases for long structures, it is necessary to exaggerate the vertical scale (see Section 9.5) to obtain good vertical resolution of the design features. Fig. 7-9 shows an example of a profile view. Note that two scale bars are required in an exaggerated profile: one for the vertical and a second one for the horizontal. In the example shown in Fig. 7-9, there is a 4:1 exaggeration (1 in. = 5 ft in the vertical direction, and 1 in. = 20 ft in the horizontal direction).

7.6 Details

Details show the design features and requirements when the overall plan, sections, and other views do not have the proper scale and resolution to do so. Details are essentially enlargements of certain design features and can be shown in any view that is convenient. Examples for which details are required include toe drains, weep drains, structural connections, pipe connections, and instrumentation. Typically, details are called out from other views, and design requirements are shown on these

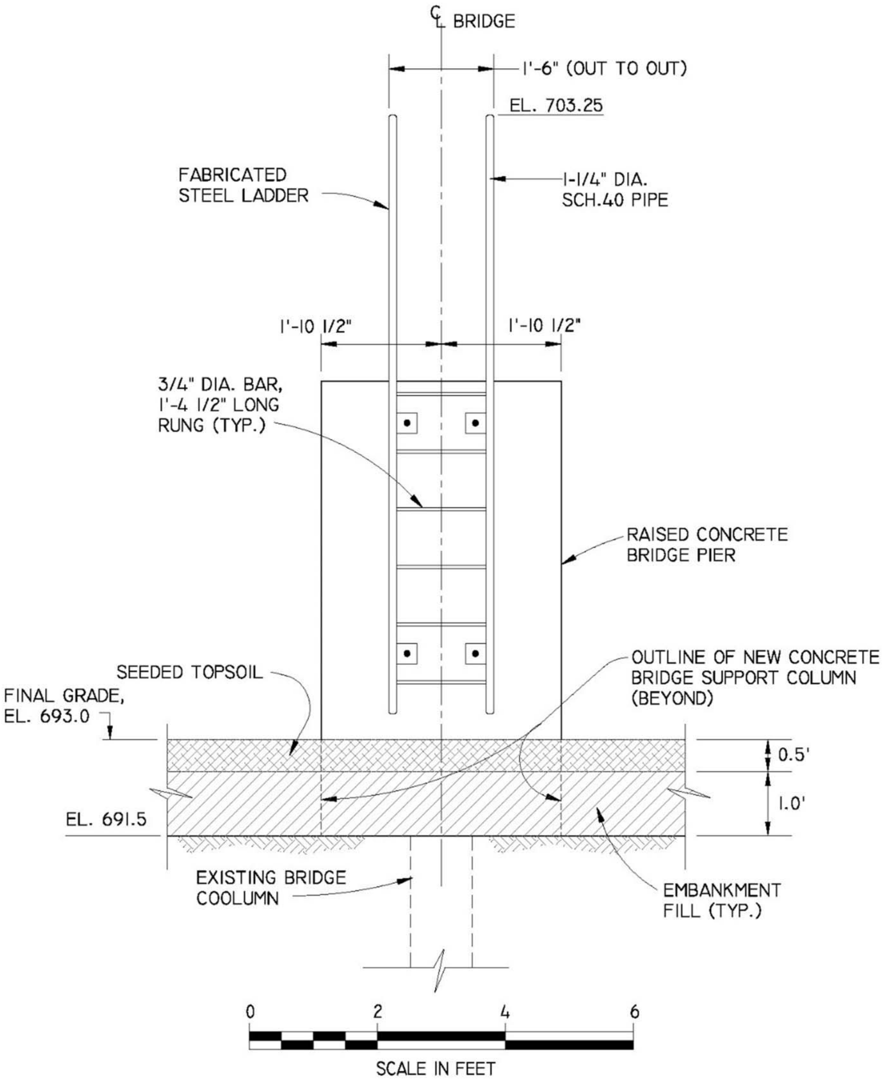


Fig. 7-8. Example of an Elevation View

enlarged views. When showing the details called out from another view, it is important that the same perspective be used. For example, if a certain portion of a plan view requires a detail, then the detail should also be in plan view, not in a section view. In addition, the detail itself should be oriented in the same way and not rotated to other directions.

In addition to detail titles, details can be numbered consecutively (1, 2, 3, etc.) for each design discipline. Alternatively, letters should be used to designate details if a numbering system is used for cross sections (see Section 7.3).

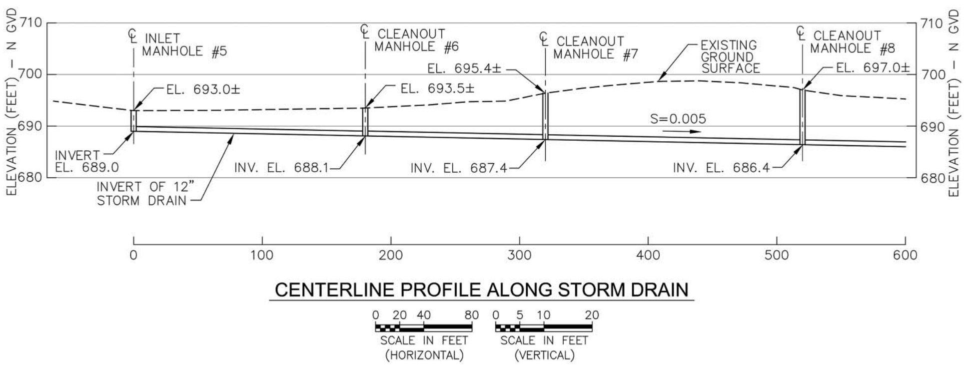


Fig. 7-9. Example of a Profile View

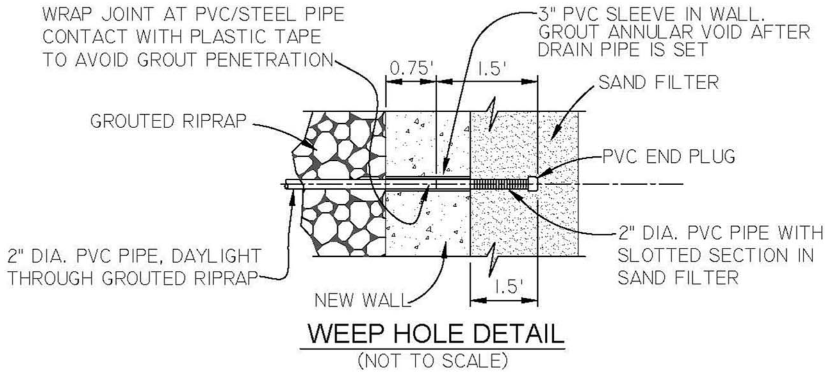
When the purpose of a detail is to add dimensions and other callouts, it is frequently not necessary to draw the detail to scale. When a detail is not drawn to scale, it should be labeled as "NOT TO SCALE" or "NO SCALE" under the title (see Section 9.5). Examples of details are shown in Fig. 7-10.

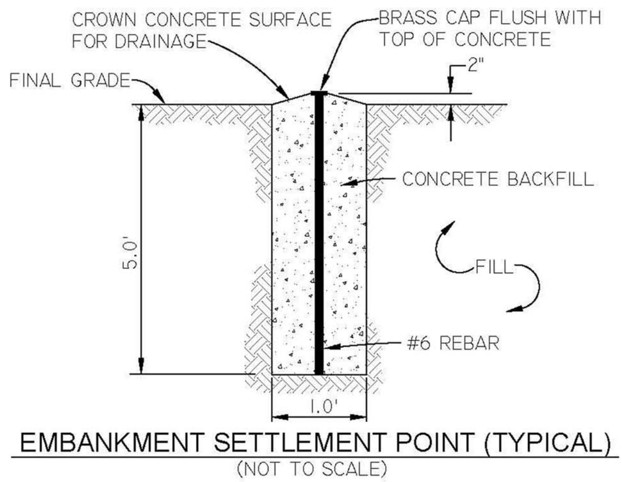
7.7 Line Types

A civil design drawing is composed of line segments that describe and define the geometry of specific features. Contrary to an artistic drawing, line segments in a technical drawing, such as a civil design drawing, have specific meanings and functions. Different line types are required to show a three-dimensional structure on a two-dimensional drawing sheet. Correct usage of various line types is essential in showing the features to be constructed. Incorrect applications of various line types can, in some cases, lead to misleading information and representation, and ultimately can cause confusion that requires clarification during construction. In this section, various line types that are commonly used in civil drawings are defined and described, and examples are provided to illustrate their applications. A summary of the line types and uses is presented in Fig. 7-11.

Visible Line. A visible line (also called an *object line*) is a solid line that defines the outline, size, and shape of a feature that is directly visible or exposed in a particular view. It is the most basic building component of a technical drawing, and it should be the most prevalent and prominent line type in a civil design drawing. This line can be a straight line or any irregular shape that is required to describe a particular feature. A view is most effective and well-chosen when visible lines are used most frequently for that view. If a view contains too many other line types (e.g., hidden lines or phantom lines), then perhaps other views are more logical to show a particular feature.

Centerline. A centerline generally shows the line of symmetry of a particular feature, and it is commonly used as the reference for dimensioning. Examples are the centerline of a roadway, dam crest, pipe, tunnel, or a drainage channel, as shown





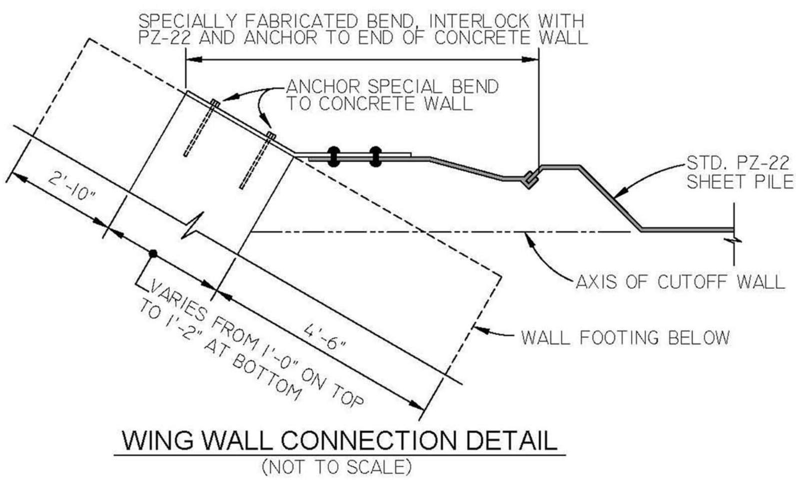


Fig. 7-10. Examples of Details

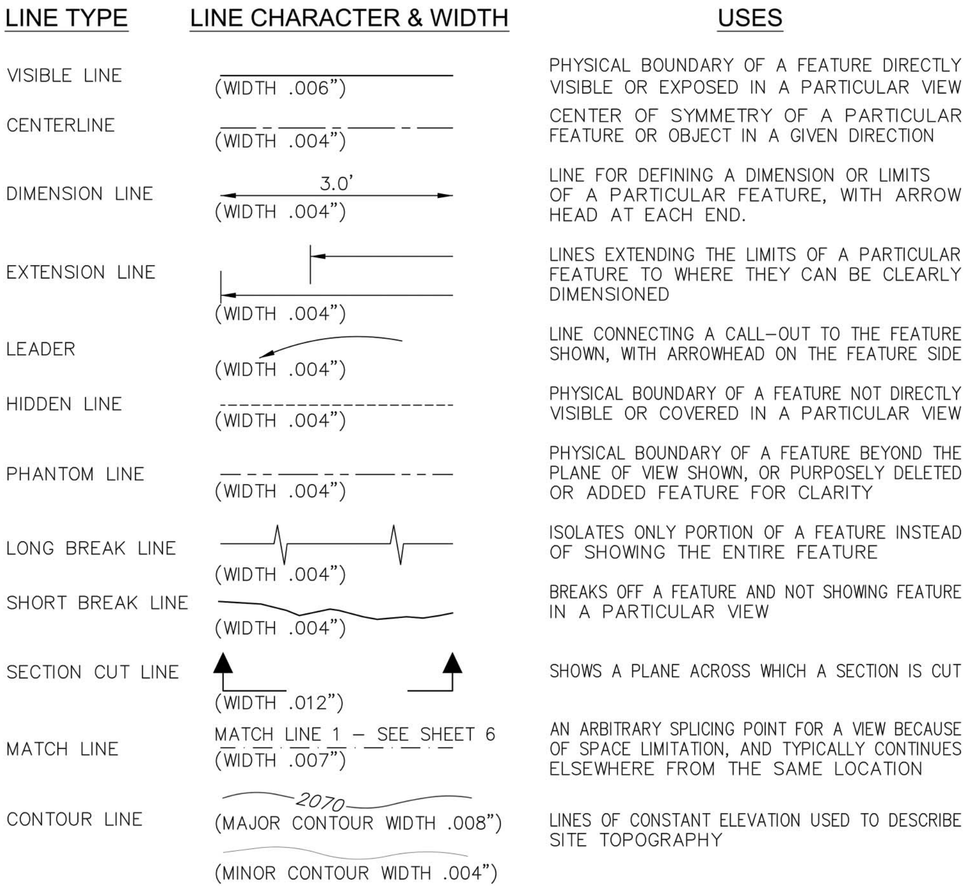


Fig. 7-11. Summary of Line Types and Uses

in Fig. 7-12. A centerline is an important reference, not only to prepare construction drawings of a particular feature, but it is also important to a contractor during construction of that feature. Most construction survey and staking are performed to locate centerlines of key features to be constructed. A layout of a particular feature always starts with the centerline, and dimensions are then taken from that line to complete the drawing of the feature. Where two features intersect, the relationship between the two features (e.g., the station and angle of intersection) is best defined using the intersection of the two respective centerlines.

Dimension Line and Extension Line. A dimension line defines the distance or length between two points or two sides in a particular feature. A dimension line always has an arrowhead at each end of the line, with a dimension centered adjacent to the line. Several ways to dimension civil design features are illustrated in Fig. 7-13. Note that extension lines may be needed for dimensioning. Extension lines are used to extend the limits of two points or two sides far enough away from the feature so

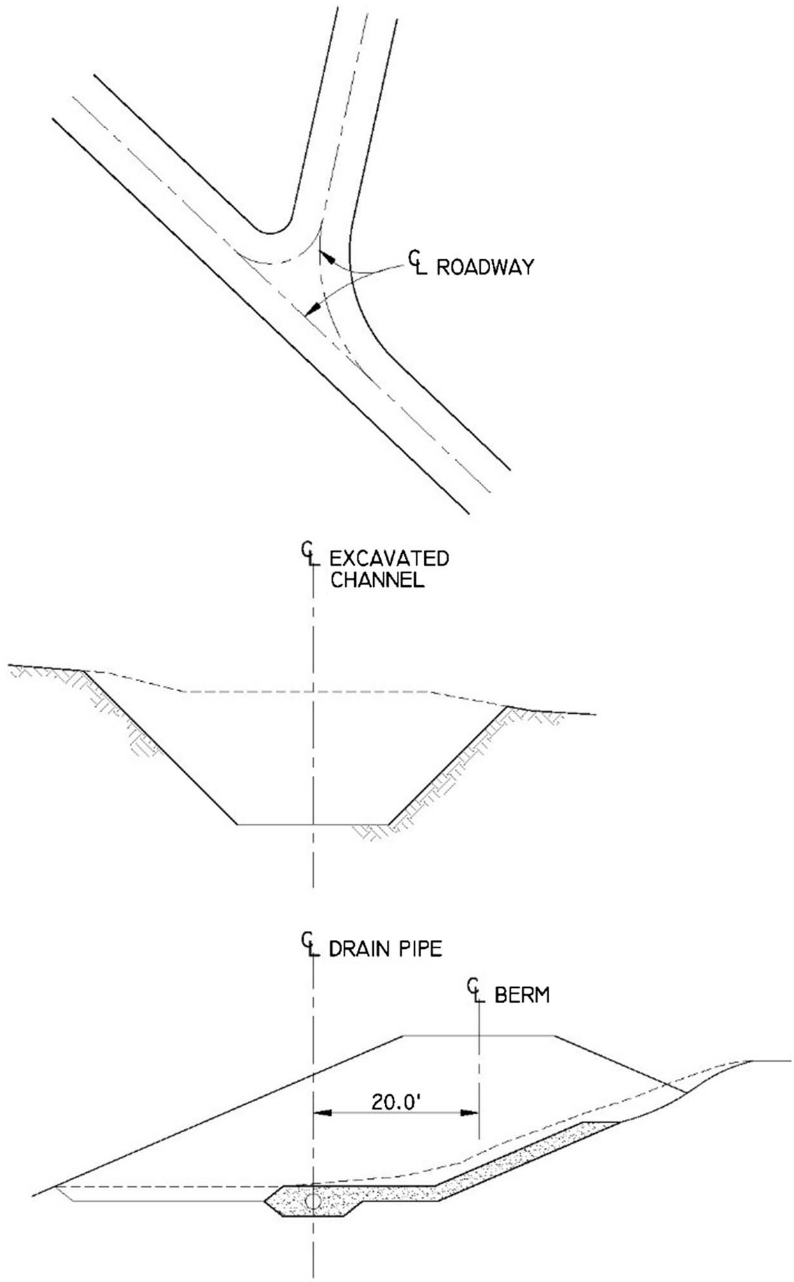


Fig. 7-12. Examples of Centerline Applications

that dimensions can be added without crowding the drawing. It should be noted that an extension line should not touch the physical boundary of that feature; a small gap is typically used between the line and the boundary (Fig. 7-13).

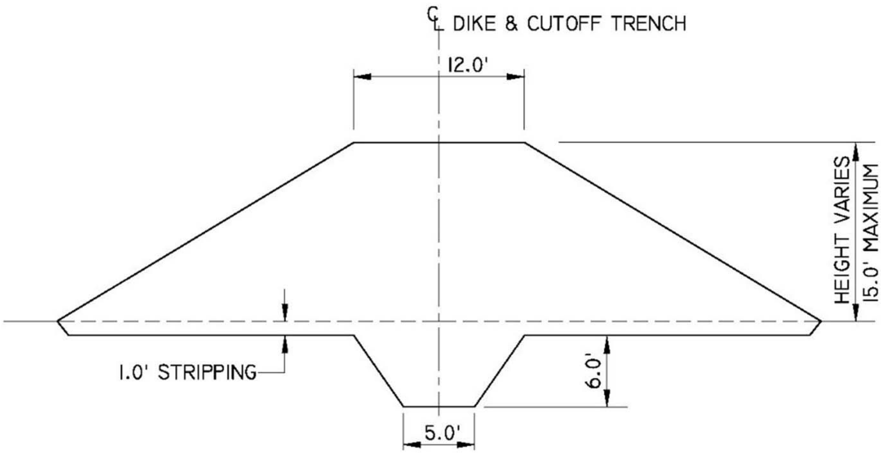


Fig. 7-13. Example of Dimension Lines and Extension Lines

Leader. A leader is a line connecting a callout to the feature or portion of the feature shown. An arrowhead is used at the end of the leader, pointing to the feature. It is important that the arrowhead touches the physical boundary of that feature. In addition, the leader should be connected to the beginning or end of a callout, but not connected at some intermediate location of that callout. There are several common ways to draw a leader, as shown in Fig. 7-14, and all of them are quite acceptable. The important thing is to be consistent. In the example shown in the figure, the leader is connected to the end of the callout "LIMIT OF EXCAVATION," and it is also appropriate if the leader is connected to the beginning of the callout; the leader should not be connected to the word "OF," which is the intermediate location of the callout.

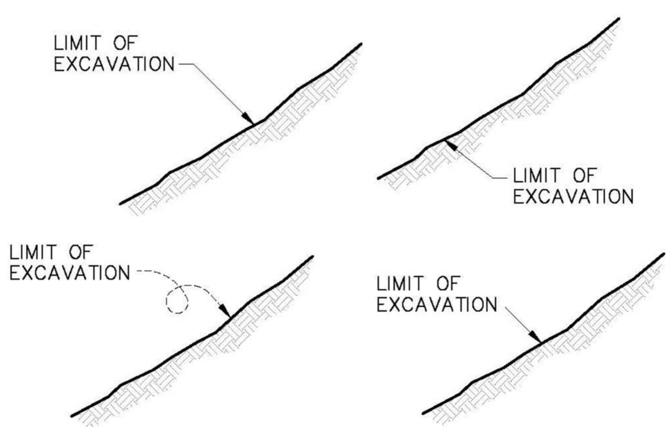


Fig. 7-14. Examples of Ways to Draw Leaders

Hidden Line. A hidden line is a dashed line showing a physical boundary that is covered in a particular view and is not directly visible, such as a buried structure or structure behind the section being shown. It is also used to show a physical boundary that has been changed and therefore no longer exists. Examples where hidden lines are used include buried pipes, conduits, and footings, and existing ground surface in an excavation section. In general, the use of hidden lines in a particular view should be minimized to improve readability and simplicity. When too many hidden lines are shown in a particular view, the designer should consider another more appropriate view to remove some of the hidden lines.

Phantom Line. A phantom line, as the name suggests, is used for something that is not in the view presented. For example, it can be used to show a feature that is projected onto a section from beyond that section. In other instances, it can be used to show an outline of a feature that is deliberately omitted in the view for clarity and simplicity, or it can be used to show the outline of a finished structure in a partially constructed stage to illustrate overall relationships. Fig. 7-15 illustrates some common applications of a phantom line to show the outline of new fill and a grouted rock wall that will be constructed in this excavation section.

Long Break Line. A long break line is used to discontinue a long feature that would allow a long plan view or sectional view to be shortened to a manageable size. A long break line is also used as a discontinued dimensional line for dimensioning features in a view in which the view itself has been broken by other long break lines. It

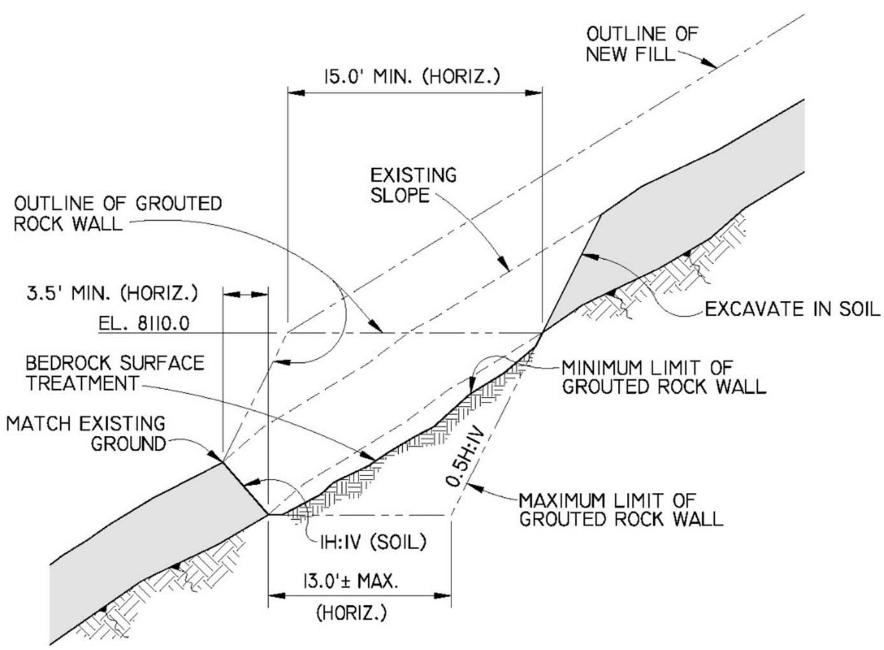


Fig. 7-15. Examples of Applications of Phantom Lines

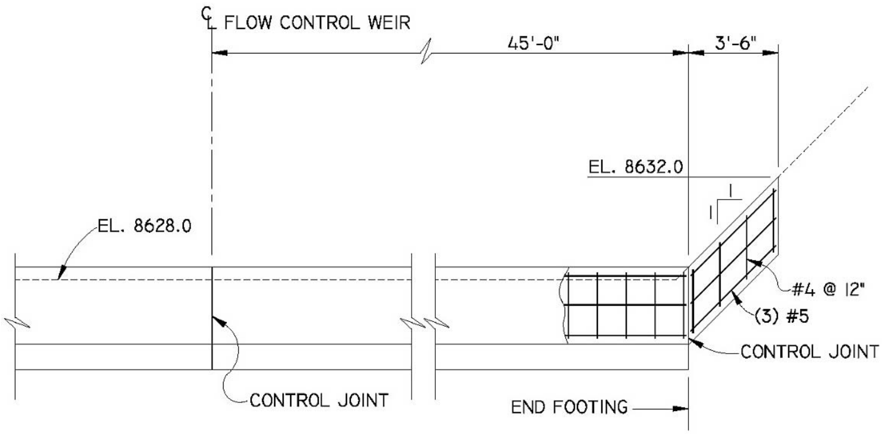


Fig. 7-16. Example of the Application of a Long Break Line

is important that unique features of the view are not cut off between the long break lines and that only repetitive information has been omitted. An example of the application of the long break line is shown in Fig. 7-16.

Short Break Line. A short break line is used to isolate a typical portion of a feature in lieu of showing the entire feature itself for clarity and simplicity. It can also be used to define an isolated "window" in an elevation view to show what is inside or behind that view. An example of the application of the short break line is shown in Fig. 7-17.

Section Cut Line. A section cut line shows the location of a perpendicular plane where the cross section is drawn. The cut line terminates at each end with an arrow, which shows the direction of the cut. The arrows also show the limits of the cross section. A section cut line can be a continuous line across the entire cut, or only the two ends of the cut line are shown. Section cut lines can be drawn in any views, such as plan view, section view, elevation view, profile, and details. An example of section cut lines is shown in Fig. 7-1.

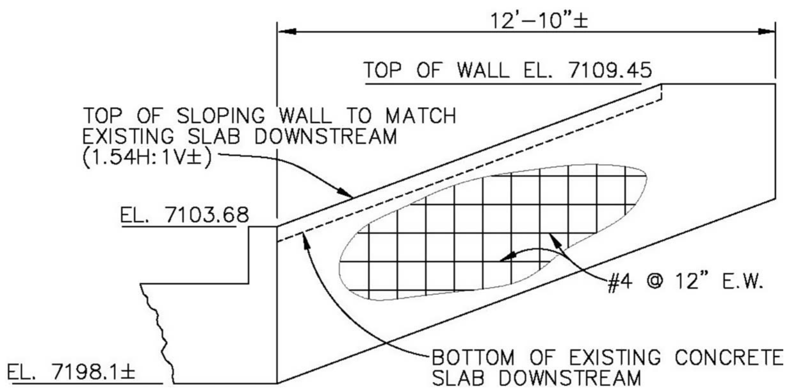


Fig. 7-17. Example of the Application of a Short Break Line

Match Line. A match line is an arbitrarily chosen splicing point in a view because the entire view itself does not fit within the drawing sheet. The remainder of the view is normally continued either on the same sheet, beginning at the match line, or on the next sheet. A match line allows the entire view of a very long feature to be shown without losing any part of that feature. A match line should always be identified with a number or other designation, including the sheet number where the remainder of the view is continued (see Fig. 7-11).

Contour Line. A contour line is a line of constant elevation. Topographic contour lines are used in a topographic map, which is the essential base map in a civil design project. Development of a topographic base map is discussed in Chapter 3, which also summarizes some of the basic rules involving contour lines. Contour lines should be labeled with the actual elevations adjacent to the lines. It is a good practice to use all digits of the elevation in the label instead of only using the last two digits. For clarity, not all contour lines need to be labeled. Typically, only major contours are labeled, not intermediate contours. For a map with 2-ft (0.6-m) contour intervals, for example, contours can be labeled every 10 ft (3.0 m), unless in very flat areas, in which case, it is useful to label even intermediate contours. Contour lines should be solid lines for both existing grades and final grades, except where the grades are changed. In that case, the new contours should be solid lines, and the existing contours under the new contours should be shown as hidden lines.

Water Line. A water line is used to show the limits of moving or stationary bodies of water, such as streams, lakes, or reservoirs. A single water line is sometimes used at the lowest point of the streambed, or a water line is used on each bank of the stream. It is always a good practice to add an arrow along the water line for a moving stream to show the direction of the flow, even though one can deduce the flow direction from the topographic contours. The water line for a stationary body of water, however, always coincides with the topographic contour of the water elevation, because the surface of the water is always horizontal.

7.8 Effective Use of Line Weights

Line weight is a term used to denote the width of the line. Different line types use different line weights to best bring out the graphical quality of a civil drawing and to show the important information. When a drawing uses the same line weight for different line types, the drawing looks “flat,” and some of the key features in the drawing may not stand out as desired by the designer. On the other hand, when proper line weights are used, the drawing has a certain three-dimensional quality and, along with effective hatching and symbols, allows certain key features to stand out and becomes more easily understood by the contractor. Fig. 7-18 is a comparison of two drawings, one with a single line weight for all of the lines and the other with different line weights. This comparison illustrates the graphical advantages of using different line weights.

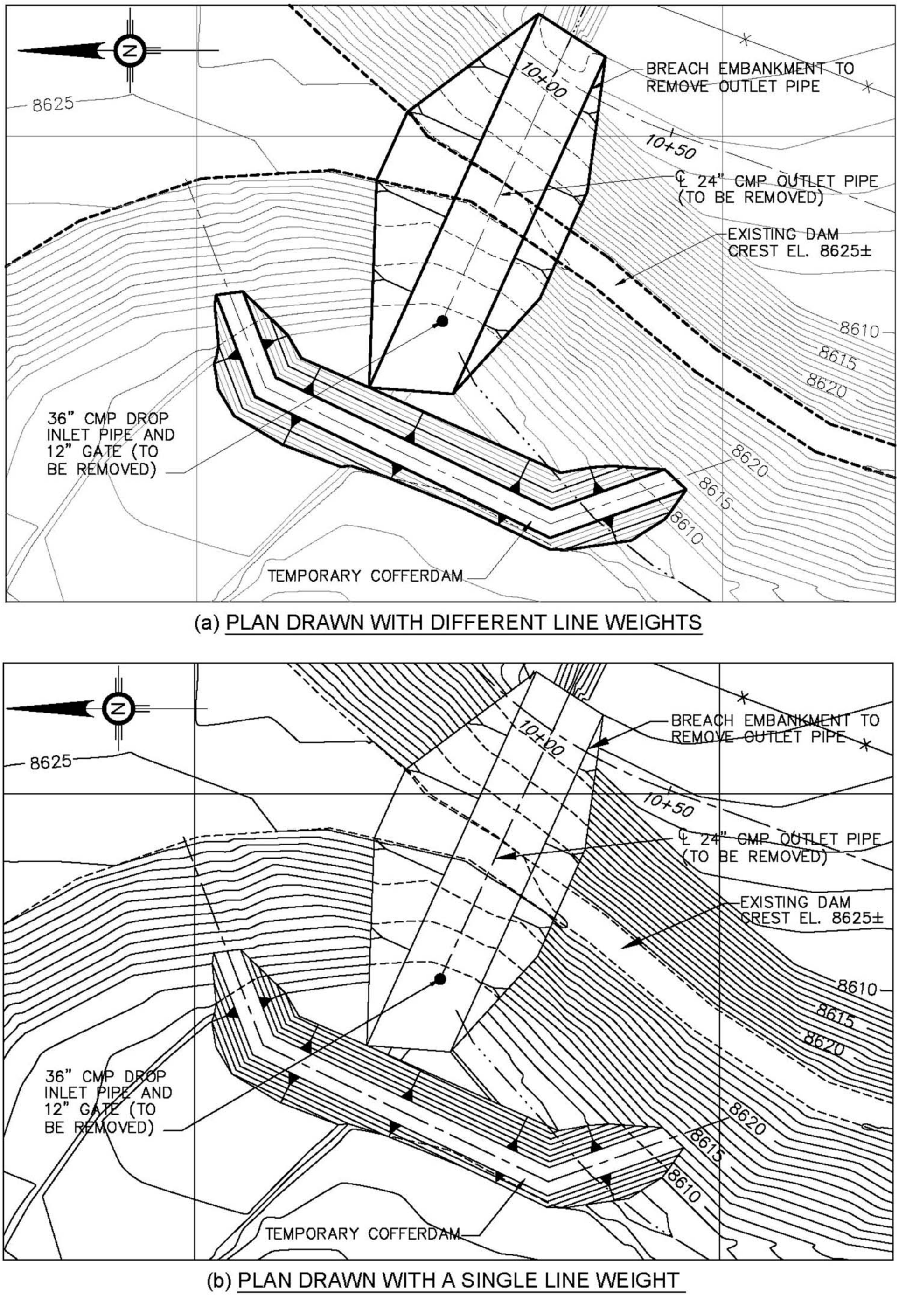


Fig. 7-18. Illustration of Effective Use of Line Weights

Recommended line weights for the commonly encountered line types are shown in Fig. 7-11. It is important to point out that these line widths represent guidelines only and are not intended to be standards. Some designers may prefer using somewhat different line widths for various line types.

Table 7-1. Lettering Guidelines

Purpose	Font Type	Size
Callouts, dimensioning, notes, abbreviations, scale	Simplex	0.10–0.12 in.
Headings for plan, section, detail, notes, legend, abbreviation	Arial	0.20 in.
Subheadings, section or detail symbols	Arial	0.16 in.

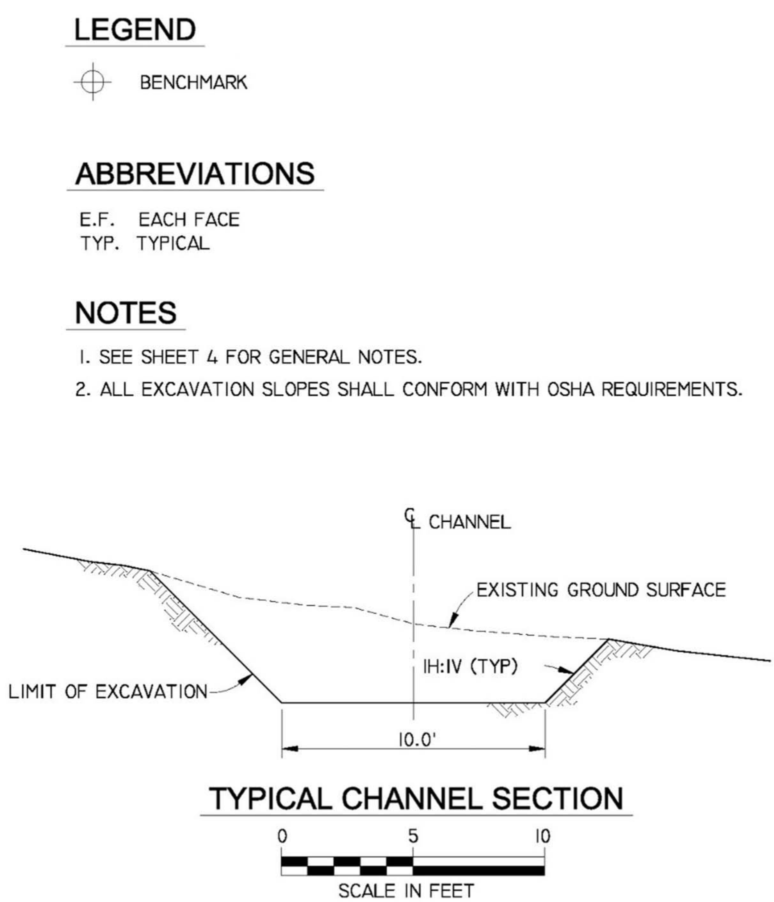


Fig. 7-19. Illustration of Proper Use of Lettering Size

7.9 Lettering

Lettering is used in drawings for headings, callouts, dimensions, notes, and abbreviations. The traditional freehand lettering and hand-lettering guides are now replaced with electronic lettering fonts available in CAD software. There are literally hundreds of lettering fonts available, but surprisingly, only a few fonts (e.g., Simplex and Arial) are used in civil engineering drafting. In engineering drafting, fonts should be selected based on clarity and simplicity. Use of artistic fonts does not enhance or improve the technical quality, and it is discouraged in engineering drafting.

The use of proper lettering sizes cannot be overemphasized. The most common problem in engineering drawings is undersized lettering. In general, lettering smaller than 0.10 in. (2.5 mm) should not be used. The use of a minimum lettering size is dictated, in most cases, by the fact that most drawings are now reproduced in half-size format, and the use of a minimum lettering size ensures that all of the lettering will be legible when reduced to half size. Most engineering firms and

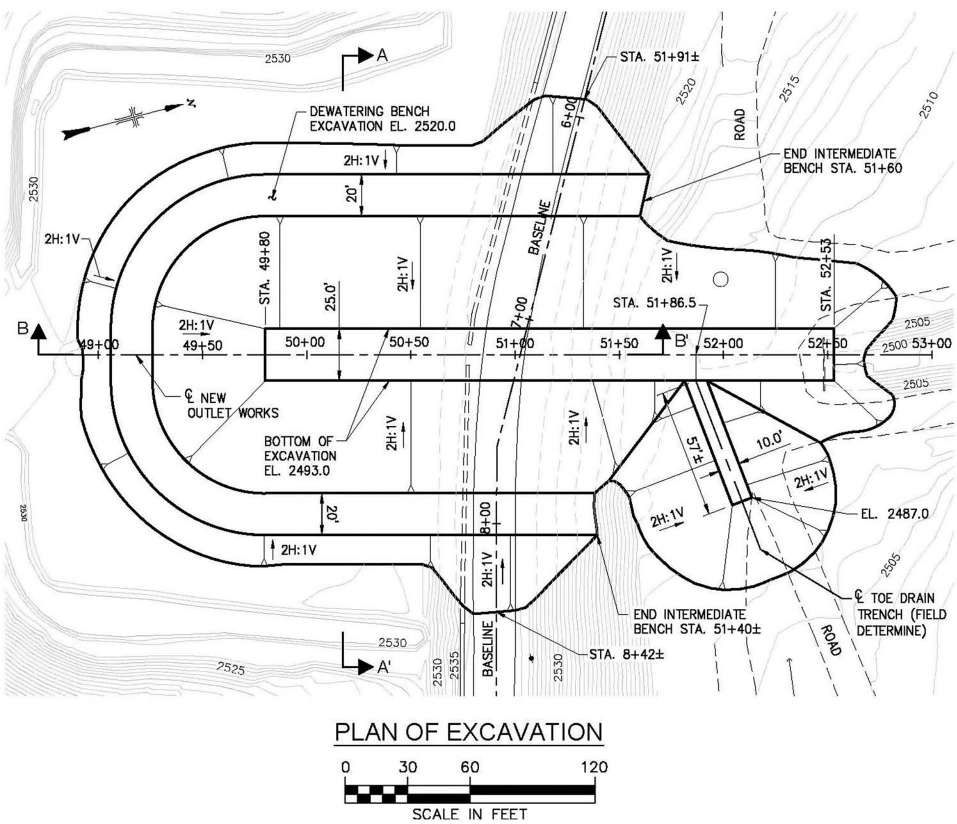


Fig. 7P-1. Plan of Excavation for New Outlet Works agencies maintain their own drafting standards, which dictate appropriate letter sizes. Table 7-1 provides a set of guidelines for lettering. Fig. 7-19 is an illustration of lettering using the guidelines from Table 7-1.

Exercise Problems

7.1 Fig. 7P-1 is a plan of excavation for a new low-level outlet works. The cut lines for Sections A–A′ and B–B′ are shown on the plan.

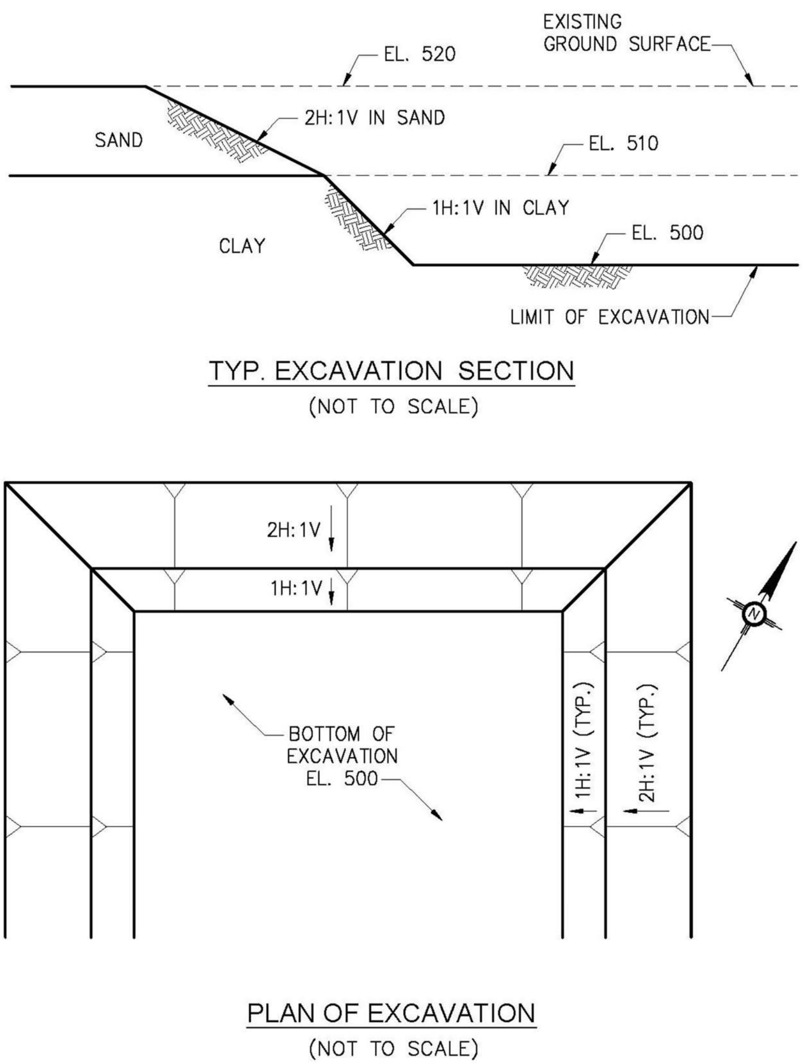


Fig. 7P-2. Plan and Section of Excavation in Sand and Clay

a. Draw Section A–A′, including the existing ground surface.
b. Draw Section B–B′, including the existing ground surface.

7.2 Fig. 7P-2 shows a plan of excavation and typical cross section. The subsurface condition consists of 10 ft of sand overlying clay. To comply with OSHA, the excavation in the sand is sloped at 2H:1V (horizontal:vertical), and the excavation in clay is sloped at 1H:1V. The plan of excavation is shown with slope lines and slope inclinations. Redraw the plan of excavation using only topographic contour lines with 2-ft contour intervals.

7.3 Fig. 7P-3 shows a plan of temporary road detour for Highway 63 when three new box culverts will be constructed under the highway embankment to improve drainage. A gravel-surface road is constructed on the south side of the highway to provide a one-lane detour during the excavation and construction of the new culverts. The detour embankment has a 20-ft-wide road surface at crest El. 425, and a slope of 2H:1V (horizontal:vertical) on each side. The plan of the detour embankment is drawn with contour lines. Redraw the plan of the road detour embankment using slope lines and inclinations.

7.4 Fig. 7P-4 shows a profile and a typical cross section for a new culvert to be installed in an excavated open trench and then backfilled to the existing ground surface. The ground surface slopes from El. 240.0 at Sta. 12 + 00 to El. 226.0 at Sta. 12 + 70. The culvert invert (inside floor) slopes from El. 216.0 at Sta. 12 + 00 to El. 209.0 at Sta. 12 + 70. The trench excavation (subgrade) is 10 ft wide at the bottom and slopes 1H:1V (horizontal:vertical) on each side. Construct two cross sections (A–A′ and B–B′), one at Sta. 12 + 20, and one at Sta. 12 + 50, based on the information provided. Each cross section should show

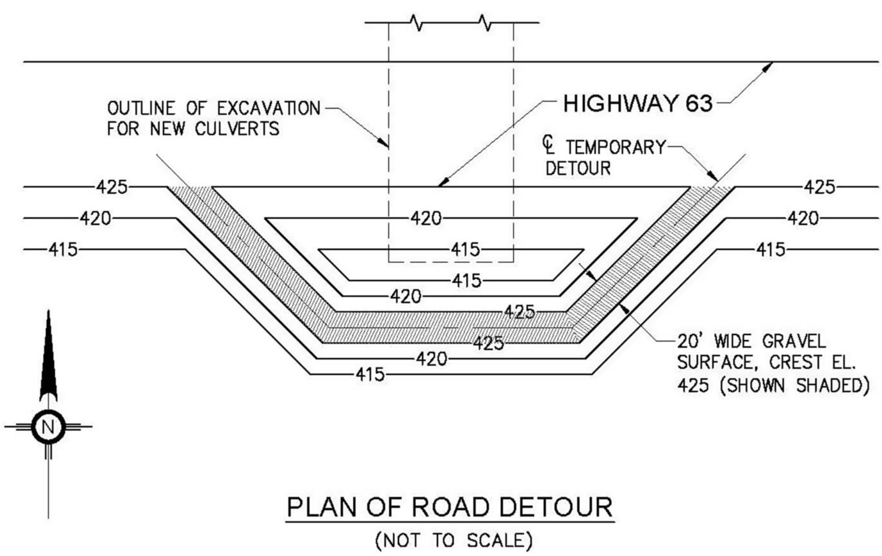


Fig. 7P-3. Plan of Road Detour Showing Topographic Contours

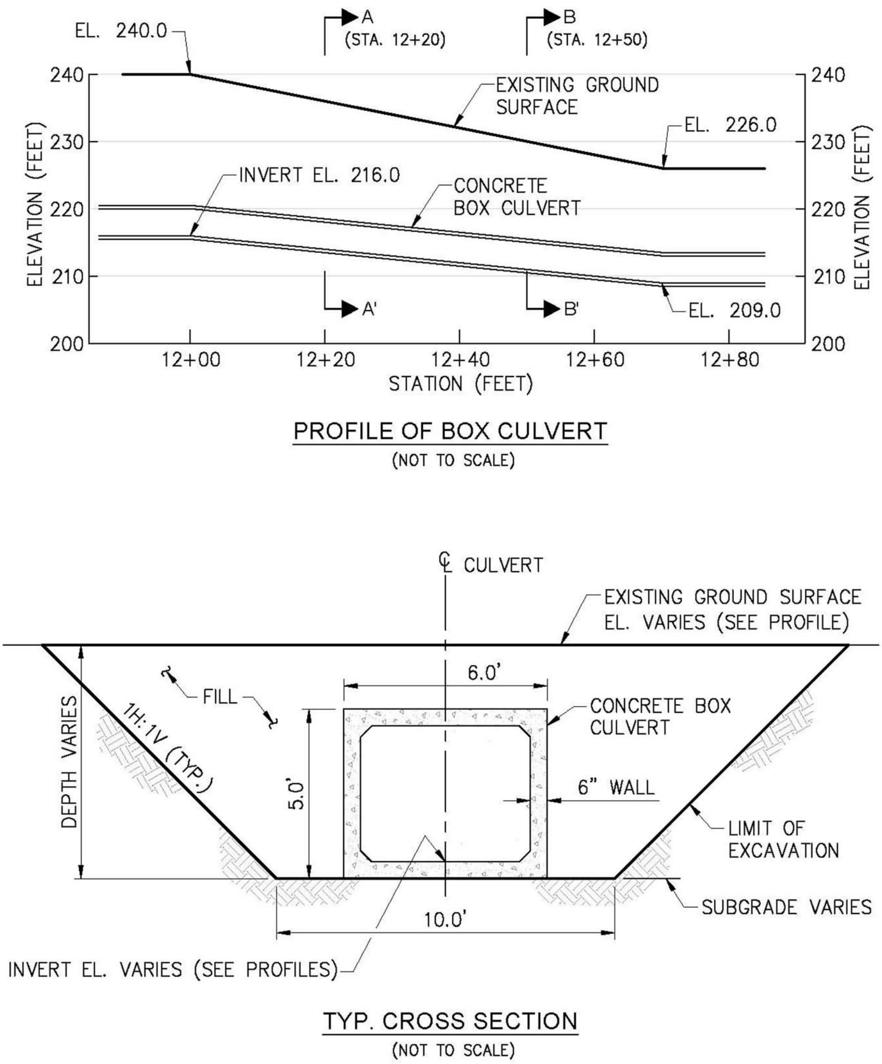


Fig. 7P-4. Profile and Typical Cross Section of Box Culvert

an elevation scale, limit of excavation, ground elevation, subgrade elevation, culvert invert elevation, and section heading that calls out the section title, station number, and scale.

CHAPTER 8

Legend, Abbreviations, and Notes

8.1 Legend and Symbols

A *legend* is needed to define graphical symbols and graphical notations in drawings. Graphical symbols and notations should be defined on the sheet where they are first used, or on the general note sheet, and a note can be used on other sheets thereafter to refer to the legend. Not repeatedly defining symbols and notations on every sheet saves drafting time, and more importantly, avoids inconsistency in legends on the drawings when changes to the symbols or notations are required.

The following graphic symbols, hatchings, and notations should be adequately defined in the legends:

Symbols. Symbols are used to represent certain physical features in the drawings. These features may be boreholes, test pits, control points, vegetation, fences, roads, streams, pipes and culverts, and wetlands, all of which are commonly encountered in civil design work. There are many different symbols available to represent these features, and all of them are acceptable as long as they are used consistently within the drawing package and are properly defined in the legend. Small symbols should be avoided because they may bleed together and become unreadable in a reduced drawing. Fig. 8-1 is a set of symbols that may serve as guidelines for designers who do not currently have their own standard symbols.

Hatching. Hatching is a two-dimensional graphic pattern that is used to represent different construction materials. Materials used in heavy civil construction include different types of earthfill, bedrock, riprap, gravel and sand backfill, steel, concrete, masonry, wood, and wire mesh. Shading is also considered as hatching. Fig. 8-2 is a set of hatching patterns that may serve as guidelines for designers who do not currently have their own standard hatching patterns.

A special set of hatch patterns is commonly used by geotechnical engineers to represent subsurface conditions. These patterns are typically used in simplified borehole logs or test pit logs that may be included in construction drawings. Fig. 8-3 is a set of hatch patterns of earth and rock materials that can be used to represent subsurface conditions.

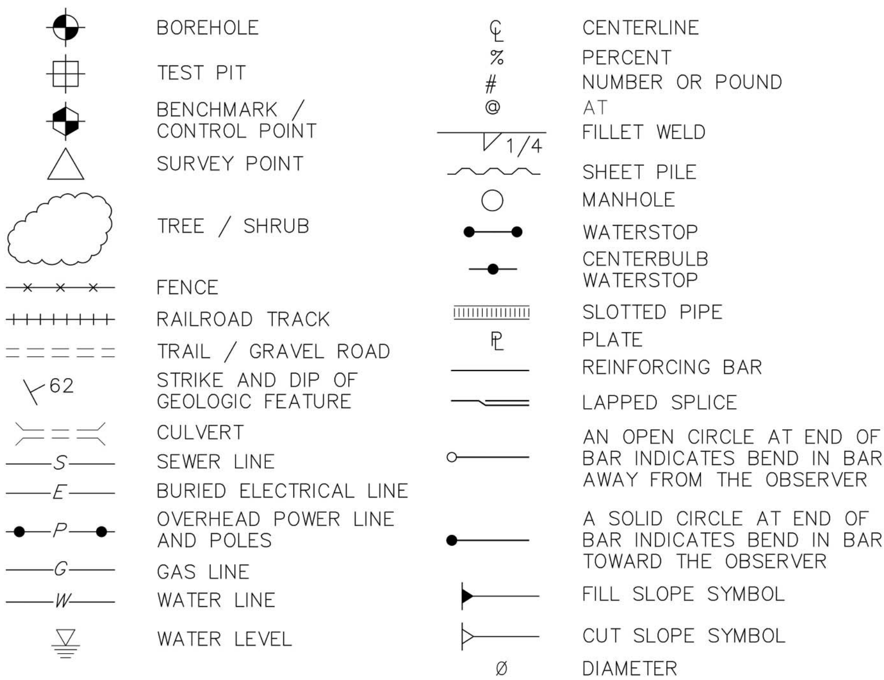


Fig. 8-1. Guidelines for Symbols

Notations. Each set of design drawings contains a number of special notations that are unique for that project, depending on the imagination and creativity of the designer. For example, a set of notations can be used to call out the rows and columns of foundation piles or anchors. The legend should always contain a description of notations for section cuts and detail callouts. Different designers use different notations for section cuts and detail callouts, and all of them accomplish the intent as long as these notations are defined in the legend and are used consistently throughout the package. Fig. 8-4 provides one method for section cuts and detail callouts. The advantage of this system is that, in the section or detail bubble, the following information is known:

- Section or detail designation is located on the upper hemisphere.
- The sheet number where the section is cut or where the detail is referenced is shown on the left lower hemisphere.
- The sheet number where the section or detail is given is shown on the right lower hemisphere.

Some designers prefer to use a simpler system of section cuts and detail callouts, as shown in Fig. 8-5. In that system, there is only one sheet number in the lower hemisphere of the section or detail bubble. In the section cut or detail callout, the

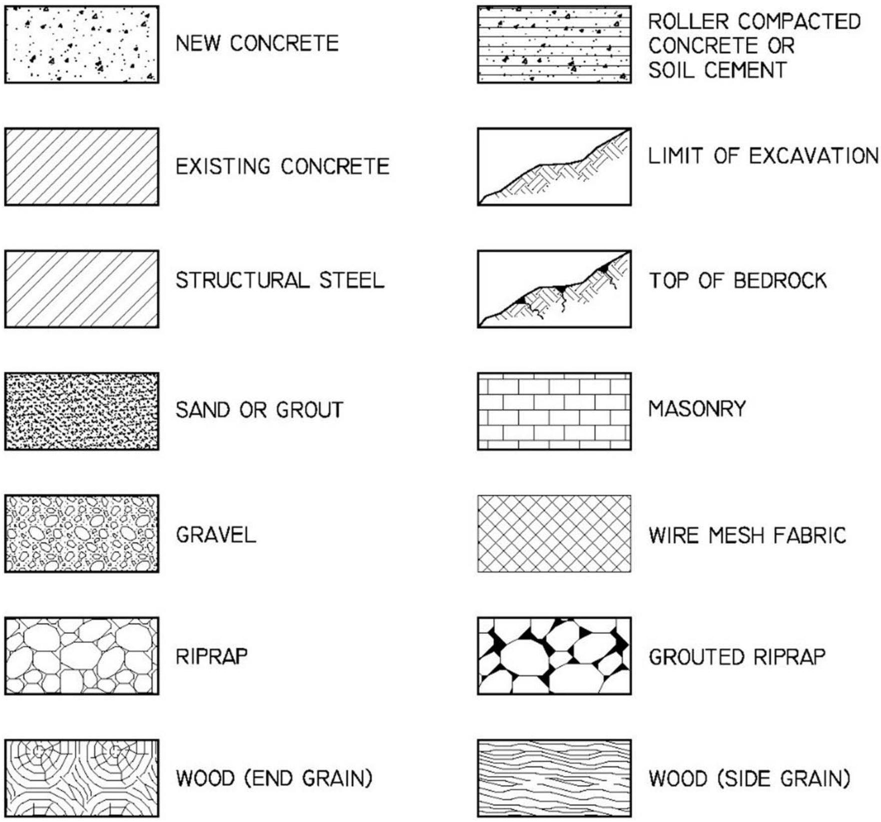


Fig. 8-2. Guidelines for Hatch Patterns

sheet number refers to the sheet where the section or detail is shown. In the section or detail, the sheet number refers to the sheet where the section cut or detail callout is made.

8.2 Abbreviations

Abbreviations are used in drawings to shorten drawing callouts where space is limited on plans, sections, and details, and to facilitate ease of reading the callouts. Abbreviations should be defined in the drawing set and also in Division 1 of the technical specifications (see Chapter 18). Abbreviations, once defined in the list of abbreviations on the general notes sheet, should be used consistently throughout the entire design. For example, *El.* or *Elev.* can be used for the term *elevation,* and the designer should use only one or the other. In general, an excessive use of abbreviations in the drawing should be discouraged, and only the most common abbreviations should be used. In addition, any given callout

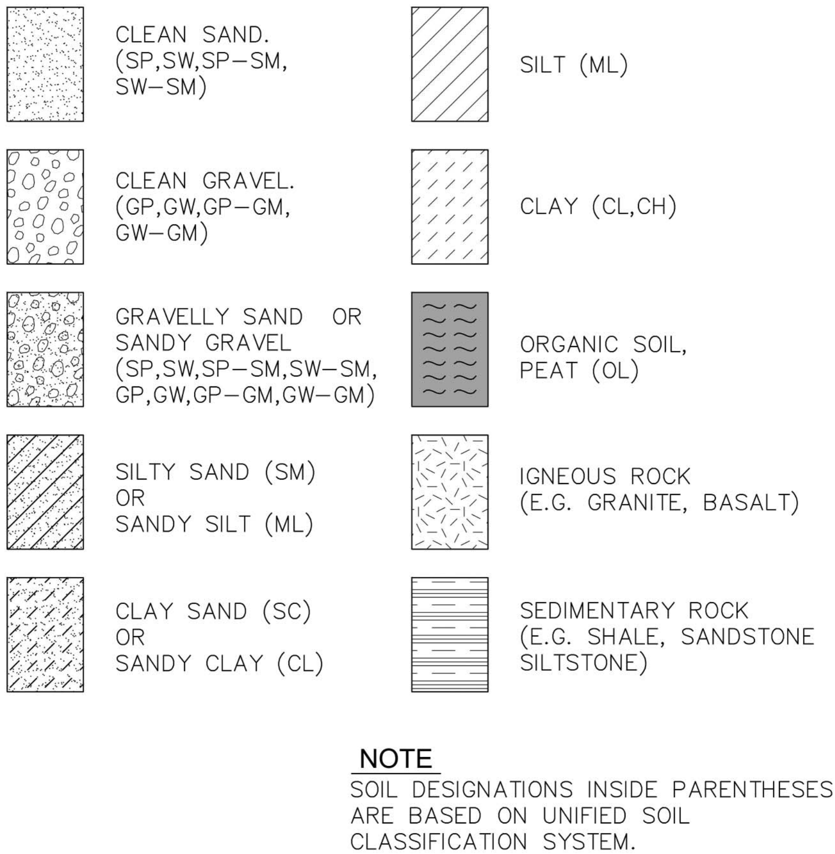


Fig. 8-3. Guidelines for Hatch Patterns for Subsurface Conditions

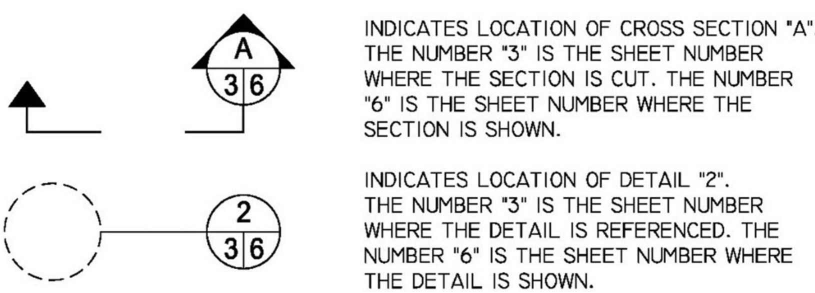


Fig. 8-4. Section and Detail Notations

should contain no more than one or two abbreviations. The following is an example of improper use of abbreviations:

1/2″ CS PLATE, W/4-3″Φ HOLES DRILL THRU

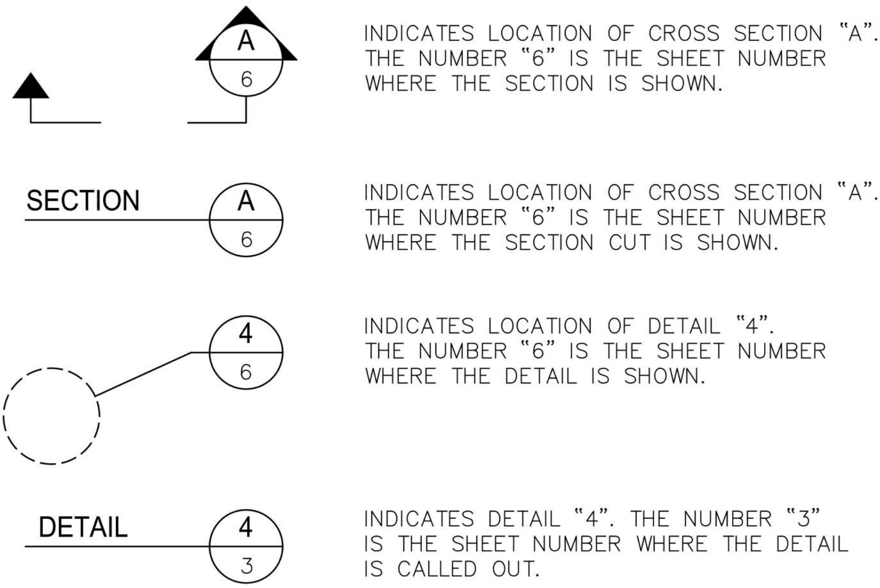


Fig. 8-5. Alternative Notation for Section and Detail

Instead, the above callout should be replaced with the following:

1/2″ CARBON STEEL PLATE, WITH FOUR-3″ DIA. HOLES DRILL THROUGH

Fig. 8-6 is a list of commonly used abbreviations that are encountered in typical civil design drawings.

In general, abbreviations should not be used in the following places:

- On drawing or sheet titles.
- In notes.
- In definitions of abbreviations.
- In section or detail titles.

A complete list of abbreviations is included in the U.S. National CAD Standards for Architecture, Engineering, and Construction (AIA 2008).

8.3 Notes

Notes are used in the drawings under the following circumstances:

- To provide additional clarification to a drawing detail.
- To supplement a drawing callout or as an extension of a drawing callout.

APPROX.	APPROXIMATE
B.F.	BOTTOM FACE
B.M.	BENCH MARK
B.O.B.	BOTTOM OF BOREHOLE
B.O.T.P.	BOTTOM OF TEST PIT
C	CENTIGRADE
C.C.	CENTER TO CENTER
CFM	CUBIC FEET PER MINUTE
C.I.	CAST IRON
C.J.	CONSTRUCTION JOINT
CLR	CLEAR
CMP	CORRUGATED METAL PIPE
CONC.	CONCRETE
CONT.	CONTINUOUS
CT.J.	CONTRACTION JOINT
DEG.	DEGREE
DIAG.	DIAGONAL
DWL	DOWEL
E	EAST, EASTING
EA.	EACH
E.F.	EACH FACE
E.J.	EXPANSION JOINT
EL.	ELEVATION
E.W.	EACH WAY
EXIST.	EXISTING
F	FAHRENHEIT
F.F.	FAR FACE
FIG.	FIG.
FT	FEET
FTG	FOOTING
FIN.	FINISH
GA.	GAUGE
GAL.	GALLON
GALV.	GALVANIZED
GR.	GRADE
GPM	GALLONS PER MINUTE
H.P.	HIGH POINT, HORSE POWER
HR	HOUR
HORIZ.	HORIZONTAL
I.D.	INSIDE DIAMETER
I.F.	INSIDE FACE
INV.	INVERT
IN.	INCH
JT.	JOINT
KIP	KILOPOUNDS
LB	POUND
L.P.	LOW POINT
LG.	LONG
LONG.	LONGITUDINAL
MAX.	MAXIMUM
MIN.	MINIMUM
M.H.	MANHOLE

MFR.	MANUFACTURER
NGVD	NATIONAL GEODETIC VERTICAL DATUM
N	NORTH, NORTHING
N.I.C.	NOT IN CONTRACT
N.T.S.	NOT TO SCALE
N.F.	NEAR FACE
O.C.	ON CENTERS
O.D.	OUTSIDE DIAMETER
O.F.	OUTSIDE FACE
O.W.	OUTLET WORKS
P.C.	POINT OF CURVATURE
P.T.	POINT OF TANGENCY
P.D.	PLAIN DOWEL
P.I.	POINT OF INTERSECTION
PL.	PLATE
PREFAB.	PREFABRICATED
PSI	POUNDS PER SQUARE INCH
PSF	POUNDS PER SQUARE FOOT
PVC	POLYVINYL CHLORIDE
R	RADIUS
RCC	ROLLER-COMPACTED CONCRETE
RCP	REINFORCED CONCRETE PIPE
REINF.	REINFORCEMENT
REQD.	REQUIRED
REV.	REVISION
S	SOUTH
SCH.	SCHEDULE
SH.	SHEET
S.S.	STAINLESS STEEL
SECT.	SECTION
SIM.	SIMILAR
SQ.	SQUARE
SPEC	SPECIFICATIONS
STA.	STATION
SYM.	SYMMETRICAL
STD.	STANDARD
T&B	TOP AND BOTTOM
T.F.	TOP FACE
THK.	THICK
TOPO.	TOPOGRAPHY
TYP.	TYPICAL
T.O.W.	TOP OF WALL
U.N.O.	UNLESS NOTED OTHERWISE
VERT.	VERTICAL
W	WEST
W/	WITH
W/O	WITHOUT
W.S.	WATERSTOP

Fig. 8-6. List of Abbreviations

- To identify and explain the basis or source of a design detail or data shown in the drawings.
- To refer to other sheets or specifications for the source of information, other notes, or other legends not contained in the current sheet.
- To make a statement regarding the contractor's duties and responsibilities that cannot be expressed graphically in the drawings but are directly related to information shown in the drawings or specifications.

- To define additional abbreviations not contained in the standard list of abbreviations.
- To suggest sequence of construction, caution, or other special requirement for a particular design feature or component.

Where possible, the preferred location for notes is at the lower-right corner of the drawing sheet just above the title block. Notes should not be scattered all around the drawing because it can be difficult to locate them and they are easily missed.

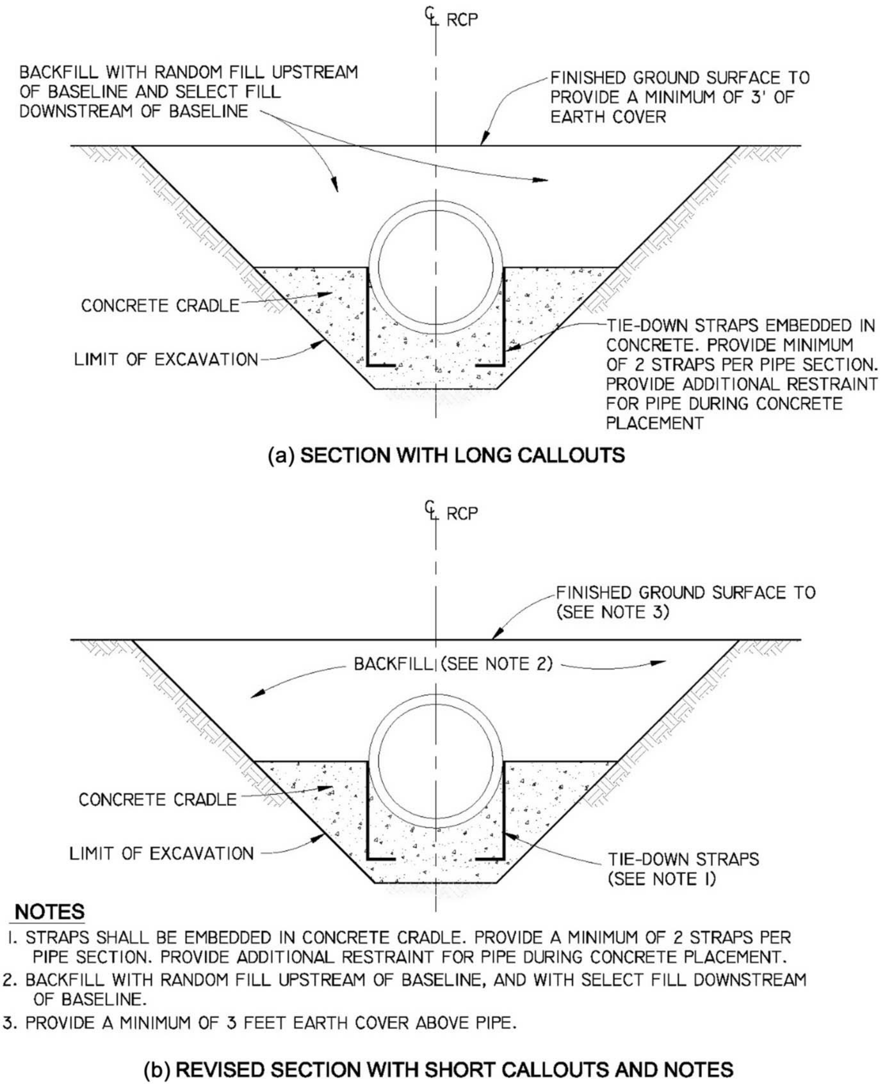


Fig. 8-7. Example of Effective Use of Notes

Notes should be numbered consecutively for each drawing (1, 2, 3, etc.). Note that numbers should not continue from one sheet to the next.

Identical notes should not be repeated on multiple sheets. Notes should be stated on the first sheet when they are needed, and then these notes should be referred to from other sheets. This practice is consistent with an important principle in design—that is, *to say it once, and say it right.*

Fig. 8-7 is an example drawing showing how notes are used to make the drawing details easier to read and understand. Long callouts are shortened significantly by the use of notes.

Exercise Problems

8.1 Excessive use of abbreviations in callouts in drawings may lead to confusion or uncertainty. Reduce the abbreviations in the following callouts to improve readability:
   a. 26″ DIA. AL. M.H. COVER, NEEDHAM TYPE R-1594 OR APPROVED EQ.
   b. 1/4″ Ø NYLON BOLTS & S.S. DROP-IN ANCHORS.
   c. END U/S R.E. WALL, STA. 5 + 10.
   d. T.O. RCC, U/S EDGE OF DAM CREST.
   e. 18″ × 18″ FABRICATED UNION, C.S. X-STRONG PIPE W/150# FLANGE EACH END.

8.2 Use a note to shorten the following long callouts in the drawings:
   a. EXCAVATE 6 INCHES UNDER TRI-LOCK BLOCKS. SOME LOCAL GRADING MAY BE REQUIRED TO FILL IN LOW SPOTS AND TRIM OFF HIGH SPOTS.
   b. 3-1.5″ CONDUITS FOR 480VAC. 1-1.5″ CONDUIT FOR CONTROL WIRING. 2-1.5″ CONDUITS FOR ANALOG WIRING. ALL SECURED UNDER WALKWAY TO ACTUATORS.
   c. LIMIT OF SITE DISTURBANCE SHALL BE LIMITED TO 15 FEET BEYOND TOE OF NEW RIPRAP, EXCEPT AT NEW RETAINING WALL WORK AREA. SEE SHEET 2.
   d. PROVIDE A BLOCKOUT FOR ELECTRICAL CONDUITS IN THE TRANSFORMER PAD IF THE PAD IS PLACED PRIOR TO THE INSTALLATION OF THE CONDUITS. THE BLOCKOUT LOCATION AND DIMENSION SHALL BE FIELD DETERMINED.
   e. 42″ × 36″ CONCENTRIC REDUCER. CARBON STEEL PIPE WITH 150 LB SLIP-ON FLANGES EACH END (2″ RUBBER LINING TYPICAL).

CHAPTER 9

Drawing Production Techniques

9.1 Drawing Production Process

Drawing production is a staged process, whose goal is to meet the requirements of a particular design submittal. Unless the design is for an emergency construction, typical final design is accomplished in several submittals, such as 30%, 60%, 90%, and 100%. The requirements of construction drawing documents for various submittals are summarized in Table 2-1, which indicates that progressively more details are produced in the drawing package from one design submittal to the next. The process should start after completion of design analysis, which provides the technical and theoretical basis of the design features required in the project. Of course, the results of design analysis should always be guided by experience and judgment of the designer before the design features are produced on the drawings. In fact, as a designer matures and becomes more experienced, the design analysis merely becomes guidance and confirmation for what needs to be designed. A good designer should not be afraid to question the validity of the design analysis if the results of the analysis are contrary to the designer's judgment and experience.

This chapter introduces drawing techniques to produce various views and details to represent the design, and how to call out and dimension various key features in the design. These techniques can be used to improve efficiency, to enhance the graphical quality, and to clarify technical and construction requirements. The basis and principles of establishing catch points and catch lines on a plan view are explained. The role and practicality of three-dimensional drawings in civil design are discussed. This chapter also contains the techniques and recommendations for checking drawings during production.

9.2 Establishing Catch Points and Catch Lines

One of the most basic graphic techniques in civil design is the establishment of catch lines for cut-and-fill construction. Catch lines define excavation and earthfill limits in the drawings. A catch point is the intersection of a cut or fill slope with a particular existing ground contour. A catch line is a line connecting the catch points from a cut or fill slope. The determination of a catch line is based on descriptive geometry. *Descriptive geometry* is the science of graphic representation and the solution of spatial relationships of points, lines, and planes by means of projections (Giesecke et al. 1975). Fig. 9-1 illustrates the intersection of an excavation face (cut) with the existing ground surface, and Fig. 9-2 illustrates the intersection of a fill slope (fill) with the existing ground surface.

Two examples are used to illustrate the technique of establishing catch lines. Fig. 9-3 shows the establishment of excavation limits for a road cut. Fig. 9-4 shows the establishment of fill limits for a detention embankment. A detailed discussion of each example is given below.

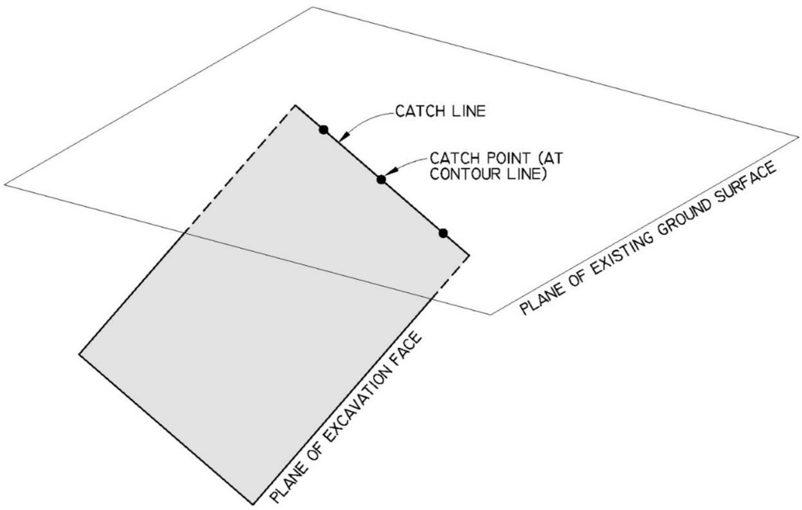


Fig. 9-1. Schematic Illustration of a Catch Line from Excavation

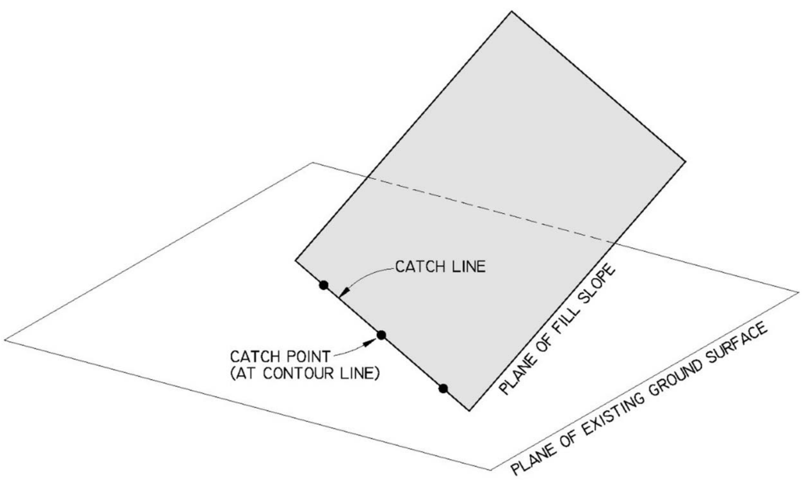
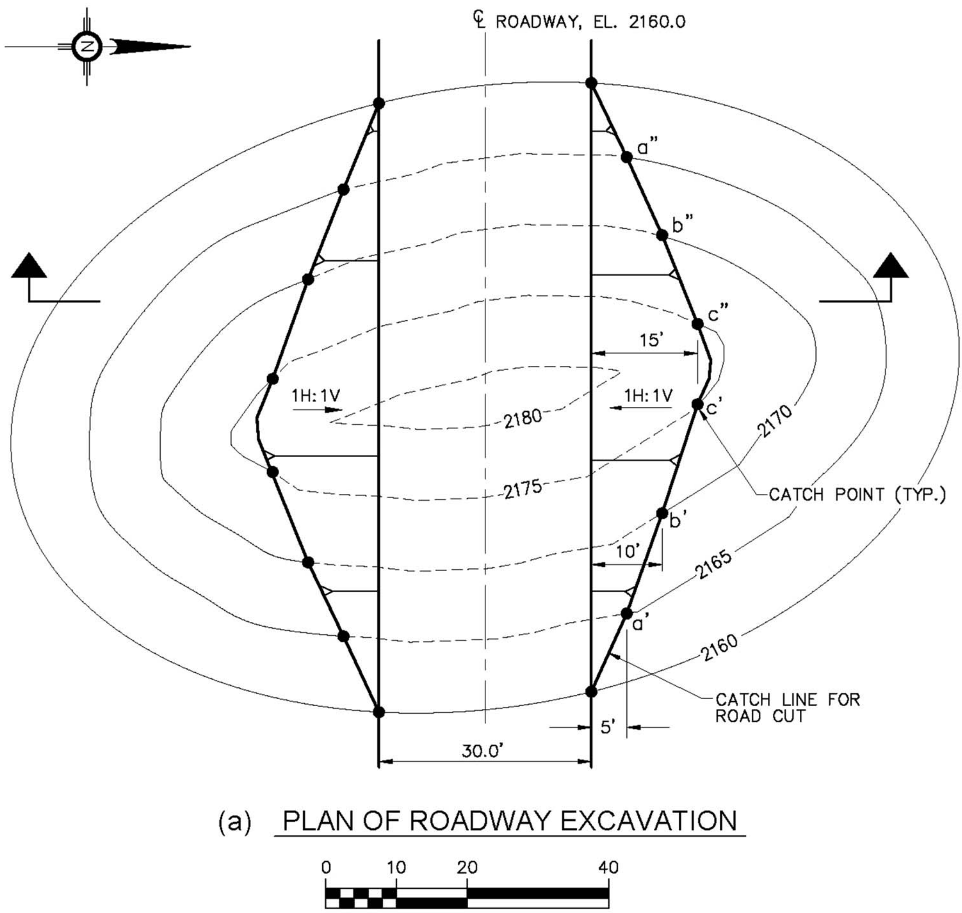


Fig. 9-2. Schematic Illustration of a Catch Line from Filling



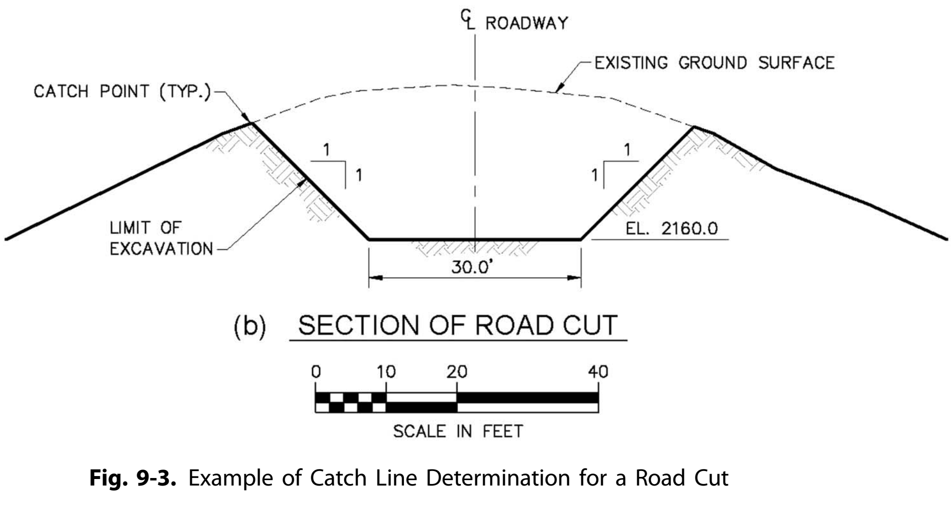


Fig. 9-3. Example of Catch Line Determination for a Road Cut

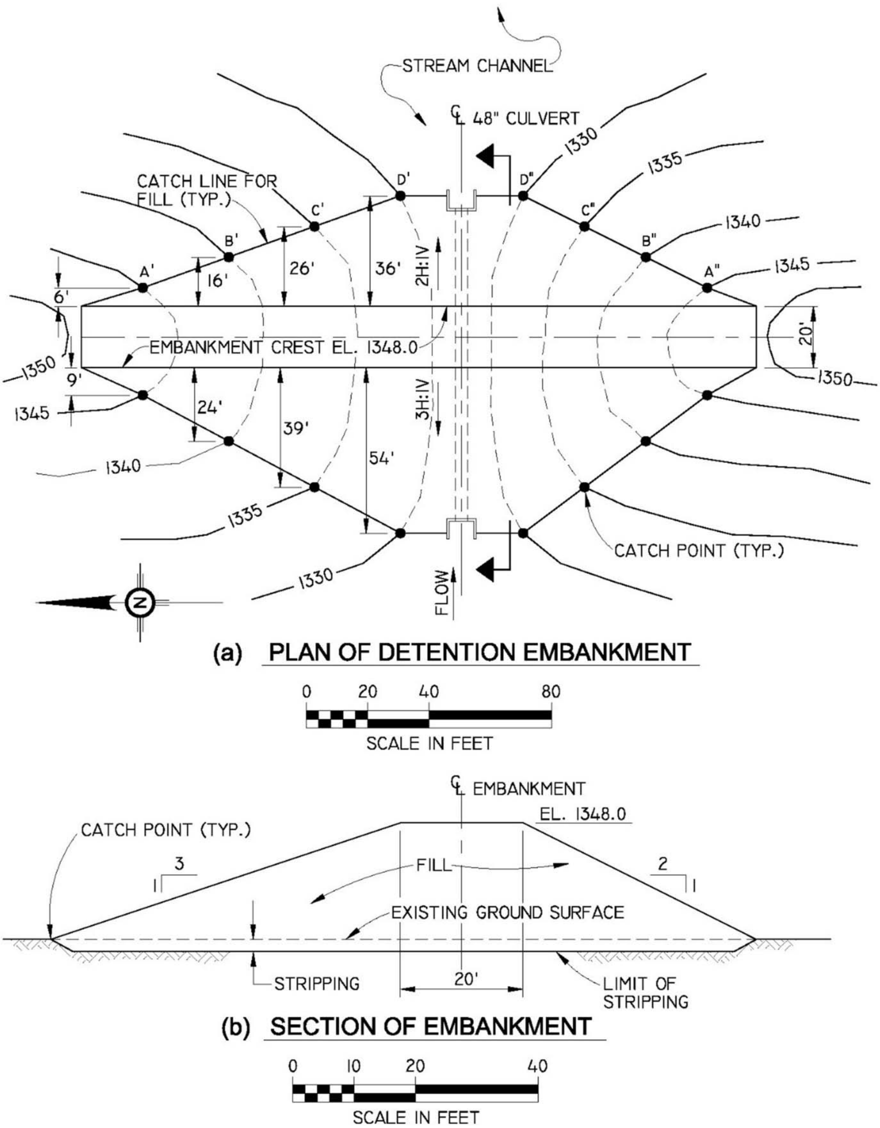


Fig. 9-4. Example of Catch Line Determination for a Detention Embankment

Excavation Limits for a Road Cut

A 30-ft (9.1-m)-wide roadway is required to pass through a topographic knob in bedrock. The knob will be removed to the roadway grade by excavation. For simplicity, the road grade across the knob is assumed to be flat at elevation 2,160 ft. The permanent cut slope in the rock will be at 1H:1V (horizontal: vertical). Fig. 9-3(a) shows the plan of the cut, and Fig. 9-3(b) shows the cross section.

To determine the limits of excavation in the plan view, the centerline and the limits of the 30-ft-wide roadway are drawn first. From the edge of the road ditch (e.g., the north side), catch points for the excavation limits are established by calculating and then measuring the distance for each catch point from the edge of the road (at elevation 2,160 ft) to meet a particular existing contour. Since the cut slope is at 1H:1V [that is, an offset distance of 5 ft (1.5 m) is needed for every 5-ft (1.5-m) rise in elevation], it would require a horizontal distance of 5 ft to establish the catch points to meet the 2,165-contour; points a' and a'' are established this way. Similarly, points b' and b'' are established by offsetting a distance of 10 ft (3.0 m) from the edge of the road to meet the 2,170-contour. The catch points thus established are connected to form a continuous limit of excavation on the north side of the road. The limit of excavation on the south side of the road is drawn using the same technique.

Fill Limits for a Detention Embankment

A detention embankment dam is required to temporarily store stormwater runoff on a stream. The embankment crest is at elevation 1,348 ft (410.9 m), with a crest width of 20 ft (6.1 m). The embankment will have a 3H:1V upstream slope, and a 2H:1V downstream slope based on stability considerations. A 48-in. (1,219 mm) culvert will be located at the bottom of the embankment to drain the detention pond. Fig. 9-4(a) shows the plan of the embankment, and Fig. 9-4(b) shows the cross section.

To determine the limits of the embankment on the plan view, the centerline and the limits of the 20-ft-wide embankment crest are first drawn. From the edge of the embankment crest [i.e., the east (downstream) side], catch points for the fill limits are established by calculating and then measuring the distance for each catch point from the edge of the embankment crest (at elevation 1,348) to meet a particular existing contour. Because the fill slope on the downstream side is at 2H:1V [that is, an offset distance of 10 ft (3.0 m) is needed for every 5-ft (1.5-m) drop in elevation], it would require a horizontal distance of 6 ft (1.8 m) to establish the catch points to meet the 1,345-contour [that is, two times the 3-ft (0.9-m) change in elevation]; points A' and A'' are established this way. Similarly, points B' and B'' are established by offsetting a distance of 16 ft (4.9 m) from the edge of the embankment crest to meet the 1,340-contour [that is, two times the 8-ft (2.4-m) change in elevation]. The catch points thus established are connected to form a continuous toe trace of the fill line on the east side of the embankment. The fill line on the west (upstream) side of the embankment is drawn using the same technique, except that the upstream slope has a 3H:1V slope [that is, an offset distance of 15 ft (4.6 m) is needed for every 5-ft (1.5-m) change in elevation]. These catch points are connected to show the upstream heel trace of the embankment.

Before computer-aided drafting (CAD), establishing catch lines for civil design could be a tedious undertaking, especially for complicated excavation or fill plans. With CAD, catch lines can be determined on the computer (see Chapter 11) with certain software. With or without the assistance of CAD, a civil designer must understand how cut-and-fill limits are established, at least in principle, and must be able to check CAD drawings for cut-and-fill accuracy.

9.3 Effective Use of Hatching and Shading

Hatching and shading are graphical representations of different material types. They are generally used to show separation among different materials or to make certain features stand out. This graphical enhancement is necessary because construction drawings are not generally drawn in colors, and a black-and-white medium is used for original drawings and copies. A list of suggested hatching patterns for various materials of construction and for various earth and rock materials is contained in Chapter 8. Shading can be considered as hatching, but shades of different darkness or lightness are used instead of graphical symbols.

Some guidelines are provided below for using hatching and shading in civil design drawings:

- A legend is required to define the hatching and shading used in the drawings. The only exception might be the standard concrete symbol, which is so universally used that a definition is generally not required. It is important to point out that the legend cannot replace a material description on the drawing detail itself, and a callout for that material is still needed.
- In addition to a legend, hatching or shading can also be called out in the drawing itself, using phrases such as "EXISTING CONCRETE (SHOWN CROSS-HATCHED)," or "AREA TO BE STRIPPED (SHOWN SHADED)."
- Different hatched patterns are effective when a detail contains several different materials that abut one another. The graphic symbols allow the various materials to stand out (see Fig. 7-7), facilitating their locations in the drawings for both the designer and the contractor.
- Graphic hatching and shading should not be used when there is inadequate space in the drawing for them. The added symbols in a small drawing space would only make the material boundaries more difficult to read instead of achieving the intended purpose, especially when drawings are printed in half size.
- Even when ample space is available in the drawing for hatching, the symbol does not necessarily have to fill in the entire area that it represents (see, e.g., the grouted rock wall in Fig. 9-5). In that example, selective hatching of the grouted rock wall allows the anchor head to be shown clearly without being "buried" among the rock hatchings.
- Hatching and shading should not be used behind callouts or dimensions so that the callouts or dimensions can be read clearly without interference from the hatching symbols.

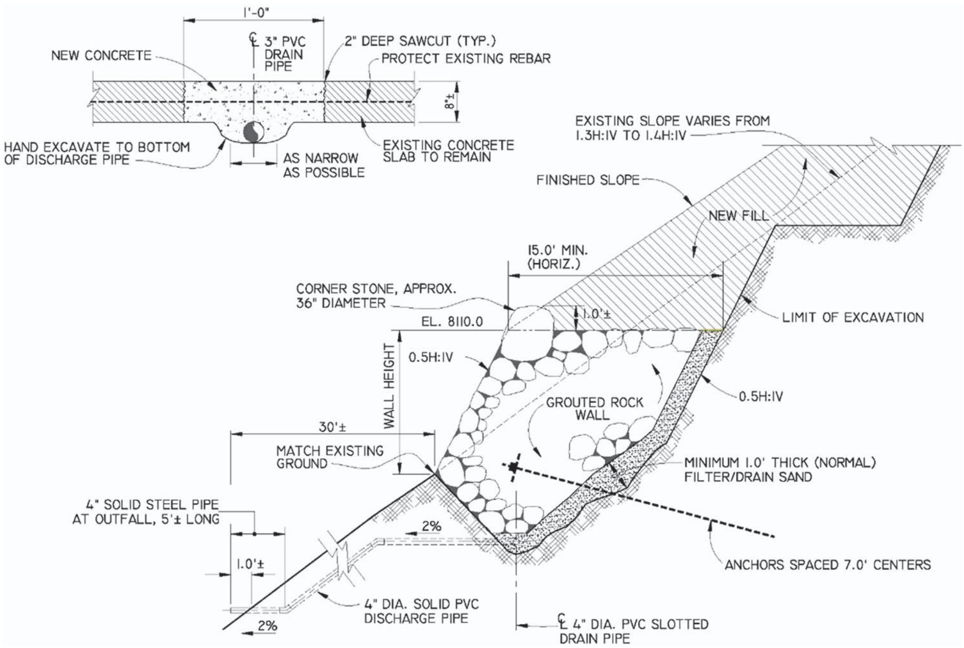


Fig. 9-5. Examples of Effective Use of Hatching and Shading Patterns

Fig. 9-5 contains two design details in which hatching and shading are used effectively.

9.4 Use of Callouts and Dimensioning

Callouts are narrative descriptions of drawing components and features. A callout is used in conjunction with a leader and arrowhead pointing to the feature being described. Graphics and callouts on a drawing work hand in hand. Whereas the graphics show where the various features and components are located, callouts define and describe those features and components. Some general guidelines for the effective use of callouts are given below:

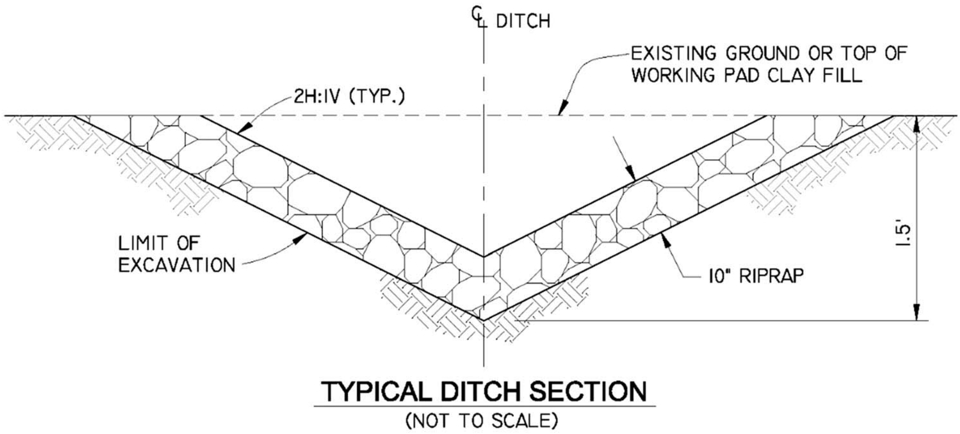
- Callouts should be as short as possible. When a long callout is required, an abbreviated callout should be used, with a reference to a note in the drawings (see Section 8.3). The main reason for this practice is to avoid using excessive space around a drawing detail for one particular callout; the space may be needed for other important callouts, or excessively long callouts may interfere with other sections and callouts in a drawing. For example, when a foundation subgrade is required, do not use a long callout such as "THE CONTRACTOR SHALL PROOF-ROLL THE FOUNDATION SUBGRADE BY FIRST SCARIFYING THE SUBGRADE FOR AT LEAST 6 INCHES, MOISTENING THE SUBGRADE, AND COMPACTING WITH AT LEAST TWO PASSES OF AN APPROVED ROLLER."

Instead, a short callout should be used, such as "PROOF-ROLL FOUNDATION SUBGRADE (SEE NOTE 2)." The note being referenced should then contain the details of the requirement: "NOTE 2: SUBGRADE TO BE PROOF-ROLLED SHALL BE SCARIFIED FOR AT LEAST 6 INCHES. MOISTEN THE SUBGRADE PRIOR TO COMPACTION, AND COMPACT WITH AT LEAST TWO PASSES OF AN APPROVED ROLLER." If compaction requirements are already included in the specifications, then the note should be: "NOTE 2: PROOF-ROLL SUBGRADE IN ACCORDANCE WITH SPECIFICATIONS."

- Avoid using abbreviations in the callouts to the extent possible. Only the most commonly used abbreviations should be used, such as "EL. (ELEVATION)," "TYP. (TYPICAL)," and "STA. (STATION)." All abbreviations should also be defined in the drawings (see Section 8.2).
- Use consistent terminology within the drawings and specifications (see Section 14.4).
- Avoid repeating requirements that are already in the technical specifications (see Section 14.4).
- Leaders for callouts should not cross each other to the extent possible. A callout should be located as close to the drawing feature as possible (i.e., the use of long leader lines should be minimized).
- Leaders for callouts should be connected to the beginning or the end of the callouts, but not at an intermediate point (see Fig. 7-14).
- In general, callouts should be located outside a drawing detail, and they should be fanned out in a balanced fashion around the drawing. In some cases, such as when ample space is available inside the material boundary, it is quite acceptable to put the callout on the inside of the drawing, as long as the callout is outside the hatched or shaded patterns (see, e.g., Fig. 9-5, Grouted Rock Wall).
- When a drawing detail contains many repetitive features, it is not necessary to label every one of these features. Instead, only one of the typical features needs to be labeled, with the abbreviation "TYP." in parentheses. This technique is effective in reducing the number of callouts and thus simplifies the drawing. Fig. 9-6 illustrates this technique. In one example in the figure, both ditch slopes are 2H:1V (horizontal:vertical), and only one of the slopes needs to be labeled. In another example in the figure, the twine and wood stake shown in the repetitive staking pattern need to be labeled only once.

Dimensioning is the process of labeling linear distances or angles in the drawings. Dimensions are considered callouts and are accomplished in conjunction with dimension lines, extension lines, and lettering. As such, discussion in both Section 7.7 for dimension lines and extension lines and in this chapter for callouts are applicable to dimensioning.

The following is a list of recommended guidelines on dimensioning civil design drawings:



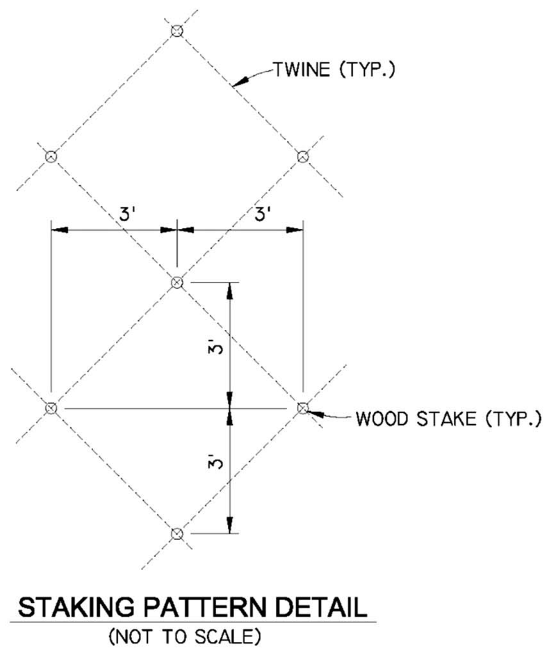


Fig. 9-6. Using "Typical" for Callouts

- To conserve drawing space, only symbols or abbreviations should be used for the units involved. For example,

For 6.3 ft	use 6.3′
For 7 ft 4 in.	use 7′-4″
For 47 degrees	use 47°
For bearing	use, for example, N47°31′27″E

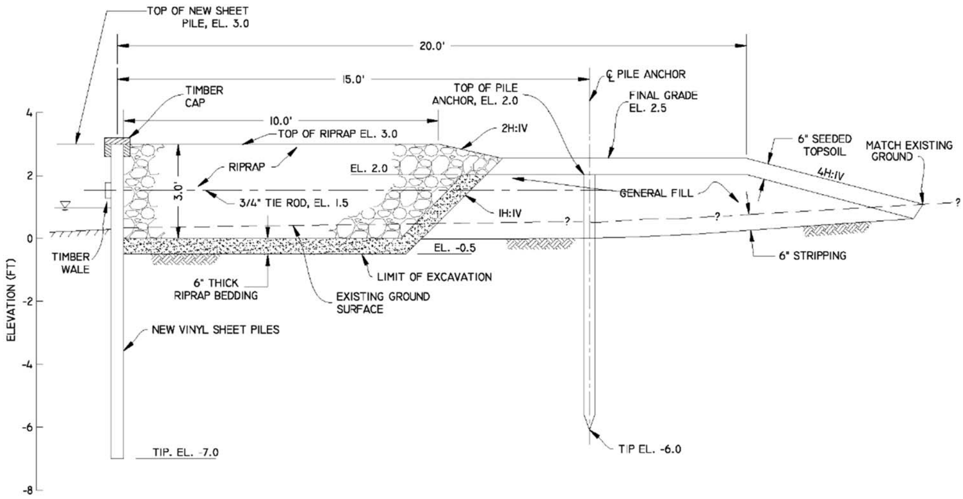


Fig. 9-7. Example of Stacking Dimensions

- To the extent possible, dimensions should be shown around the outside of the drawings. Dimensions placed inside a drawing are acceptable, provided that they are not placed directly over graphic symbols, hatching, or shading.
- When several dimensions are stacked on top of one another, the shortest dimensions should be located nearest the drawing, and the dimensions can progressively increase toward the top of the stack with an overall dimension on the outside. An example of this stacking technique is shown in Fig. 9-7.
- Only dimensions that can be measured and constructed practically with conventional tools, equipment, and techniques during construction should be shown in the drawings, unless there is a special reason for requiring a very tight tolerance. For earthwork, the practical tolerance is plus or minus 0.1 ft (30 mm), and earthwork dimensions or elevations should be shown in decimals to the nearest 0.1 ft (30 mm), not feet and inches. Concrete structures can be built and finished to the nearest 1/8 in. (3 mm), and concrete dimensions should be shown in feet and inches to the nearest 1/8 in. (3 mm). Fabricated metal structures in the shop can be built more accurately than concrete structures in the field, and dimensions can be shown in feet and inches to the nearest 1/32 in. (1 mm), and, in some cases, to the nearest micrometer. Field erection of concrete or fabricated metal structures, however, should be specified within an accuracy of 0.01 ft (3 mm) for controlled structure elevations.

9.5 Use of Scaled and Unscaled Details

All drawings can be categorized into three groups: scaled, exaggerated scaled, and unscaled. A discussion of each group of drawings is given below.

Scaled Drawings

In general, all drawings should be drawn to scale to the extent possible. When a drawing—whether it is a plan, profile, section, detail, or elevation—is drawn to scale, the first design decision by a designer is the selection of a proper scale (see Section 6.3 for scales for U.S. customary units, and Section 10.2 for metric units).

When a drawing is done to scale, the scale and the unit for the scale should be shown in the drawing. Recommendations on scale display are discussed in Section 6.4.

It is important to point out that, even when a drawing is done to scale, all pertinent controls and dimensions should be called out in the drawing. The controls and dimensions called out explicitly are the basis for construction. It is unreasonable and an unacceptable design practice to expect the contractor to scale the dimensions from a full-size or half-size drawing to obtain any missing information that is not shown. Because of the limited accuracy in hand measurements, hand measurements by the contractor may lead to misinterpretation and errors. When information is missing from a scaled drawing, it is the contractor's responsibility to request the required information from the design engineer in a process called request for information (RFI) during construction.

Exaggerated Scaled Drawing

A drawing is exaggerated when the vertical scale is different from the horizontal scale. In a long profile view, for example, the longitudinal dimensions usually far exceed the vertical dimensions, and it is customary to exaggerate the vertical dimensions to obtain a sufficient resolution for features along the profile. Other than in a long profile, it is recommended that the use of exaggerated scaled drawings be minimized. Exaggerated scaled drawings are somewhat awkward to draw, and the resulting graphics are distorted and look unnatural. For example, in an exaggerated drawing, a circular pipe appears elliptical, a thin concrete footing appears thick, and a flat slope looks steep. When exaggeration is used in a drawing, both the vertical and horizontal scale bars and units should be shown. An example of an exaggerated scaled drawing is contained in Fig. 7-9.

Care should be exercised in estimating quantities from an exaggerated scaled drawing using a planimeter. Some planimeters cannot measure quantities when the vertical and horizontal scales are different, but some of the new electronic planimeters can do so by specifying both scales. Exaggerated scale drawings do not introduce a problem for quantity takeoffs on the computer.

Unscaled Drawings

Unscaled drawings should be used only for simple details or details where all of the relevant controls and dimensions are called out in other drawing details. A drawing not drawn to any scale should be labeled "NOT TO SCALE" or "NO SCALE" under the title. The abbreviation NTS is also commonly used. Preparing NTS drawings has the following incentive from a production standpoint:

- The drawing can be drawn quickly without attention to the actual dimensions.
- When part of the unscaled drawing is changed, e.g., from a 4-in. pipe to a 6-in. pipe, only the dimension callouts need to be changed, and it may not be necessary to change the graphics portion at all, thus saving some drawing time.

An unscaled drawing can also be used to illustrate a construction method or sequence where the dimensions are not critical. Because a scale is not used, these schematic drawings cannot be used to take off quantities for a cost estimate.

It is advisable that an unscaled drawing be drawn somewhat to scale to maintain the natural appearance of the design feature. Unscaled drawings should not be drawn like a cartoon, without regard for actual dimensions, sizes, and shapes of a design feature. Two examples of details that are not drawn to scale are illustrated in Fig. 9-8.

9.6 Detailing in Same View

Section 7.6 discusses how to prepare a new designated detail from a view whose scale is too small to show additional design information. Instead of preparing a separate detail with a designation, and then showing that detail separately on the same sheet or on a different sheet with a separate heading, a technique that is quite effective is to use an enlarged "bubble" acting essentially as a magnifying glass. The detail thus enlarged is still "attached" to the view, and generally, the enlarged scale does not need to be identified with a heading as long as the pertinent information or dimensions are called out. The enlarged detail shown can be drawn to scale or not to scale. It is important to note that this technique is effective when the detail to be enlarged will not be repeated elsewhere in the design. If a detail is recurring, it is better to call out the detail with a specific designation (see Section 7.6) and show the detail separately. Fig. 9-9 shows an example of detail enlargement in the same drawing view.

9.7 Distinguishing New and Existing Work

This discussion applies to both new construction and modifications to existing facilities. For new construction, the distinction is between new grades and existing grades of the ground surface, and existing grades and new grades should be properly labeled, with correct line types. It is important to distinguish in the drawings between existing and new facilities or features, and what is in the contract scope of work and what is not, and that distinction should be clear.

For new construction, the existing topographic contours under the new work should be shown as dashed lines (see examples in Figs. 7-3, 9-3, and 9-4), and all new contours and existing contours that remain unchanged should be shown as solid lines. In some cases, leaving all of the existing contours (major and intermediate contours) within the footprint of the new work would unnecessarily interfere with detailing the new work. In such situations, the practice is to dash in only the major

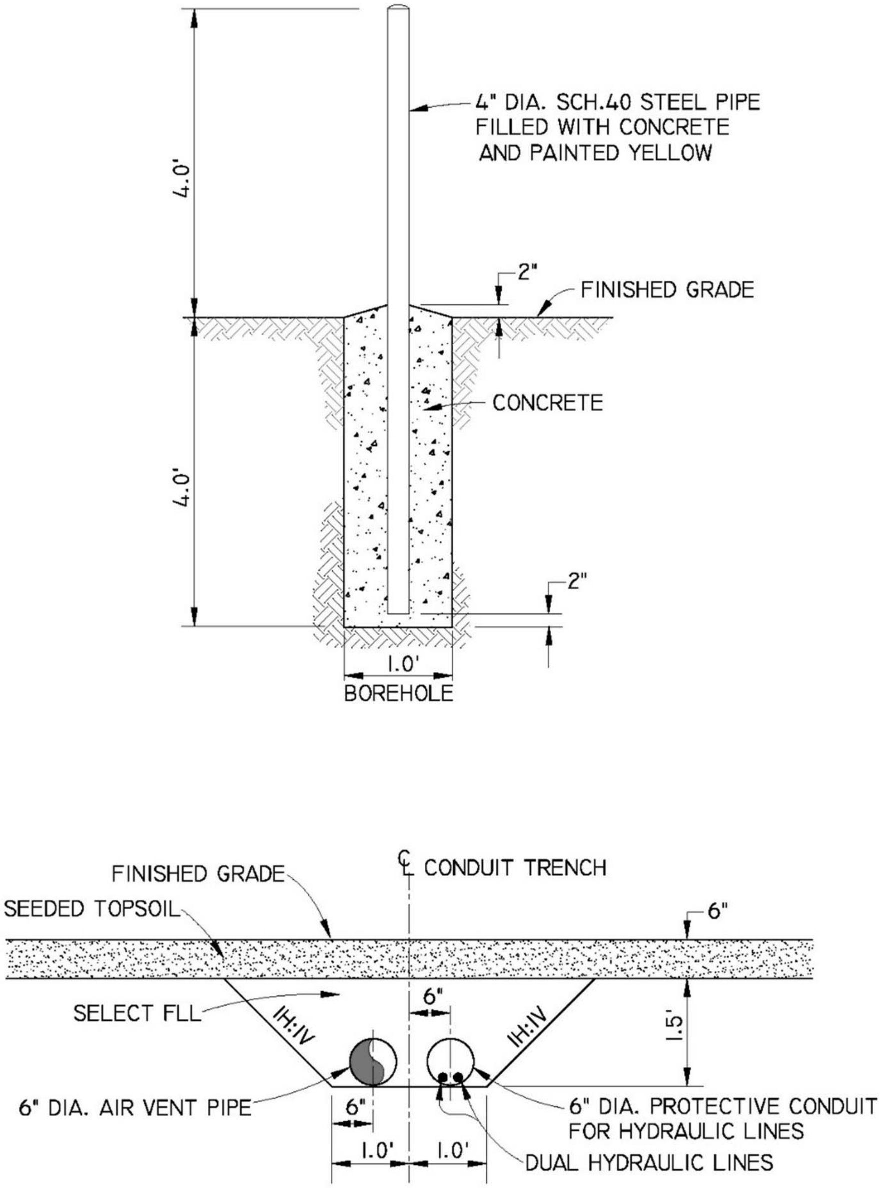


Fig. 9-8. Examples of Details Drawn Not to Scale

contours and delete the intermediate contours (see, e.g., Fig. 7-18). It should be cautioned that, when this is done with CAD, intermediate contours that are deleted may be lost permanently in that drawing file, and any future design changes to the new work might not include these contours. Therefore, it is recommended that dashing of the major contours and deleting of the intermediate contours under the

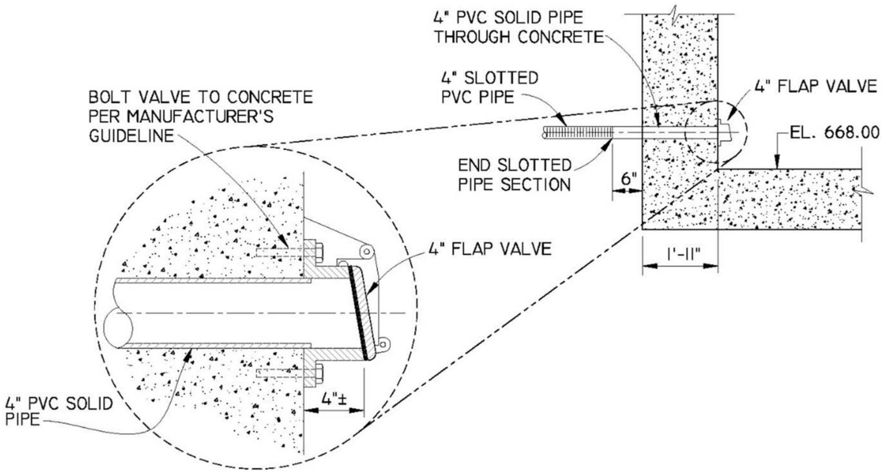


Fig. 9-9. Detailing in Same View

new work be performed only when the design is near completion, and additional major changes to the design are not anticipated.

In civil design, the most frequently encountered situation is work involving excavation and new fill. Excavation, whether it is temporary or permanent, is considered new work, and the limit of excavation relative to the existing ground surface is important design and construction information. Other than stripping, excavation should be shown both on plan (referred to as excavation plan) and in cross sections. Excavations shown in cross sections should include the existing ground surface and the limit of excavation. Showing the limit of excavation without showing the existing ground surface would be meaningless. Without the existing ground surface, the contractor does not know the depth of the excavation or where the end of the excavation meets the existing ground surface. The limit of excavation shown in the drawings can also be used for measurement and payment by designating the limit of excavation as a neat line for excavation payment purposes. Common drafting practice is to add hatching below the line to emphasize the limit of excavation (e.g., Figs. 9-5 and 9-7).

When construction involves rehabilitating existing facilities or modifying existing facilities, the general guideline is to show the following:

- Limit of removal (demolition) of existing structure,
- Limit of existing structure to remain (or protect), and
- Interface and connection details between new work and existing work.

Fig. 9-10 is a simple cross section illustrating this guideline. An existing concrete structure is being lowered 2 ft (0.6 m) by saw-cutting, and the structure will be rebuilt with new concrete. The section shows the limit of concrete demolition, the existing

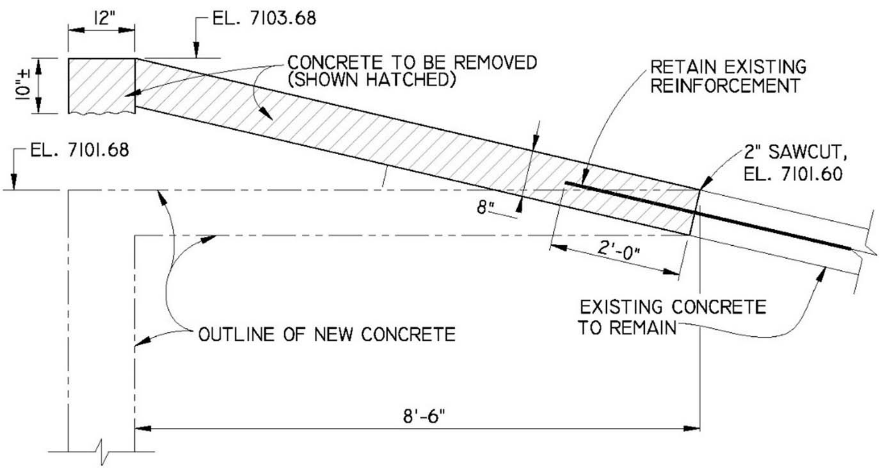


Fig. 9-10. Example of Distinguishing New Work from Existing Facility

concrete slab to remain, and the outline of the new concrete. To effectively show these three components (demolition, existing concrete to remain, and new concrete), cross hatching is used for the demolished concrete, and a phantom line is used to outline the new concrete. Other combinations of hatching, shading, and line types can be used, depending on the preference of the designer.

It is important to clearly call out what is existing work and what is new work. When details of the new work are shown, including how the new work interfaces with the existing structure, the existing structure or topography can be shown as background using lighter line weights, and the new work should be emphasized. The technique of using lighter line weights and lighter objects to deemphasize the background is called *screening*. Before CAD, screening was a two-step process that involved photographic production of a lighter original, and the lighter original was then used for hand drafting. With CAD, screening is done electronically and rapidly, and many levels of screening (e.g., 95%, 90%, 85%, 80%,) can be accomplished. An example of screened lines representing intermediate contours is shown in Fig. 7-18a.

9.8 Representing Symmetry

Many civil engineering structures are symmetrical in geometry and layout, with features identical in every respect on each side of the centerline. For a symmetrical structure, the entire structure is still drawn in its entirety on plan, except that only half of the structure would need to be detailed. Callouts that are used to detail half of the structure but are intended for the entire structure should include the word "TYPICAL" or the phrase "SYMMETRICAL ABOUT CENTERLINE," which would suggest that features on the other side of the centerline are similar (see Section 9.4 for use of callouts).

Strictly speaking, it is only necessary to show half of a symmetrical structure or section because both halves are identical. Compared to hand drafting, there may be some savings in drafting time when drawings are prepared by CAD for a symmetrical structure. With CAD, when half of a symmetrical structure is already drawn, the other half can be reproduced quickly by using the technique of *mirroring* (see Section 11.2). Therefore, showing only half of a symmetrical structure is hardly justified from a CAD production standpoint, and it is not recommended because the absence of half a structure in the drawing can cause confusion.

There is a technique that can be used for preparing cross sections for a symmetrical structure (Fig. 9-11). For simplicity, no dimensions or scales are used in this illustration. When one side of a symmetrical structure is shown in cross section, there is no need to show the cross section from the other side of the centerline. Instead, below the title for the cross section, a statement can be added to indicate that the other section is similar but opposite hand. For the south wing wall shown in the example, the phrase "NORTH WING WALL SIMILAR BUT OPPOSITE HAND" is sufficient to show the contractor that the same cross section and details can be used for both wing walls. In other words, everything in the north wing wall section is similar to the south wing wall section, except that the approach channel will be on the right side instead of the left side.

9.9 Use of Three-Dimensional Graphics

In general, three-dimensional graphical techniques, such as isometric, perspective, or oblique views, are not used in civil drawings. The principal views, namely plan, section, and elevation, drawn in two dimensions, are still the basic graphical representations of civil design features. There are some instances in which a three-dimensional view may be more economical to produce than using the three principal views. Fig. 9-12, which shows an intricate connection of a network of foundation drainpipes, is such as example. To show the same connection in two dimensions, at least three views (one plan view and two elevation views) are required.

In general, however, the use of three-dimensional views in civil drawings is not recommended. Three-dimensional views can be used for minor design features where multiple two-dimensional views are more time-consuming to produce, and to provide clarity to the contractor for construction layout.

9.10 Checking Drawings

Checking drawings is part of the quality control process during drawing production. This effort represents one of the most significant quality control protocols in applied engineering design and therefore should be performed with the utmost care, dedication, and precision. Significant errors may remain undetected if the drawings are not carefully checked and back-checked during the production process.

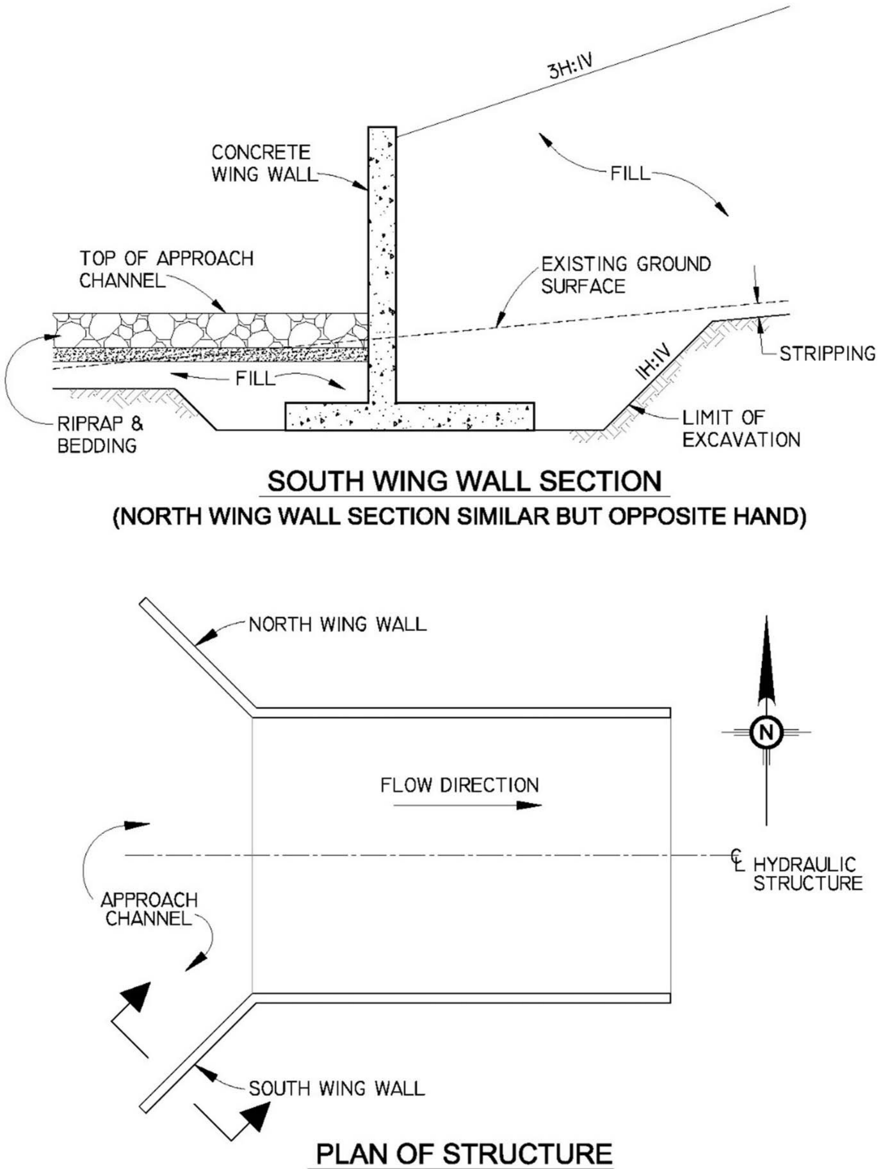


Fig. 9-11. Example of Detailing Symmetrical Structures

The marking of progress drawings during production is also known as *redlining* because a red pen is usually used for making changes on the drawings. Drawings that are not checked systematically by experienced design personnel undoubtedly often contain errors, regardless of how competent the designer is. It is also quite safe to say that drawings that are produced in a hurry to meet tight deadlines have a high probability of errors, resulting in construction and other problems.

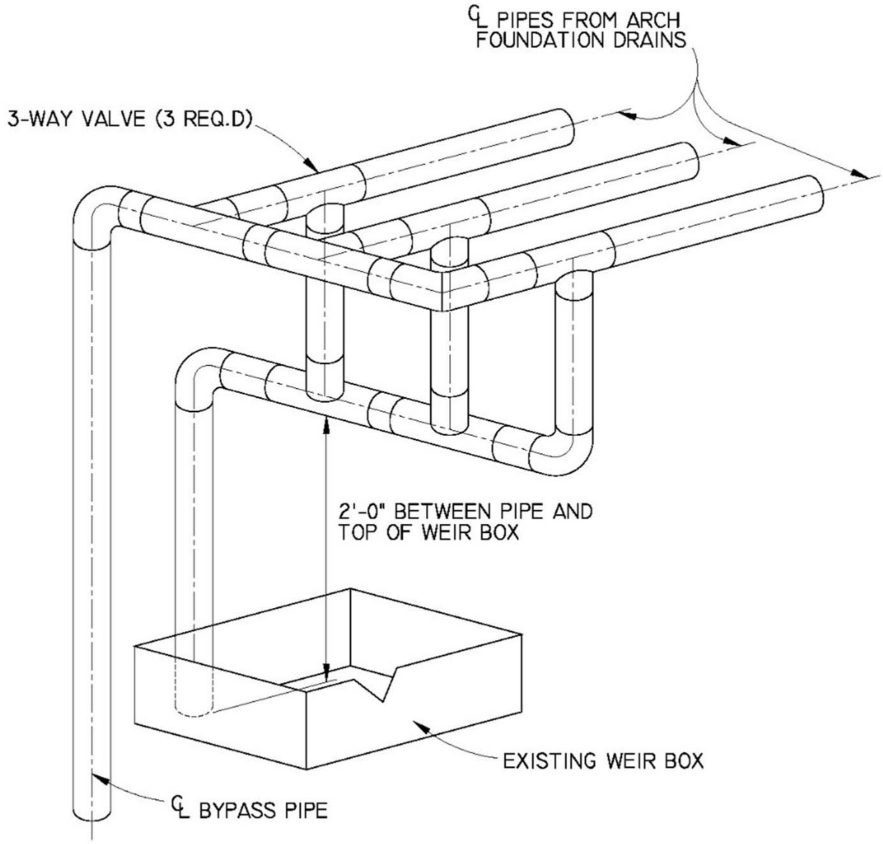


Fig. 9-12. Example of Three-Dimensional View

There are several levels of checking that should be performed during the production of design drawings.

Checking for Drafting Errors

This first line of defense against errors in design drawing production should be performed by the design engineer. When the design drawing is first sketched by hand and submitted to the CAD drafter to be drawn electronically, the design engineer should check the CAD plot against the original hand drawing for accuracy and completeness. When the CAD drafter produces a drawing based on verbal or written instructions of design requirements from the design engineer, the design engineer should check the drafted version against the instructions given. In addition, the design engineer should also check to make sure that all of the views drawn and plotted are consistent with the instructions given. Specifically, the design engineer should check for the following items:

- Control points, baselines, and centerlines are drawn correctly. Survey and control information should be checked independently by the engineer.
- Elevations, distances, dimensions, and angles are represented correctly.
- The spatial relationships among project features are portrayed correctly in the views.
- Catch points and catch lines are drawn correctly. This can be done manually or by CAD.
- Drafting standards (e.g., line types, line weights, and symbols) are applied correctly.

As discussed in Chapter 11, hand checking certain features of CAD drawings (such as northings and eastings of control points, stations, dimensions, and angles) may not be possible because CAD is significantly more precise than hand checking. For example, control points identified in CAD and expressed in 0.01-ft (3-mm) accuracy cannot possibly be measured and checked by the engineer, unless the engineer can do so independently on the computer. For those design engineers who are not trained in CAD, it is suggested that this type of information be checked independently by another CAD drafter. It is the responsibility of the design engineer to identify what part of a CAD drawing should be checked independently by another CAD drafter on the computer.

Checking for Technical Accuracy

Someone other than the designer should check for technical accuracy and constructability. This is normally done by a senior design reviewer in the organization, such as the project manager or principal in charge. It is sometimes performed by an outside consultant during an independent review. The responsibilities of technical design review are not to focus on minor drawing standards such as spelling errors or wrong graphic symbols or line types. Rather, the design reviewer should focus on the following aspects of the design:

- Does the design meet the project scope of work, design criteria, and other design assumptions?
- Are the design features and construction methods appropriate for the site conditions?
- Are the designs constructable and satisfactory according to health and safety requirements?
- How risky are the designs from the standpoint of construction safety and safety of the structures?
- How many unknowns are present in the design?
- What is the potential for claims and changes during construction?

To meaningfully address these issues, the design reviewer should perform a simultaneous review of the technical specifications, design report, bid schedule, and the engineer's cost estimate.

Exercise Problems

9.1 Fig. 9P-1 shows the plan view of a fishing jetty in a reservoir. The jetty is level at crest elevation 430.0, 50 ft wide, and 200 ft long. The jetty will be constructed with an earthfill embankment. Preparation of the existing ground consists of stripping 12 in. of topsoil before placing embankment fill. The east and west side slopes of the embankment are 2H:1V (horizontal:vertical), and the south slope at the end is 4H:1V. Construct the following views for this embankment:

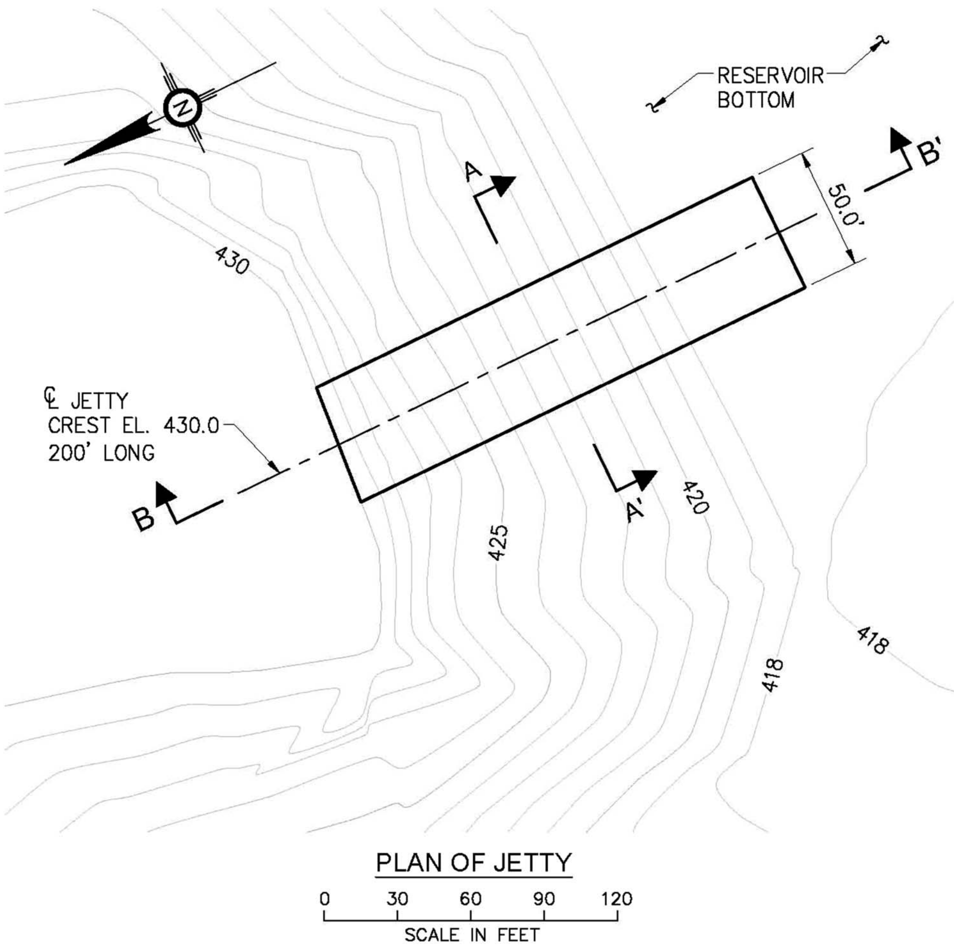


Fig. 9P-1. Top of Fishing Jetty in a Reservoir

a. The plan view of the entire embankment, showing the limits of the fill slopes (catch lines) on the east, west, and south sides.
b. Typical cross section A–A′.
c. Centerline profile B–B′.

9.2 Fig. 9P-2 shows the plan view of the bottom of excavation of a new outlet works in an embankment dam. The bottom of the excavation is 10 ft wide and 160 ft long, and slopes from El. 5,635 at the upstream end (i.e., the reservoir side) to El. 5,630 at the downstream end. The excavation side slopes are 2H:1V (horizontal: vertical). Construct the following views for this excavation:
a. The plan view of the entire excavation, showing the limits of the excavation slopes (catch lines) on the north and south sides.
b. Typical cross section A–A′.
c. Centerline profile B–B′.

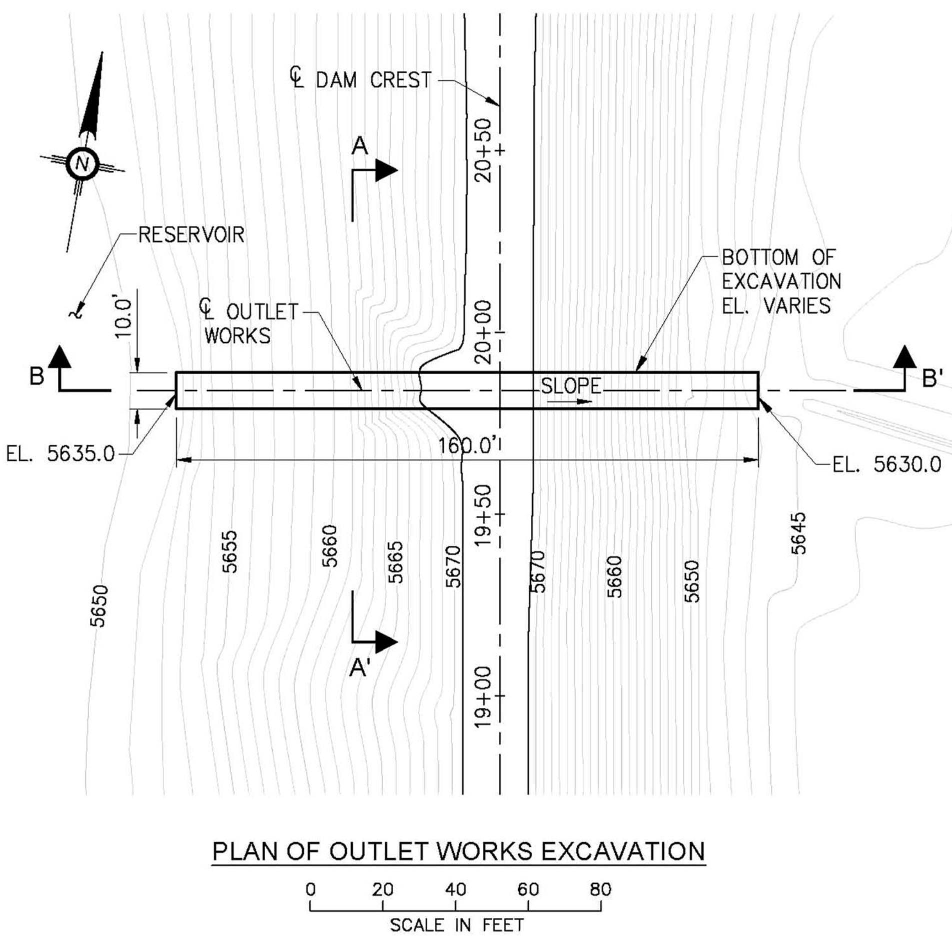


Fig. 9P-2. Bottom of Outlet Works Excavation

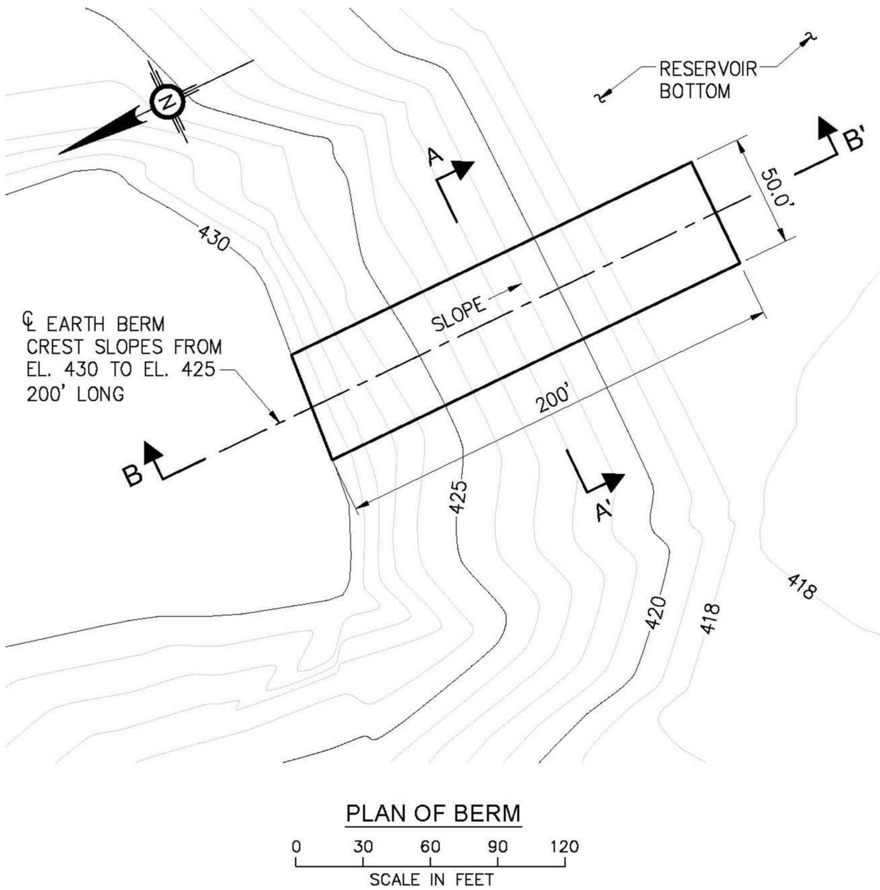


Fig. 9P-3. Top of Sloping Berm in a Reservoir

9.3 Fig. 9P-3 is a plan view of a sloping earth berm in a reservoir. The earth berm slopes from El. 430 to El. 425 from the shore to the reservoir. Preparation of the existing ground consists of stripping 12 in. of topsoil before placing earthfill. The east and west side slopes of the embankment are 2H:1V (horizontal: vertical), and the south slope at the end is 4H:1V. Construct the following views for this embankment:

a. The plan view of the entire embankment, showing the limits of the fill slopes (catch lines) on the east, west, and south sides.
b. Typical cross section A–A′.
c. Centerline profile B–B′.

9.4 This problem is similar to Problem 9.2, showing the same plan view (Fig. 9P-2) of the bottom of excavation for a new outlet works in an embankment dam, except that the excavation side slopes are different. The bottom of the excavation is 10 ft wide and 160 ft long, and it slopes from El. 5,635 at the

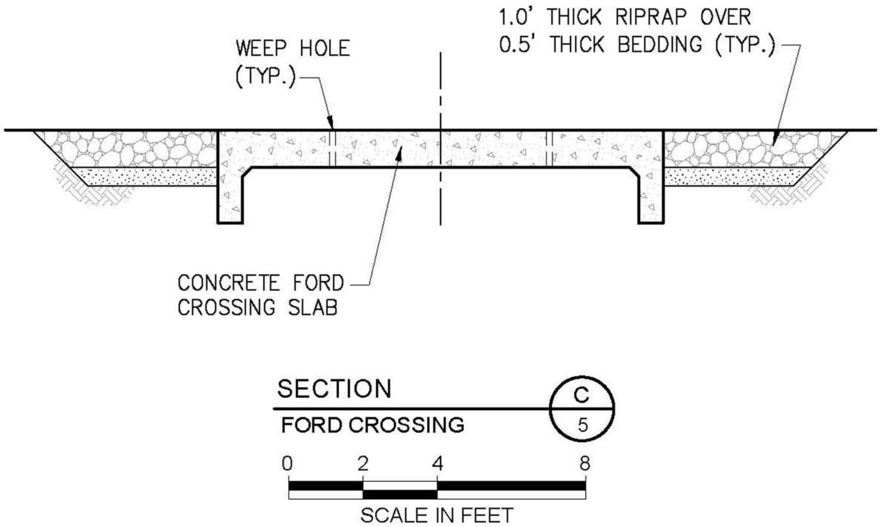


Fig. 9P-4. Section C Ford Crossing, before Dimensioning

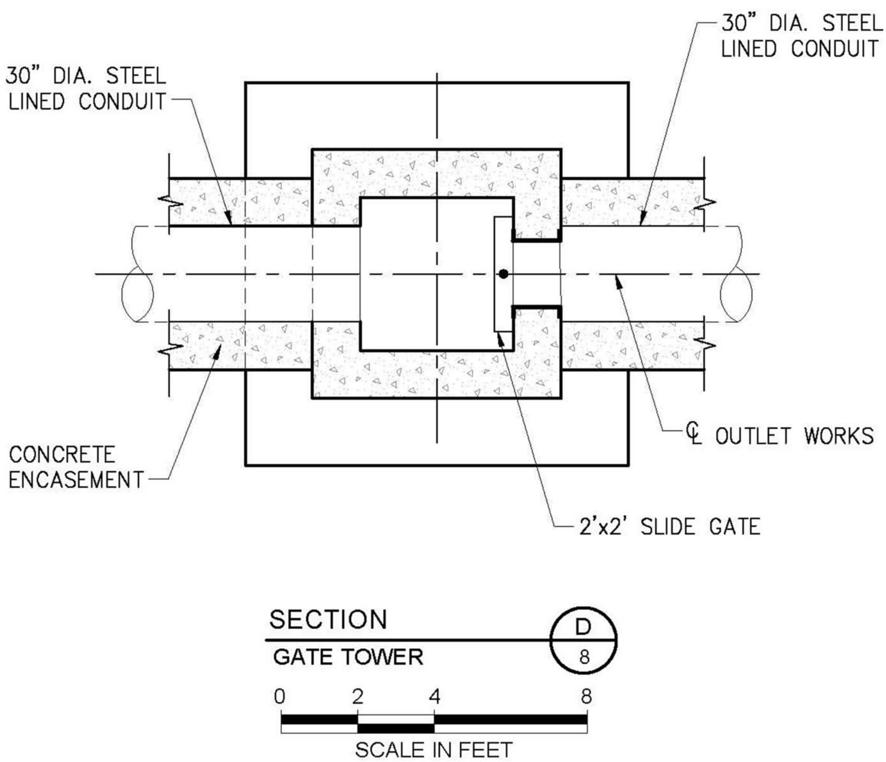


Fig. 9P-5. Section D Concrete Gate Tower, before Dimensioning

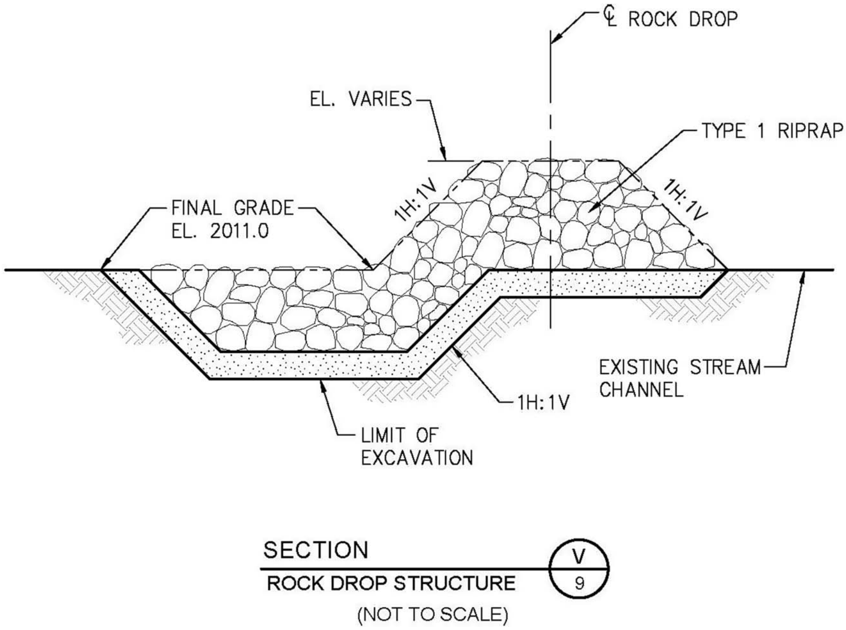


Fig. 9P-6. Section V Rock Drop Structure, before Dimensioning

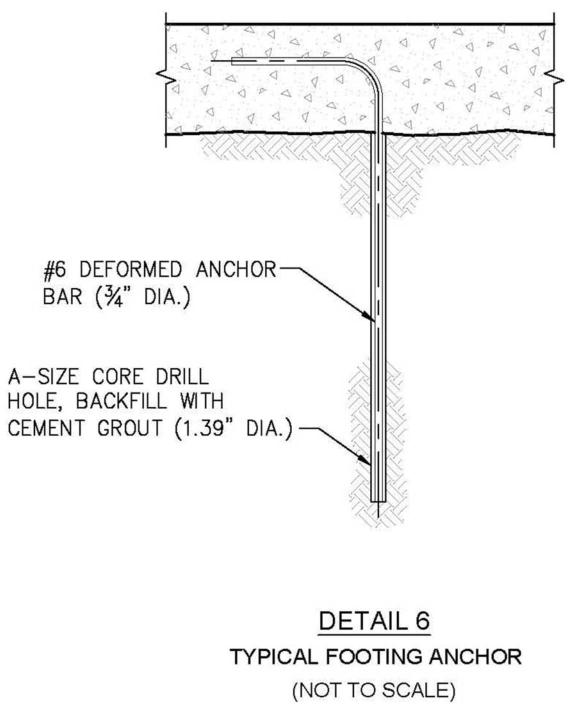


Fig. 9P-7. Detail 6 Typical Footing Anchor, before Dimensioning

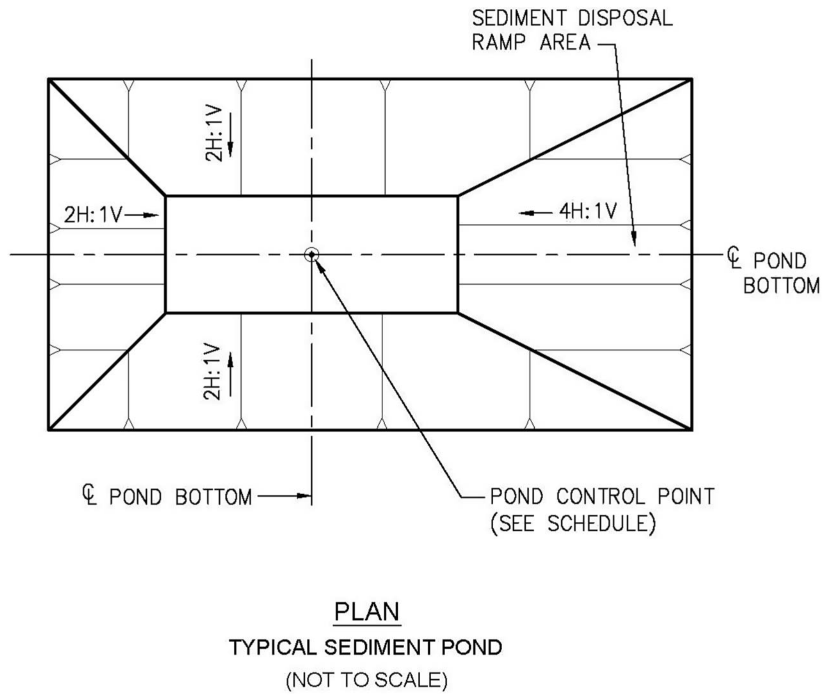


Fig. 9P-8. Plan of Typical Sediment Pond, before Dimensioning

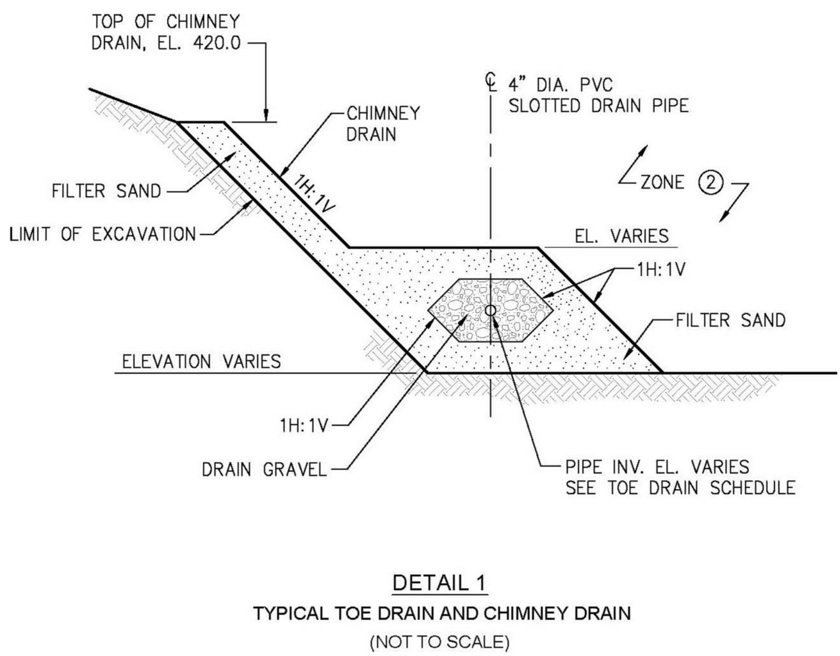


Fig. 9P-9. Detail 1 Typical Toe Drain and Chimney Drain, before Dimensioning upstream end (i.e., the reservoir side) to El. 5,630 at the downstream end. On the north side, the excavation side slope is 2H:1V (horizontal:vertical) from the bottom up to El. 5,655, where a 10-ft-wide flat bench is excavated. On the south side, the excavation side slope is 2H:1V from the bottom up to El. 5,660, where a 10-ft-wide flat bench is excavated. The excavation side slopes above both benches are 2H:1V. Construct the following views for this excavation:

a. The plan view of the entire excavation, showing the limits of the excavation slopes (catch lines) on the north and south sides, including both benches.
b. Section A–A′, which is cut along the dam crest.

9.5 The dimensions for each of the following construction drawing views are deliberately deleted for this problem. Add dimension lines and extension lines to each of the following views, so that each of the features or objects can be

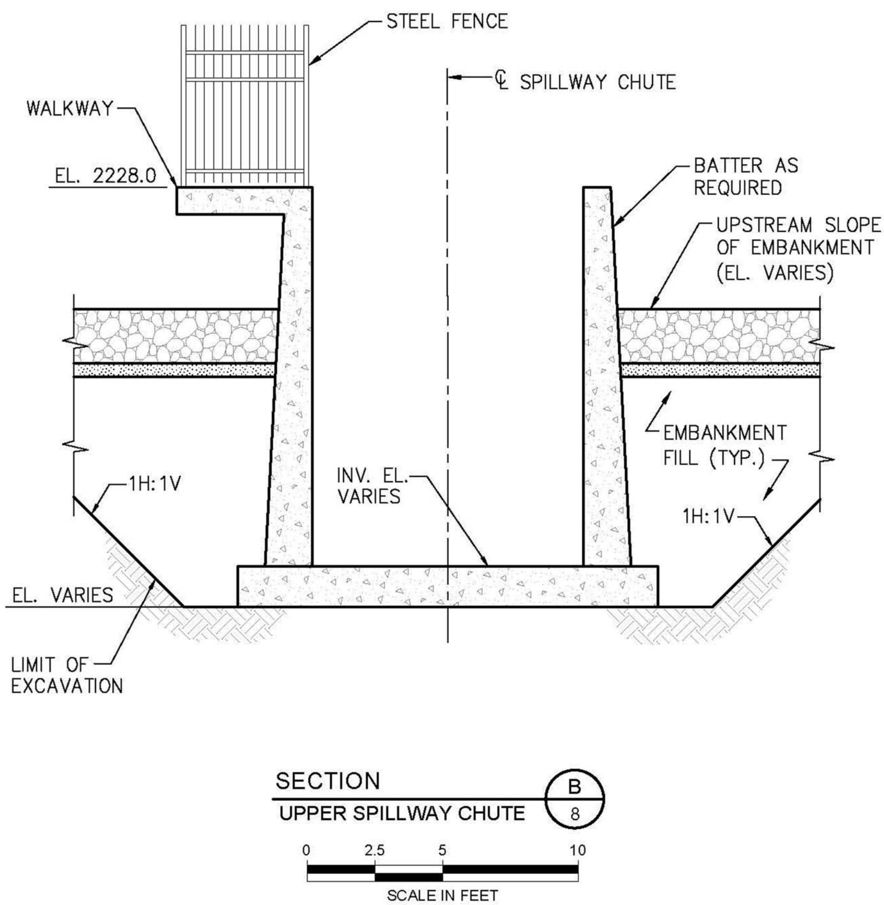


Fig. 9P-10. Section B Upper Spillway Chute, before Dimensioning constructed. The objective of this problem is to practice where to add the dimensions, and it is not necessary to include the dimensions themselves in the solutions.

a. Section C Ford Crossing across a stream (Fig. 9P-4). Dimensioning of the following features is needed: riprap, riprap bedding, and concrete ford crossing.
b. Section D Concrete Gate Tower (Fig. 9P-5). Dimensioning of the following feature is needed: concrete structure.
c. Section V Rock Drop Structure (Fig. 9P-6). Dimensioning of the following features is needed: limit of excavation, riprap, and riprap bedding.
d. Detail 6 Typical Footing Anchor (Fig. 9P-7). Dimensioning of the following features is needed: concrete slab and anchor bar.
e. Plan of Typical Sediment Pond (Fig. 9P-8). Dimensioning of the following feature is needed: pond geometry.
f. Detail 1 Typical Toe Drain and Chimney Drain (Fig. 9P-9). Dimensioning of the following features is needed: chimney drain and drain gravel.

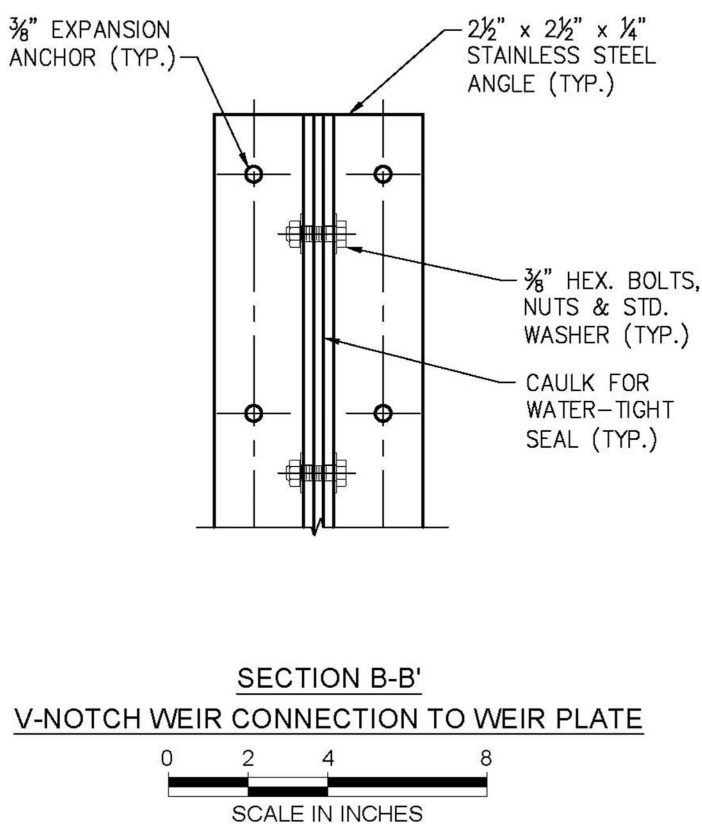


Fig. 9P-11. Section B–B′ V-Notch Connection to Weir Plate, before Dimensioning

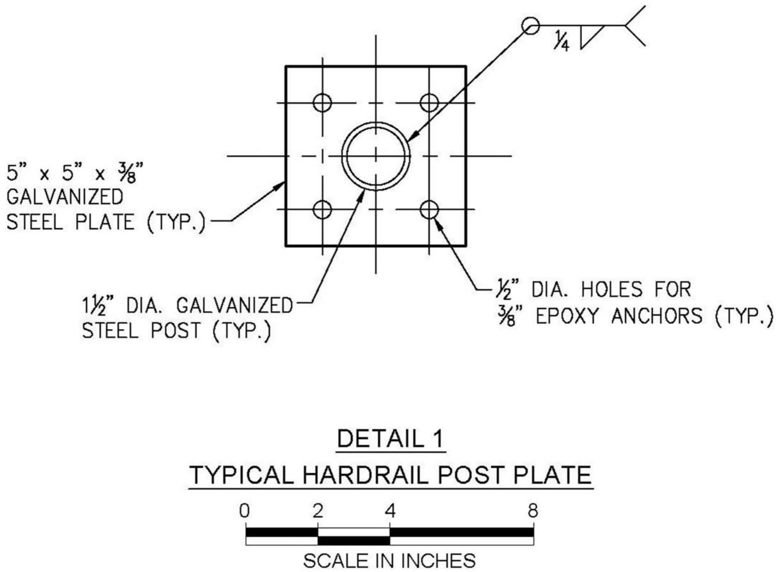


Fig. 9P-12. Detail 1 Typical Handrail Post Plate, before Dimensioning

g. Section B Upper Spillway Chute (Fig. 9P-10). Dimensioning of the following features is needed: excavation limits, concrete structure, riprap, riprap bedding, embankment fill, and steel fence.
h. Section B–B′ V-Notch Connection to Weir Plate (Fig. 9P-11). Dimensioning of the following features is needed: steel angle, expansion anchors, and bolt holes for the weir plate.
i. Detail 1 Typical Handrail Post Plate (Fig. 9P-12). Dimensioning of the following features is needed: steel plate, post, and anchor holes.

CHAPTER 10

Designing with the Metric System

10.1 Systems of Design Units

Civil design discussed thus far has been based on the U.S. customary system of units. Despite numerous efforts in the private sector and in state and federal government to change to SI (Système International) units, i.e., the metric system, the U.S. customary system of units continues to be the predominant system used in the United States. The American Society of Civil Engineers, for example, requires that all of their publications, such as journals and conference proceedings, be written in SI units, with conversion units allowed. Most of the state and federal departments of transportation have changed their specifications for bridge and road construction to the metric system, even though the U.S. customary unit versions are also available in some states.

This entire book is written with U.S. customary units because it is still the dominant system used in the design and construction industry in the United States. Nevertheless, a designer may have the opportunity to work on international design projects for which the metric system is required. This chapter is written for those designers who are interested in working in SI units.

In this chapter, design practices that are unique to the metric system are discussed and compared with the principles presented in this book. To illustrate the differences between the U.S. customary and metric systems, examples of drawings prepared with the metric system are shown.

10.2 Metric System Design Practice

The general principles to prepare design drawings in the metric system are no different from those discussed in Chapters 5 through 9. All graphical techniques are the same for both systems. Some of the design features that are unique to the metric system are listed and discussed below.

Sheet sizes. Full-sized metric sheets are either 817 × 570 mm or 817 × 1,105 mm. In the United States, even when a design is based on metric units, the drawing sheet sizes are still in U.S. customary units because most reprographic copiers only use U.S. customary-size paper (see Section 5.1). Therefore, metric-sized sheets are rarely used in the United States.

Common units. The common units and their abbreviations used in design drawings are the following:

- Distance (civil drawings): meters (m)
- Civil drawing dimensions: meters (m)
- Structural/mechanical dimensions: millimeters (mm)
- Angular dimensions: degrees, minutes, and seconds
- Area: square meters (m^2)
- Volume: cubic meters (m^3)
- Temperature: degrees centigrade (°C)

Perhaps the most interesting practice is the use of millimeters for structural and mechanical dimensions. For comparison, in the U.S. customary system, the units of feet and inches are used for structural and mechanical dimensions. In the metric system, structural dimension is expressed in millimeters to the nearest millimeter. Fractions of millimeters are not used because they cannot be practically measured during construction. For example, a structural dimension of 3 m should be labeled 3,000 mm on the drawing. However, the length of 3 m can be labeled for civil drawings, such as depth of cut and fill, similar to the practice in U.S. customary units. The level of accuracy for earthwork construction is 0.03 m (3 cm).

Fig. 10-1 illustrates a cross section of a civil drawing, and Fig. 10-2 illustrates a structural cross section, both prepared using metric units.

Metric scales. Similar to the U.S. customary system, two sets of scales are available for metric drawings. The metric civil engineer's scale consists of the following common scales:

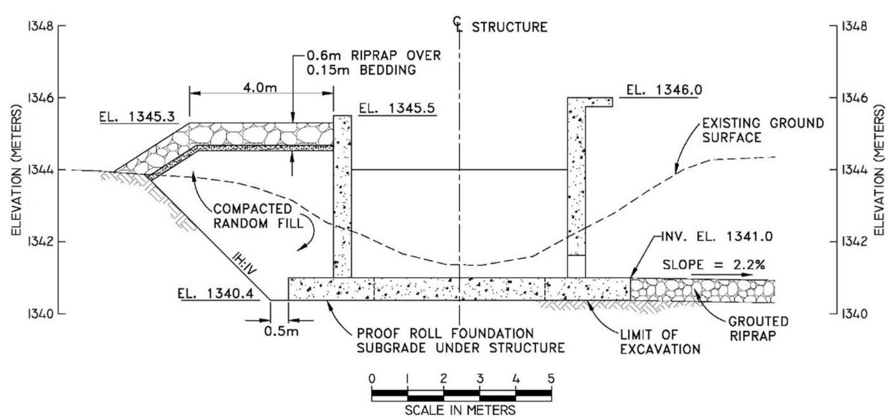


Fig. 10-1. Example of a Cross Section Prepared with Metric Units

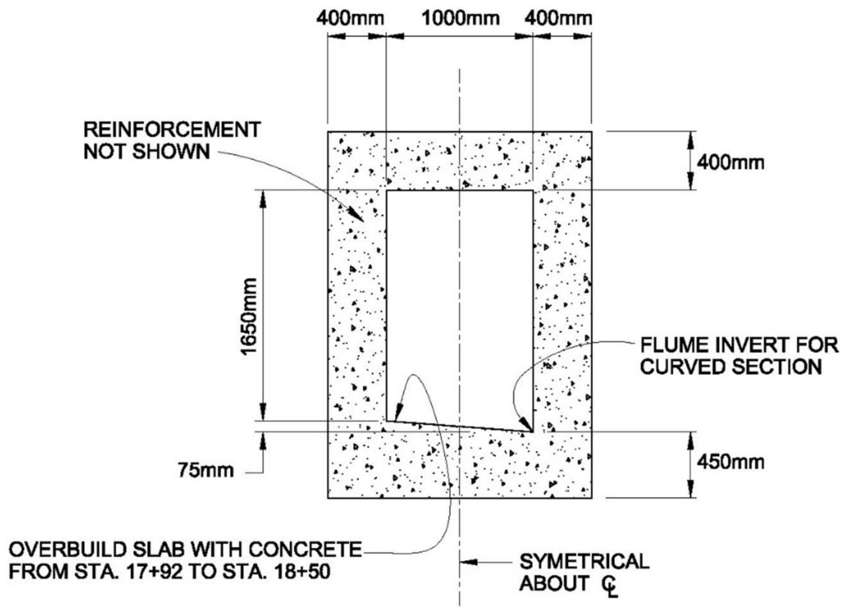


Fig. 10-2. Example of a Structural Cross Section Prepared with Metric Units

1:500 (1 cm = 5 m)
1:1,000 (1 cm = 10 m)
1:1,250 (1 cm = 12.5 m)
1:1,500 (1 cm = 15 m)
1:2,000 (1 cm = 20 m)
1:2,500 (1 cm = 25 m)

The architect's scale, which is used in structural and mechanical design, consists of the following common scales:

1:100 (1 cm = 1 m)
1:200 (1 cm = 2 m)
1:250 (1 cm = 2.5 m)
1:300 (1 cm = 3 m)
1:400 (1 cm = 4 m)
1:500 (1 cm = 5 m)

10.3 Equipment and Products

The specification for manufactured equipment and products when using the metric system requires some discussion. Although most equipment and products manufactured outside of the United States are based on metric units, those

Table 10-1. Comparison of Reinforcing Bar Designations

Customary Units		Metric Units	
Designation	Diameter (in.)	Designation	Diameter (mm)
No. 3	3/8	No. 10	10
No. 4	1/2	No. 13	13
No. 5	5/8	No. 16	16
No. 6	3/4	No. 19	19
No. 7	7/8	No. 22	22
No. 8	1.0	No. 25	25
No. 9	1-1/8	No. 29	29
No. 10	1-1/4	No. 32	32
No. 11	1-3/8	No. 36	36
No. 12[a]	1-1/2	No. 38	38
No. 14	1-3/4	No. 43	43
No. 16[a]	2.0	No. 51	51
No. 18[a]	2-1/4	No. 57	57

[a]Not an ASTM standard bar size.

manufactured in the United States are still manufactured using U.S. customary units. When a domestic project, that is, in the United States, is designed with metric units, the designer can still call out a certain pipe, gate, valve, or structural steel member in U.S. customary units, and the contractor can procure these products. For projects outside of the United States, the designer is faced with the following decision: Should he or she specify a U.S.-made product or equipment (made with U.S. customary units) that needs to be imported, or should he or she specify a metric product that is available locally? The answer is usually determined by economics.

Because manufactured products are only available in certain standard metric sizes, one cannot simply convert a product or equipment from U.S. customary units to metric units in selecting a metric product or equipment in specifications. For example, a 42-in. (1,067-mm) steel pipe may only be available in 1,000 mm, and a 1/4-in. (6.35-mm) steel plate may only be available in 6-mm stock. In the United States, reinforcing bars are numbered based on multiples of 1/8 in.; in the metric system, the reinforcing bars are numbered based on the nearest millimeter. For example, a No. 3 bar (3/8 in.) in the United States is equivalent to a No. 10 bar (10 mm) in metric, and a No. 7 bar (7/8 in.) in the United States is equivalent to a No. 22 (22 mm) bar in metric. Table 10-1 contains reinforcing bar designations in both U.S. customary units and metric units.

When combining metric equipment with U.S. customary units in structural or mechanical work, the designer is solely responsible for compatibility and clearances. Therefore, a designer needs to be knowledgeable in the standards and technical specifications regulating the manufacture of metric products and materials.

CHAPTER 11

Computer-Aided Drafting

11.1 Current Trend

In the United States, essentially all design drawings are now prepared with computer-aided drafting (CAD) software. The use of CAD software in engineering design became popular in the 1980s, when high-speed, affordable personal computers with large storage memories became available. The days of the drafting table, lettering guides, and inked pens are all but over, but a good design engineer does not necessarily have to be a computer wizard or an expert in CAD software. Production of design drawings should be the responsibility of CAD drafters, who are technicians specifically trained for this type of work; however, a new breed of engineers have CAD training in their education curriculum, and they are using the computer essentially as a design tool while also doing CAD production. Because the hourly rate for an engineer is significantly higher than that of a CAD technician, such a practice is not cost-effective from a business perspective.

This chapter describes some common CAD tools and their usefulness in civil design, the advantages of CAD drawings, and the roles and responsibilities of design engineers and CAD drafters in the production of construction drawings. This chapter also contains some guidelines regarding the use and transmission of electronic design information, including design drawings, shop drawings, and design changes.

11.2 Computer-Aided Drafting Tools and Capabilities

A variety of CAD software packages is available on the market for engineering and architectural drafting. Many of these CAD software packages have some basic capabilities that are common among them, but each can have some unique capabilities. It is not the intent in this chapter to identify the capabilities or limitations of these CAD tools, nor is this chapter meant to be used for training CAD drafting; rather, CAD software as a civil design tool is discussed in general without identifying software by trade names. It is not a basic requirement for a civil design engineer to be able to operate CAD software, even though many young civil engineers are already knowledgeable in CAD from their academic training. A design engineer should, however, understand how CAD can be used to perform various design tasks and what design tasks can be delegated to a CAD technician to take advantage of the full capabilities of modern technology.

The following is a general description of some capabilities of CAD software programs. No attempt will be made to identify the programs or to distinguish the capabilities of one program from another.

Drawing capability—In the hands of a skilled CAD operator, all of these programs can generate a set of civil design drawings in any views that are equal to or better than the hand-drawn drawings of the past. The same basic principles described in Chapter 7 are followed to create drawing views in CAD. Some creative and artistic aspects of hand-drawn drawings are gone, and the creation of design drawings is becoming more technical and machine-oriented. Nevertheless, good-quality drawings are created by capable practitioners, and poor-quality drawings are created by less capable and inexperienced drafters. All CAD software programs contain an abundance of symbols, shadings, font types, and font sizes to represent all of the basic graphical requirements for civil design. For example, one excellent graphical capability in CAD is the ability to screen any line and object to enhance the graphic quality (see Section 9.7). Before the advent of CAD, the use of screening in drawings required an extra step in the screening process using the photographic method. CAD allows an almost infinite variety of screening and shading without resorting to that extra step.

Computational capability—CAD software is no longer used just for creating design drawings. Essentially all CAD software has computational and mathematical capabilities to perform complicated design layouts. A good example is the survey computations that are routine in civil design. Vertical curve or horizontal curve computations can be performed rapidly as part of the CAD design process, and the CAD drafter now can easily identify such things as points of curvature and points of tangency for curve design.

Improved accuracy—CAD software is a far more accurate design tool than the tools that were used for hand-drafting. For example, in hand-drafting, the accuracy of the lengths and distances in a drawing with a scale of 1 in. = 10 ft is ±0.1 ft. A protractor can only read an angle to within half a degree. On the other hand, the accuracy of CAD software is not dependent on the drawing scale, and lengths and distances can be measured to as many significant figures as are required. Using a computer, distances can be measured and identified to the nearest 0.001 ft, and angles can be measured and identified to the nearest second. For all practical purposes, the accuracy that can be physically surveyed or measured in the field should control what dimensions are shown on the drawings, not how these dimensions are obtained in design computations. Equally important is the consideration of constructability in heavy civil construction. Whereas it is acceptable to perform earthwork computations in CAD design to the accuracy of six to eight significant figures, the same accuracy and tolerance are not constructable in the field by conventional earthwork equipment and methods. When the design is performed in CAD, whether by a technician or by an engineer, it is the responsibility of the design engineer to properly dimension a drawing so that the feature in question can be surveyed, measured, and constructed in the field.

Drawing layout—CAD is more than just tracing a hand-drawn drawing digitally. Some CAD programs have the capability to lay out plan, sections, and profiles for civil design after the triangular irregular network (TIN) has been set up for a digital topographic map. The TIN is a vector-based representation of the physical land surface, made up of irregularly distributed nodes and lines with three-dimensional coordinates (x, y, and z) that are arranged in a network of nonoverlapping triangles. When the TIN of an electronic base map is established, the CAD drafter can perform—in a fraction of the previously required time—numerous types of design work traditionally performed by hand by an engineer. These design tasks include establishing catch points and catch lines for cut-and-fill construction, cutting cross sections and profiles, and laying out excavation plans and grading plans.

Most CAD programs can also perform the following tasks, which are usually time-consuming when performed by hand:

- Changing drawing scale—During design, different scales are needed for a base map to show different levels of detail. Before CAD, changing the scale of a base map required photographic or xerographic enlargement or reduction, which is time-consuming and causes distortion of the map. With CAD, this process can be done digitally and quickly, and there is no distortion associated with enlargement or reduction of a drawing or map.
- Cut-and-paste work—There are some situations in which cutting and pasting or copying and pasting design layouts or details is used to greatly reduce the drawing time, such as drawing repetitive patterns, hatchings, and symbols. CAD software can perform this type of work quickly. This technique can also be used to detail reinforcing bar patterns, which are frequently spaced equally in both directions in some repeating patterns.
- Mirroring—Mirroring is the technique of reversing a drawing or detail. When a detail is symmetrical, only half the detail needs to be drafted; the other half can be reproduced by the mirroring technique. Sometimes, an opposite view may be more desirable for an available detail; instead of redrafting the entire detail, the opposite view can be produced using mirroring.

Quantity takeoff—Estimating quantities from design drawings is part of the design process and can be time-consuming, depending on the complexity of the design and geometry. Without CAD, the quantity calculations (see Chapter 22) are based on measurements using a scale, a planimeter, or other hand tools, supplemented by additional cross sections or profiles where necessary. Using CAD software, this tedious process can be performed in less time and with significantly increased accuracy.

From a business standpoint, the use of a computer to produce design drawings offers great advantages in cost savings and production efficiency. When one compares the time required to produce a set of drawings the first time with and without CAD, there may not be any obvious cost savings. However, there is no question that changing drawings using CAD saves a significant amount of time, because design drawings are frequently changed during the various stages of design production to address internal review comments, to address review comments by clients and regulatory agencies, and to update other design changes. The old method of making changes—erasing and redrafting by hand—is simply too time-consuming, and frequently an entire drawing requiring significant changes would need to be redrawn completely.

11.3 Roles and Responsibilities

CAD software is a design tool and should be treated as such. Drafting in CAD does not replace the technical training, experience, and judgment of an engineer. Regardless of the tool available for design, there should be a distinction between engineering design and engineering drafting. Before the advent of CAD, seasoned and experienced engineers performed most engineering design. Design responsibilities in some firms and agencies are now falling into the hands of CAD operators who are proficient in CAD software and computer skills, but have little to no engineering training or construction experience. Such a trend is indicative of the belief that the all-powerful drafting tools, such as some of the sophisticated CAD programs, can replace the technical skills and judgment of an experienced engineer. In a special report in *Engineering News-Record* (ENR 2000), building contractors voiced their opinions on the decline in quality of design in the following excerpts:

> "The largest problem in the industry is poor contract drawing."
> "Architects and/or engineers are not creating a product that contains all the necessary information. To save money, they use inexperienced personnel."
> "Dimensions are a major problem."
> "Drawings are getting worse."
> "We see structural drawings that don't even have the grid dimensions."
> "People come out of school who are fluent with a computer as if it's a video game ... But if you analyze it, you realize the operators are only drawing lines on paper—not walls, floors, and columns."

The graphical quality of design drawings has improved with the use of CAD software, but attractive drawings alone are inadequate for successful construction. Some of the problems cited here are not caused by the misuse of CAD; rather, they are caused by the management responsible for staffing and managing design projects. The remaining portion of this chapter describes the roles and separate responsibilities of a design engineer and of a drafter in the production of drawings using CAD software.

Roles and Responsibilities of a Design Engineer

- The design engineer should have primary and overall responsibility for the technical accuracy of the design within his or her area of expertise. It is critical that a designer should not be in responsible charge outside his or her area of expertise. A geotechnical designer should not be designing structural steel or reinforced concrete. A hydraulic designer should not be designing excavations and earthwork.
- The design engineer should be responsible for the constructability, health, and public safety of his or her design. A CAD drafter may not know that it is unsafe to design a very steep cut slope in a cohesionless soil, nor is he or she expected to know that a 1H:1V slope is too steep to support a riprap rock lining for a stream channel.
- The design engineer should document the design criteria and technical basis of his or her design. A CAD drafter can draw the detail of a reinforced concrete pipe or the detail of a posttensioned anchor. The technical basis for using that type of pipe or that anchor size and corrosion protection should originate from the design engineer, rather than from the CAD drafter, who can modify these details from previous projects but does not know why they are used in a certain way.
- The design engineer should be responsible for selecting the products and materials.
- The design engineer should be responsible for selecting the geometric layout and dimensions of his or her design. Whether the engineer performed the graphic design by hand or using a computer, or simply gave a set of instructions to the CAD drafter, is not important. What is important is that the decision on a particular aspect of the design originates from the engineer.
- The design engineer—or, occasionally, other staff working under his or her supervision—should be responsible for checking and back-checking drawings. The first-round checking of the drawings by the design engineer when they are first returned from the CAD drafter is the most important step in the quality control of drawing production.
- When a CAD drafter provides quantity calculation data to the engineer, it is the responsibility of the engineer to check the data for accuracy and completeness before using them for cost estimating and bidding. Unchecked quantity calculations generated by the computer may lead to significant differences in construction paid quantities, resulting in claims and project cost overruns.

Roles and Responsibilities of a CAD Drafter

- The main role of a CAD drafter is to assist the design engineer in the preparation and production of design drawings. His or her main responsibility is to ensure that the drawings are prepared accurately based on instructions given by the design engineer.
- A CAD drafter should refrain from activities that exceed the bounds of his or her knowledge or training, such as introducing technical elements in the design

drawings. When the design engineer specifies the centerline alignment of a trench excavation but neglects to include the side slopes of the excavation, it is the drafter's responsibility to request this missing information from the designer, and not unilaterally assume a slope that may not be safe or may not comply with Occupational Safety and Health Administration (OSHA) requirements.

- A CAD drafter should be responsible for all aspects of the product that he or she is producing—the accuracy and graphical aspects of the drawings, the plot, and the filing system. The drafter should have his or her own quality control procedures to make sure that all numbers (e.g., coordinates, stations, and dimensions) in the drawings are entered correctly. The drafter should know what line types and line weights are appropriate for a given design feature. A CAD drafter is also responsible for using standard symbols, standard details, and industry or company standards for drawings.
- The CAD drafter has evolved into more than just a tracer. With a powerful computer and CAD software, he or she can perform a variety of chores that greatly reduce the involvement of the design engineer in the production of design drawings. Design engineers who fail to recognize opportunities such as these are not taking full advantage of modern technology. A CAD drafter can assist the engineer in laying out the plan, sections, and profile if the engineer provides him or her with the necessary survey control and other design and site information. A CAD drafter can identify dimensional data on the computer much more accurately than an engineer can with hand scales and tools. A CAD drafter can provide quantity data from the drawings for cost-estimating purposes.

11.4 Handling of Files

The ability to digitize design drawings and save the information as electronic files introduces a whole new set of issues on storage, transmittal, and professional liability. The old method of storing reproducible drawings in a flat file cabinet has given way to electronic media. Instead of hard copies, electronic files of design drawings, shop drawings, design submittals, and even bid documents are often transmitted. Sometimes, contractors and regulators ask for these electronic files from the designer for their use, and it becomes important to look into the issue of protecting the ownership and professional liability of the design engineer.

Storage of CAD data—The development of large hard drives and efficient electronic storage media has provided engineers with the ability to store design drawings efficiently. In approximately the past 30 years, the size of hard drives on personal computers has increased from a few megabytes to hundreds and thousands of gigabytes. The size of storage disks has increased from less than one megabyte (diskette) to many gigabytes in "thumb drives." The use of rewritable compact discs (CDs) allows up to approximately 700 megabytes of data to be stored on a single CD or approximately 5 gigabytes of data on a digital video disc (DVD). The permanent electronic copy should be stored in a separate site and in a fireproof cabinet. Electronic files can also be stored on the Internet using the so-called cloud-based storage service, in which the data are maintained, managed, backed up remotely, and made available over an Internet network. Thousands of gigabytes of data can be stored in cloud storage. It is recommended that every design project be archived not only electronically, but also with a hard copy of reproducible vellum or polyester film that is stamped and signed by the engineer of record.

Transmittal of CAD data—Electronic files of CAD drawings are transmitted to clients for progress review and as final submittals, as well as among design members during design. During bidding and construction, sophisticated contractors also use CAD to prepare their bids, shop drawings, and record drawings. Frequently, bidders and contractors request an electronic copy of the design drawings to be sent to them for their use. Engineers also receive electronic files from contractors for shop drawing submittals and record drawings. Nowadays, electronic mail (e-mail), file transfer protocol (FTP), and file-sharing sites make transmittal of large amounts of electronic data almost instantaneous through the Internet. Whereas an e-mail is limited by the size of the attached data files, the FTP and file-sharing methods allow transfer and retrieval of very large files through a computer network or a website. From a design engineer's point of view, numerous important questions and concerns exist regarding this free flow of design information:

- How does a design engineer protect his or her ownership and intellectual property rights?
- How does a design engineer prevent others from altering his or her design drawings?
- How does a design engineer maintain a defensible paper trail for electronic CAD data sent and received?
- How does a design engineer prevent his or her CAD files from being corrupted or infected with electronic viruses?

There are no clear-cut answers to these questions. Some general guidelines are the following:

- All drawings sent electronically should have a hard-copy backup in the project file. The hard-copy backup should be in a reproducible medium, such as vellums or polyester film. The designer should comply with specific requirements of the client, state board of registration, or internal record departments for specific backup requirements.
- Transmitting DWG files (drawing source files) is not recommended. If only a plot is needed, then a plot file (PLT format) or a portable document format (PDF) file can be used. Files with PLT or PDF extensions cannot be altered.

- Electronic shop drawings received from contractors should not be altered and should only be used to obtain a hard-copy print for review and comment. Review comments on shop drawings should be written in red on hard copies and should be transmitted back to the contractor and owner.
- Electronic files must be routinely checked for compatibility with new software programs.

CHAPTER 12

Certifying Construction Drawings

12.1 Common Practice of Drawing Certification

When a set of construction drawings is completed, the common practice is for the engineer of record to certify the drawings. Certification by licensed professional engineers is regulated by the state board of professional engineers. Each state has somewhat different requirements for certification, but in general, certification of a design by a professional engineer implies the following:

- The design is prepared by the engineer, or it is prepared under the control and direct supervision of that engineer.
- The engineer assumes full responsibility and liability for his or her portion of the design.
- The design is safe for public health, property, and welfare.

The certification process consists of stamping (or sealing), signing, and dating the drawings. Engineers routinely sign and stamp documents, but records indicate that these tasks are sometimes mishandled and that they are the topic of the most frequently asked questions for state boards of registration for professional engineers. The information that must be disclosed in the certification process varies from state to state, but almost all of them require the engineer to stamp, sign, and date the drawings. In some states, such as Illinois, Washington, and Oregon, the engineer is also required to indicate, below the seal, the expiration date of the professional engineer registration.

Only final drawings and record drawings (formerly referred to as *as-built drawings*) must be certified before submission to the client or to the regulatory agency. Draft drawings or drawings that are issued for review purposes do not require certification. In fact, certifying drawings that are not finalized can convey the false impression that the drawings are complete. Most states require that draft drawings or review drawings indicate that they are preliminary and not suitable for construction. Similarly, design drawings for a study, a feasibility design, or a conceptual design do not require certification. Therefore, a large callout, "PRELIMINARY—NOT FOR CONSTRUCTION," is usually added prominently to those drawings.

Shop drawings requiring professional services or work should require certification by the engineer who prepares them. The State of Arizona (2014) provided the following criteria for situations that do not require stamping of shop drawings:

- Sizing and dimensioning information for fabrication purposes;
- Construction techniques or sequences;
- Components with previous approvals, or components designed by the engineer of record; and
- Modifications to existing installations that do not affect the original design parameters and do not require additional computations.

All state boards of registration require engineers to certify their original drawings and to keep duplicate sets of those certified drawings. In the event that changes are made to an electronic version of drawings submitted to a client (see Section 11.4), the original set in the engineer's possession will be used for comparison. Most states allow copies to be made from the certified originals, and wet-ink signatures on the copies are not required if the originals are stamped and wet-ink signed and are in the possession of the engineer of record.

Because policies vary from state to state, the reader should check the requirements of his or her state to ensure strict adherence to state requirements.

12.2 Who Should Certify Drawings?

In general, the engineer responsible for a design should certify its drawings. For the following reasons, however, the engineer in charge might not be easily identifiable in some cases:

- Design projects, whether in the public or private sector, are managed by project managers, who may only be involved with their projects' administrative and financial aspects, but not the detailed design. Some larger projects are also headed by a principal in charge, who serves as the in-house reviewer.
- Most civil design projects, even small to medium–sized projects, involve several disciplines (e.g., geotechnical, structural, electrical, mechanical, and hydraulic engineering). Design within each discipline is frequently headed by a lead engineer of that discipline.

Most states do not have explicit guidelines as to who should certify the drawings for all cases. The most explicit guidelines given by all of the states are that an engineer should not certify professional work outside of his or her area of expertise and that the work that he or she certifies should be performed by him or her or under his or her direction supervision. These guidelines have several important implications:

- An engineer should only certify the portion of the design that is prepared by him or her or under his or her control and direct supervision. Therefore, a project manager who only manages the administrative aspect of the project, but not the technical or design aspect, should not certify the drawings. In addition, because the work is not performed under the direct supervision and control of a reviewer, the technical reviewer should not certify the drawings.
- If a set of construction drawings contains more than one engineering discipline and is prepared under the direct supervision of more than one engineer, then more than one engineer is allowed to certify that set of drawings.

Most states strictly prohibit the practice of *plan stamping*, which involves stamping the work of others with little or no review and with no supervisory role. This practice is illegal and can be grounds for suspension of professional licenses and fines.

In some cases, the engineer responsible for a set of design drawings leaves an organization before certifying his or her drawings, and the organization replaces that former employee with an equally capable and qualified engineer, who will assume responsibility as the engineer of record for that project. In these cases, which are common in the consulting industry, state registration boards allow the new engineer of record to certify the work, provided that he or she reviews all previous design work (including drawings, specifications, design calculations, design methods, and approaches) and, if necessary, changes the design based on his or her review.

Some states (e.g., State of North Dakota 2000) require engineers who perform *pro bono* design work to certify their professional work. The reason is that a professional engineer is responsible for his or her work regardless of the fees for that work. Therefore, the engineer performing pro bono work is as responsible and liable for his or her work as if he or she were being paid. However, some state professional registration boards have the Good Samaritan law, which indemnifies pro bono professional work for certain liabilities. Engineers who intend to perform pro bono work should consult with the board of registration for professional engineers for the state in which he or she intends to perform the work. He or she should also find out the limitations of any Good Samaritan laws within that state. For example, in North Dakota, the Good Samaritan law only applies to emergency situations such as natural disasters.

12.3 Electronic Stamp and Signature

Some engineers allow their professional engineering stamp and signature to be scanned electronically and added to electronic copies of their drawings. This practice is intended to be a time-saving procedure, especially when a set of drawings involves many sheets. When an electronic source file of a drawing with the engineer's seal is submitted to a client, anyone can edit the drawing while the engineer's stamp and signature remain on the edited drawing. As a precaution, most states require that each construction drawing or its cover sheet contains the original wet-ink, dated signature. In addition, when an electronic seal is used, some states require that additional statements be added to the drawings to prove that the engineer authorized the drawing. In spite of some of these precautions, most professional engineering boards recognize digital signatures and seals for signing and sealing documents and construction drawings. In fact, many federal and local government engineering departments have identified digital signatures as the most reliable and secure option, and as the only acceptable, legally enforceable electronic signature.

CHAPTER 13

Design Changes and Record Drawings

13.1 Design Changes

Rarely is a heavy civil construction project completed without some changes during construction. In some cases, it is necessary to change the design during bid solicitation, before construction has even started. One can treat a set of design drawings as a living document that continues to evolve during design, bidding, and construction. Regardless of the amount of changes required, each revision to the design drawings should be documented. Whether they are made during bidding or during construction, design changes are usually associated with changes in construction cost. This chapter discusses common reasons for design changes and their effects on bookkeeping efforts and cost implications.

Design changes made during bid solicitation are incorporated as bid amendments or addenda. Some of the reasons for making changes to the design during bidding are the following:

Schedule considerations—When a construction schedule is tight, an owner sometimes advertises and distributes bid documents to initiate the bid process before the design is finalized, with the understanding that the finalized version can be completed by the time bids are due. This tactic may work in some cases, but is generally risky. Making significant design revisions during bidding is a practice that should be discouraged. Bidders, when presented with amendments with significant design revisions, should be given additional time to evaluate the revisions and adjust their bids accordingly. If no additional time is allowed in the amendments, the bidders will request additional time or will add substantial contingencies to their bids. Therefore, it appears that the original goal of starting the construction on time may not be met using this tactic, depending on how complete the design package is at the beginning of bidding.

Design omissions and errors—When design omissions and/or errors are discovered, whether by the design engineers or by the bidders during bidding, they can be corrected or clarified by amendments.

Value engineering—It is quite common for bidders to suggest changes to the design, usually for their own benefit and advantage. Some owners do not allow value-engineering alternatives during bidding; all the bidders must base their bids on the original design, and alternative value-engineering proposals will be considered by the owners after contract award. However, other owners allow value-engineering alternatives during bidding. The proposed alternatives can be submitted with the bid and evaluated by the engineer during bid evaluation. It is important that the contract documents indicate that the engineer's decision on a value-engineering alternative is final. For uniformity of bidding and comparison of bids, the former approach of not allowing value engineering during bidding is recommended.

Additional design and construction requirements—Because these additional requirements or data are not available during the design period, this reason is almost always related to the schedule. Additional requirements may include owner's permits, temporary easements for construction, and laboratory test data.

Once the bid is awarded, it is best for the owner to issue a revised set of drawings and specifications that incorporates all the changes made to the documents during bidding. This "conformed set" of construction documents should contain the following information:

- All addenda issued during bidding,
- All revisions to the drawings and specifications, and
- A documentation of bidders' questions and the owner's responses to those questions.

The conformed set then becomes the final documents for construction. When significant changes are made during bidding, a conformed set of documents for construction eliminates the confusion that may arise from interpreting a superseded set of drawings and specifications.

Design changes are almost inevitable during construction in most medium to large–sized heavy civil projects because these projects involve subsurface conditions, underground structures, groundwater, and other uncertain site conditions (see Chapter 3). For example, the depth of the foundation may be adjusted for unexpectedly weak subgrade encountered during excavation, or the type of foundation may need to be changed (e.g., from shallow foundation to deep foundation) if a competent subgrade is not encountered during excavation.

Most design changes are associated with changes in cost, and sometimes schedule. When a design change is made during bidding, bidders adjust their bids accordingly. When a design change is made during construction, the changes in cost and performance period depend on the nature of the changes and provisions in the general conditions and supplemental conditions allowing for changes.

When a drawing is revised during design, bidding, or construction, it is the engineer's responsibility to properly document the changes. Any time a drawing is altered, a new version or revision should be designated and issued for that drawing. The version number or revision number is shown in the title block of a drawing (see Section 5.2). Different engineers have different ways to designate revisions, and all of them are acceptable, as long as the version used is consistent for the entire project. The numbering (1, 2, 3, etc.) and lettering (A, B, C, etc.) systems are used commonly. It is important to point out that—because drawings not affected by design or field changes do not need to be revised—drawings from the same set can carry different revision numbers. When a drawing is revised, a short, abbreviated explanation should be used in the revision block of the title block to accompany the revision number (Fig. 13-1).

It is customary for designers to use a "cloud" symbol around design features in the drawings that are affected by the change. A triangle with the revision number is placed adjacent to the cloud symbol. This practice is acceptable when the added symbols do not overly complicate the graphics of the drawings. When significant revisions are made in a drawing, it is recommended that the cloud-and-triangle symbol system be omitted for the sake of simplicity. Instead, the revisions can be replaced with notes describing the changes in affected drawings. More elaborate descriptions of the design changes can be documented with a technical memorandum or a letter.

13.2 Record Drawings

Record drawings are drawings issued after construction of a project is complete. The term *as-built* (formerly used to describe these drawings) is less desirable from a professional liability standpoint because it implies that the drawings represent the exact configuration of all constructed features. When an engineer does not have a full-time inspector on site during construction, it is impossible for the engineer of record to certify that everything shown on the plans and specifications has been installed in accordance with approved plans and specifications. In fact, even when the engineer has full-time involvement during construction, it is still not possible to claim that everything shown in the plans and specifications has been installed. Because of this difficulty and uncertainty, the term *record drawings* is preferable because it implies that the drawings thus prepared are based on the engineer's observations and records on file during construction.

Record drawings should show the changes made in the design during bidding and construction. These records are typically maintained by the engineer. Some owners require the contractor to maintain a set of marked-up drawings (*redline drawings*) on site during construction, showing all current changes made to the design to date. At the end of construction, the contractor is required to submit

Revision No.	*Description*
2	Bid Amendment No. 1
3	Change Alignment and Inverts of 18-inch Pipe

Fig. 13-1. Sample of Tracking Revisions in Title Block

the redline drawings as part of the closeout documents. The engineer then prepares the record drawings based on the redline set and all of the construction records in his or her file. The complete record drawings set should be assigned a new revision number with the designation “Record Drawings” in the revision block.

PART 3

Technical Specifications

CHAPTER 14

Specifications for Heavy Civil Construction

14.1 Role of Technical Specifications

Technical specifications are written instructions and requirements that accompany construction drawings. The term *specifications* is used interchangeably with *technical specifications*. Used together, the specifications and drawings comprise all of the technical construction requirements to complete a project. Specifications are generally used for qualitative requirements, and drawings are generally used for quantitative requirements. They are part of the contract documents. As such, they carry certain legal implications. As discussed later, specifications and drawings should not contain duplicate information; however, in the event of a conflict between drawings and specifications, the provisions of the specifications usually take precedence. Therefore, the preparation of specifications should receive as much attention as that of drawings.

In general, specifications contain all necessary information that is not shown in the drawings. Specifically, specifications for a heavy civil design project contain the following information:

1. Detailed material requirements, including quality standards;
2. Testing requirements for quality control and quality assurance;
3. Procedures for installation or placement of material and equipment, including tolerances;
4. Schedules or lists of material or equipment otherwise not shown in the drawings;
5. Coordination of work among different trades and disciplines, including restrictions, conflicts, and limitations;
6. Submittal and schedule requirements;
7. Construction sequence and restrictions;
8. Measurement and payment provisions for all work items;
9. Miscellaneous general requirements (e.g., environmental abatement, temporary facilities, and waste disposal) that cannot be depicted in the drawings;

10. Permits obtained by the owner;
11. Reference data such as climatic data, streamflow records, field and laboratory test data, and records of existing sites and facilities;
12. Coordination with other contractors on site; and
13. Safety issues and responsibilities.

14.2 Users of Specifications

For the most part, specifications are written for the constructor (contractor) and his or her subcontractors, fabricators, and material and equipment suppliers. The other two parties in a construction project (the owner and the engineer) also use the specifications. The following is a description of how these three parties use the specifications.

Contractor—A contractor uses specifications when he or she expresses an interest to bid on a project. Based on the scope of work required in the specifications, the general contractor assembles a team of subcontractors, material suppliers, and equipment manufacturers. The first user within the contractor's organization is the cost estimator, who is responsible for bid preparation. In preparing his or her bid, the cost estimator uses the material and equipment requirements to obtain quotes and determines what contingencies to put in the bid for uncertain and risky factors. The contractor also determines what labor categories and construction equipment are suitable for the project and arrives at the costs for labor and for equipment and operation.

It is, of course, during construction that the construction crew uses the specifications. In the contractor's office, the manager prepares the required submittals (e.g., material test data or shop drawings), orders the material and equipment, schedules the required crew and equipment, and handles progress payments. In the field, the superintendent directs his or her crews, and sometimes his or her quality control testing personnel (which depends on contractual arrangements), and receives material and equipment delivered to the site. He or she interacts with the resident engineer of the owner on daily work progress, schedule issues, challenges and solutions, quality control, and test results. Compliance with permit requirements in the specifications is also the responsibility of the contractor.

Material suppliers and equipment manufacturers or distributors furnish products based on the specifications. Compliance with the material specifications is usually handled through the submittal process and testing.

Owner—There are several reasons that an owner is interested in the contents of the specifications. The first reason is that an owner needs to know what he or she is buying for the money that he or she is spending. During construction, the owner makes regular progress payments to the contractor based on the payment schedule and measurement and payment clauses in the specifications. Secondly, an owner may have certain preferences (e.g., for a brand name with good past performance or consistency with the spare parts inventory) regarding products or end results. Thirdly, for future operation and maintenance of the new facility, an owner will need a record of what is being built.

Engineer—Typically during construction, the owner hires an engineer (usually the designer) and a construction manager. This arrangement is frequently used in private-sector construction. Some large government agencies, such as the U.S. Department of the Interior's Bureau of Reclamation and the U.S. Army Corps of Engineers, have their own engineering and construction management teams, while other government agencies, such as the U.S. Fish and Wildlife Service and the National Park Service, hire the design engineer to perform certain technical tasks only. Regardless of the contractual arrangement, the resident engineer has the responsibility of overseeing enforcement of the specifications during construction. He or she interacts with the contractor superintendent and foremen, directs his or her field inspectors and quality assurance testing personnel, communicates with the designer, checks the material and equipment delivered to the site, and verifies permit compliance. It is important to consider the resident engineer's authoritative limitations. He or she does not have the authority to direct the contractor. For unacceptable work, the resident engineer should inform the owner, who is then responsible for notifying the contractor to fix the problems and to comply with the specifications.

14.3 Coordination with General and Supplemental Conditions

The general conditions and supplemental conditions define the duties and responsibilities of the owner, the engineer, and the contractor regarding all contractual issues (e.g., administration, technical issues, bonds and insurance, payment, dispute resolution, deliverables, and submittals). Technical issues referenced in general and supplemental conditions are handled differently from document to document and from owner to owner. The general conditions by the Engineers Joint Contract Documents Committee (2013), for example, define the guidelines for items related to technical specifications as follows:

- Reference to standard specifications [such as the American Society for Testing and Materials (ASTM) and the American National Standards Institute (ANSI)] and specifications of technical societies [such as the American Concrete Institute (ACI) and the American Water Works Association (AWWA)]—The appropriate version of these standards is defined, and guidelines are provided to resolve conflicts between these reference specifications and the contract specifications.

- Definitions of the contract parties referenced in the specifications—These parties include the owner, engineer, contractor, subcontractor, supplier, and manufacturer.
- Meanings of certain terms used in the specifications that are open to interpretation. These terms include *as directed, as allowed, to the satisfaction of,* and *acceptable to.*
- Definition of changed conditions.
- Contractor's responsibilities on safety and his or her labor, equipment, and materials.
- Handling of substitutes and items pertaining to *or equal* provisions.
- Conditions of the site and site cleanliness.
- Submittal procedure and handling of shop drawings.
- Owner or engineer's testing and inspection.
- Protocol on rejecting, correcting, and accepting defective work.
- Warranties.

Because the general and supplemental conditions contain so many references to technical specifications and drawings, it is important that the specification writer is thoroughly familiar with these contract documents so that the technical provisions are consistent with these documents. It is vital that a knowledgeable design reviewer checks all cross-references between documents.

14.4 Coordination with Drawings

Specifications and drawings work hand in hand. These two documents complement each other and fit together with no overlaps and no gaps. There are numerous discussions and examples throughout this book regarding the interrelationship between drawings and specifications. Some general correlations between specifications and drawings are listed below.

Consistent terminology should be used in specifications and drawings. Inconsistent terminology between the two documents results in confusion, errors in construction, disputes in acceptance of work and payment, changed conditions, and claims. Some examples of inconsistent terms used in drawings and specifications are the following:

- *Material types and classifications.* In earthwork, when a material called *random fill* is used in the drawings, the same term should be used in the specifications. That term should not be called *compacted fill, fill, backfill,* or other names in the specifications. This distinction is particularly important in a large earthwork project, where many different fill materials are required. Each fill material should have a separate designation, such as *general fill, random fill, embankment fill, structural fill,* and *select fill.* In concrete work, when a material called *backfill concrete* is used in the drawings, that term should not be called *mass concrete* or *lean concrete* in the specifications. In mechanical work, a *sluice gate* shown in the drawings should not be called a *slide gate* in the specifications because these two types of gates have some significant differences in quality and performance.

- *Facility and project feature components.* When a *ditch* is shown in the drawings, the specifications should not refer to this feature as a *trench.* When a *cofferdam* is called out in the drawings, this feature should not be referred to as a *protection barrier* or *enclosure* in the specifications. When a *spillway* is shown in the drawings, that feature should not be called a *sluiceway* or *outlet* in the specifications. When a *chamber* is used in the drawings, that feature should not be referred to as a *vault* or *adit* in the specifications.

There should be no duplication of information in the drawings and specifications. Strictly speaking, there is no harm in duplicating exact, consistent information in both documents. However, this practice may result in problems when that information is changed during design, bidding, and/or construction. Unless identical changes are made in both documents, conflicts and discrepancies will be the result.

Specifications are used to give a detailed description of material and equipment, and that function should not be repeated in the drawings. It is a good practice to call out material or equipment in the drawings by names or designations, but reserve the specifications for its full details. This practice avoids excessively long callouts or notes in the drawings (see Section 8.3) while allowing the written format of the construction documents to describe the required quality and performance. Some examples are given here:

- *Subgrade preparation.* When subgrade preparation is needed below a structure, the drawing should only show the limits, while other preparation requirements can be handled by calling out "SUBGRADE PREPARATION, SEE SPECIFICATIONS." In the specifications, subgrade preparation requirements of depth of scarification (breaking up of soil surface), moisture conditioning, proof-testing, and compaction can be described in detail.
- *Construction joint.* When a construction joint is needed in a cast-in-place concrete structure, the drawings should only show "C.J.," which is a commonly used abbreviation for construction joint. In the general notes of the drawings, a reference to the specifications can be used for all construction joints. In the specifications, construction joint requirements of cleaning, sand-blasting, high-pressure water jetting, and criteria of acceptance can be described in detail.

Specifications can be used as an extension of the drawing features that require excessive amounts of text descriptions. Drawing features with excessive amounts of text include schedules of materials or equipment and notes. From a production standpoint, it is much faster to produce or change these schedules and long notes with word processing software than with CAD software.

The timing of specifications preparation during design is important in obtaining a high-quality design product. In the production of construction documents, it is common for designers to start with drawings, which require a significant amount of the design effort. On the contrary, specifications preparation is usually relegated near the end of the design process, as if the document is an afterthought. Some of the reasons that designers give for this tendency are the following:

- Specifications cannot be completed until most of the drawing features are identified and drawn.
- Writing specifications is a necessary chore, and given a choice, a designer would rather engage in a more pleasant activity, such as drawing preparation.
- There are limited design resources in the organization, and specification writing is given less priority than drawing preparation.

Specifications that are prepared in a hasty manner contain errors, omissions, discrepancies, and inaccuracies that affect bid prices, result in serious construction problems, and may result in claims. Numerous court cases demonstrate that when a conflict arises between drawings and specifications, the court usually rules favorably toward the specifications (Fisk 1992). According to Federal Acquisition Regulations (FAR), which are used for all federal construction, the preference for specifications over drawings is standard. So, regardless of how perfect the drawings are, a defective set of specifications accompanying these drawings will cause serious problems on a project.

In an ideal situation, specifications should be prepared concurrent with drawing production. However, there are practical limitations within the design industry—availability of workers, schedule constraints, and budget constraints—that make it difficult to achieve this goal. Rather, the following compromise approach is suggested (see Table 2-1):

1. Using project and design requirements as a basis, establish a draft bid schedule early in the project, such as at the 30% completion stage.
2. Prepare a preliminary list of drawings at the start of the project.
3. Prepare a list of probable technical specification sections at the 30% completion stage.
4. Start detailed specification preparation when the drawing production is 60% complete. At this stage, all of the design features, materials, equipment, and other project requirements should have been identified, thus allowing detailed specifications to be developed.

When referencing drawings in the specifications, the specification writer should resist referring to detailed locations of the drawings (e.g., "AS SHOWN ON

SECTION A OF SHEET 7" or "AS SHOWN IN DETAIL 6 OF SHEET 10"). Drawing sheet numbers and section and detail designations and locations frequently are changed and moved during the course of drawing production. Therefore, a constant updating effort will be required in the specifications, which is almost impossible for a medium to large–sized project. The suggested practice in referring to drawings is to state simply "AS SHOWN IN THE DRAWINGS." It is then the responsibility of the contractor to locate the feature in the drawings.

CHAPTER 15

Technical and Design Issues

15.1 The Specification Writer

This section addresses the question: Who should write the specifications? For this discussion, the person who prepares the specifications is called the *specifier*. Traditionally, technical specifications are prepared by workers in the following personnel categories:

1. Design engineers who are also involved with engineering analysis of the project and production of the construction drawings. Depending on the different disciplines for a particular project, more than one engineer may be involved.
2. In-house specification writers whose sole responsibility is to prepare specifications. These are professionals who have certain basic training and experience in writing specifications, but who are usually not involved directly in the analysis and production of construction drawings. They may or may not be engineers. This approach is usually used in large engineering firms or large government agencies such as the U.S. Army Corps of Engineers or the Bureau of Reclamation.
3. Specification writers contracted from outside the engineering firm. The qualifications and experience of these outside specifiers can be assumed to be equal to, or better than, those of the in-house specifiers.
4. Staff engineers who have no previous involvement with the project or have little experience in specification writing, but are assigned this task because they are available and are lower paid staff.

The best specifier for heavy civil design projects should fit into Category 1. Design engineers understand the technical requirements and design intent for projects, are familiar with site conditions and site constraints, and coordinate well with construction drawings because they are involved directly with production. It is important that specifiers work within their areas of expertise. In fact, all state boards of registration for professional engineers (see discussion in Chapter 12) mandate this requirement. For example, specifications on excavation, dewatering, and earthwork should be prepared or supervised by geotechnical engineers, and specifications on structural concrete and fabricated steel should be prepared by structural engineers. Another important qualification for an engineering specifier is field experience. A specifier with little or no field experience, no matter how technically qualified, is likely to produce specifications that do not coordinate well with the construction drawings and may not be constructable or may be so difficult to construct that the cost will increase. Lack of field experience in construction specifiers is one of the most common complaints from contractors.

In large organizations, especially for large projects, technical specifications are prepared by in-house professional specifiers who fit into Category 2. This arrangement has been used successfully for many years. Some of these specifiers do not have engineering training, but most of them have vast construction experience, either as contractors or construction managers. Some of them are certified by professional organizations, such as the Construction Specifications Institute. Assuming that these in-house specifiers are qualified to prepare specifications, the success of producing a set of well-prepared project specifications should include the following work on the part of the specifiers:

- A visit to the project site to become familiar with site conditions and site constraints;
- Meetings with lead design engineers to gain an understanding of design criteria, design intents, and testing requirements;
- A review of partially completed or almost completed construction drawings;
- A review and understanding of the basis of the bid schedule;
- Obtaining from the design engineers a list of materials, product data, or material sources; and
- Agreeing on terminology and product names to be used in the drawings and specifications.

The main advantage of using in-house professional specifiers is that the design engineers can continue to focus on design analysis, design drawing production, and design report preparation. This in-house resource, when properly used, is a valuable asset in a design-oriented organization.

The considerations for using outside professional specifiers who fit into Category 3 are similar to those for in-house specifiers, except that they are usually brought in near completion of the project. When the schedule of producing the specifications becomes critical, there is a tendency on the part of the designers to overlook and omit some of the information available to the specifiers. Therefore, it is up to the specifiers to request additional information during the production process. When adequate time is available and the budget allows for it, engaging outside professional specifiers should achieve similar success as using in-house specifiers.

Using specifiers who fit into Category 4 should be avoided. In the long run, the cost of producing a set of well-prepared specifications is likely to increase because of significant changes required during the review process. In the worst-case scenario, errors in the specifications will not be detected until construction, resulting in cost overruns, claims, and disputes.

The American Society of Civil Engineers Construction Division Committee on Specifications conducted a questionnaire survey of more than 600 private owners; design professionals; and municipal, state, and federal agencies regarding various topics related to specifications (ASCE 1979). One of the questions—What minimum qualifications should a specifications engineer possess?—is relevant in this discussion. The following is a list of qualifications provided by the respondents, in order of decreasing importance:

- Field (construction experience), frequently expressed in the 5-year to 10-year range, with a few suggesting resident engineer experience;
- Engineering degree;
- Professional registration;
- Design experience;
- Design and field (construction) experience;
- Technical writing ability;
- Prior knowledge or understanding of the project;
- Legal understanding, knowledge, or education;
- Knowledge of materials and their availability;
- Fluency in English and ability to communicate;
- Specification writing experience;
- Two years of college education;
- Common sense;
- Knowledge of the Construction Specifications Institute;
- Formal training in specification preparation;
- Project manager;
- Master's degree;
- Familiarity with state standards or local codes;
- Maintenance experience;
- Research ability;
- High school graduate; and
- Principal of firm.

It is interesting that the "principal of firm" is listed dead last, behind "high school graduate." From the perception of owners, the principal of a firm is the person least qualified to write technical specifications. Some of this perception is unfounded, as some principals are well qualified with sound field and design experience and technical backgrounds.

15.2 Problem Areas

What are the so-called "bad specifications"? In general, specifications are problematic if the contents of this document are responsible for the following design and construction problems:

- Significant changes in the design features or scope of construction;
- Significant increase in project budget as a result of changed conditions, unforeseen conditions, construction delays, disputes, claims, and litigation; and
- Frequent needs for requests for information (RFIs) from the contractor.

The main goal in good specification writing is not to produce a perfect construction document, which is impossible to achieve even by the most experienced specifier. Rather, the goal is to avoid the problems listed above, so that a project is completed as originally designed, on time, and within the owner's budget. This chapter first identifies what most of the problem areas are, and the remainder of this chapter and Chapter 16 discuss how to mitigate these problems.

The next sections make up a list of potential key problem areas.

Technical Inaccuracy

One of the most difficult design problems to resolve during construction is when the specifications contain inaccurate technical data or deficiencies in product performance. The sources of this problem may not be evident without some investigation on the nature of the inaccuracy. When a design engineer makes an error in analysis or design, inappropriate material ends up in the specifications or an inaccurate design feature ends up in the drawings. Deficiencies in product performance can result from design error or from a defective product. Some of these problems are not manifested until after construction, when the new product or material is put into use or when the facility has been operating for some time.

Examples of technical inaccuracy in the specifications include the following:

- A design engineer makes an error in selecting the thickness or type of a pipe, and the pipe ultimately deforms excessively under the design load.
- A design engineer makes an error on the gradation of a sand and gravel filter, and the filter ultimately fails and leads to loss of fines and inadequate hydraulic capacity.
- A geotechnical engineer does not adequately characterize the foundation of a site during investigations, resulting in extra cost in foundation dewatering and temporary foundation support during excavation.
- A Type I cement is specified for a cast-in-place concrete structure below grade, even though laboratory testing indicates that the foundation soil is prone to severe sulfate attacks. A Type II or Type V cement should have been specified.

- An aluminum handrail is bolted directly to a steel-frame decking, resulting in serious cathodic corrosion problems.
- A new product or new construction technology is specified, and the performance does not meet the advertised expectations.

Product Substitution

One of the most controversial problems in construction is related to product substitution provisions. Specifically, the controversy is on the interpretation of one of the many versions in product specifications, such as “or equal,” “or approved equal,” and “or approved equivalent.” In federal construction projects, proprietary specifications (see Section 17.7) cannot be used unless they are followed by “or approved equal,” or some such allowance to encourage fair competition. When a product is specified with one or more brand names plus a provision to allow the contractor to substitute an equal product, the contractor is given a choice. The problem arises when the contractor’s choice and the engineer’s design intent are different. The controversy continues to be a problem, in spite of the fact that all contract documents contain explicit guidelines regarding product substitution.

Disputes on product substitution that involve “or equal” provisions are based on the following circumstances:

- During bidding, a bid is based on a substituted product that is later rejected by the engineer.
- During construction, a specified product with a particular name is no longer available, and the contractor and engineer cannot agree on an equivalent product for substitution.

Mitigation of this problem area is discussed in Section 15.6.

Ambiguities and Conflicts

During construction, ambiguities and conflicts in the specifications may cause disputes between the contractor and the engineer. An ambiguous specification requirement has more than one meaning and interpretation. Examples of ambiguous language include the following:

- “The minimum thickness of the fill shall be 12 inches.”—The contractor placed 18 in. of fill, which met the specifications, but the owner only intended to pay the contractor for 12 in. of fill.
- “The Contractor shall submit rebar shop drawings to the Engineer for review and acceptance at least 10 days before forming the structure.”—The contractor interpreted that 10-day period as 10 calendar days, when the engineer’s intent

is 10 working days (which is two weeks), resulting in a difference of four days in the submittal schedule.
- "The Contractor shall dispose of all waste materials off site."—The engineer considers excavated earth materials to be included as waste materials, but the contractor does not, and the contractor demands additional compensation to haul the excavated earth materials off site.

In litigation on ambiguous specifications, courts have interpreted strongly against the party that prepares the specifications—that is, the engineer. Therefore, the burden of avoiding ambiguous language and requirements is on the engineer.

Conflicts arise when there is a discrepancy between the drawings and specifications on the same requirement or a discrepancy in the specifications for the same requirement. Examples of conflicts in the specifications include the following:

- A pipe flange is called out with a pressure rating of 150 lb per square inch (psi) in the drawings. In the specifications, a standard American Water Works Association reference specification is specified (AWWA C207, Class E), which has a pressure rating of 275 psi.
- A 10-ft-high temporary excavated slope in sandy soil is shown with an inclination of 0.5H:1V (horizontal:vertical) in the drawings, and the contractor is also required to comply with OSHA safety requirements. According to OSHA excavation regulations, the slope shown in the drawings is too steep for that type of material.
- A concrete mix is specified using the descriptive approach (see Section 17.2), i.e., all mix proportions are specified, while requiring the slump to a high enough consistency that can be pumped. The contractor furnishes the concrete as specified, but the consistency is too stiff for pumping.

When there is a conflict, several outcomes are possible:

- The contractor requests a clarification from the engineer, and the engineer provides the contractor with the proper clarification, which may have cost implications.
- The contractor deliberately makes an interpretation on his or her own that is to his or her best interest (i.e., at the lowest cost to him or her).
- Both the engineer and the contractor are unaware of the conflict, and an unintended error is made in the construction.

Recommendations to mitigate ambiguities and conflicts by avoiding repetition are discussed in Section 16.2.

Constructability

Constructability is the ability to complete construction work with a specified end result using customary industry means and methods. Unconstructable design is a direct result of inexperienced designers and unqualified specifiers who lack adequate construction field experience. Examples of unconstructable design include the following:

- Tolerances that are too strict to be practical—It is not reasonable to specify tolerance for earthwork grading or for laying a drainpipe to within 0.01 ft. Earthwork tolerance is generally limited to within 0.1 ft.
- A no-tolerance approach to field quality control is used, particularly on earthwork—It is difficult to expect a contractor to adhere to 100% compliance on earthwork (e.g., regarding compacted density and in-place moisture content). This unreasonable tolerance is one of the major contractor complaints.
- A compacted fill, placed in 12-in. lifts, is required directly above a soft clayey foundation—Even with low-pressure equipment, the contractor cannot be expected to compact the fill adequately because of the soft subgrade.
- A tunnel-boring machine (TBM) is specified for constructing a tunnel along an alignment that is known to contain shear zones, clay gouge, and breccia zones—Because of concerns that the TBM will be frequently stuck in the bore with frequent downtime and loss production, the contractor chooses another method of tunnel excavation. In the worst case, the TBM can be permanently lost in the bore and cannot be retrieved.

Constructability problems may also be caused by inadequate investigation or testing during design by the engineer in situations where the end results are specified, but the contractor is responsible for the means and methods to achieve those results. Consider the following two examples:

- Testing of a riprap borrow source—A large rock outcrop is specified as a source for riprap for the upstream slope of a new embankment dam. During design, the engineer performed geologic reconnaissance, rock coring, and laboratory testing, but did not perform a test blast program. During construction, the contractor was not successful in producing the riprap stones that meet the specified requirements of gradation range and shapes because of the rock types and fracture patterns in the rock mass. Ultimately, this borrow source was abandoned, and the riprap was imported from off-site commercial sources, resulting in a significant increase in cost. This problem would have been discovered if a test blast program had been performed during design; the on-site rock outcrop should not be designated as the primary source of the riprap.
- Testing of posttensioned anchors in a clay shale—The engineer specifies high-capacity posttensioned anchors to stabilize a high concrete wall in a clay shale foundation. A *clay shale* is a Cretaceous-age highly plastic sedimentary rock, such as Bearpaw shale, Fort Union shale, and Mancos shale, which are prevalent in the western United States. Typically, the engineer is responsible for the design of

the unbonded lengths of the anchors, and the contractor is responsible for the design of the drill hole diameter and bonded lengths of the anchors. During construction, the performance of the contractor design will be verified with proof-testing and performance testing. During design, the engineer performed core drilling and laboratory strength testing of the clay shale, but did not perform a full-scale test anchor program. During construction, the contractor was unable to meet the specified capacities of the anchors because the bond stress between the anchor grout and the rock is not controlled by the shear strength of the foundation; rather the bond stress is controlled by creep phenomena, which would have been revealed in the test anchors. Ultimately, a much lower bond stress is used for the design, and significantly more anchors are required, resulting in a significant increase in cost.

Unenforceable Requirements

Whether it is intentional or not, some specifications contain provisions and requirements that cannot be enforced during construction. Most of these provisions are called *open targets* that are essentially unbiddable. Examples of unenforceable requirements include the following:

- "As directed by the Engineer, to the satisfaction of the Engineer, as determined by the Engineer"—Without acceptance criteria or provisions to compensate the contractor, the amount of work required to satisfy the engineer is unknown and is therefore subject to dispute.
- "The Contractor shall provide cofferdams, pipes, pump, etc., for proper diversion of streamflows away from the construction site."—There are two open targets here: the words "etc." and "proper." The contractor understands that he or she needs to provide cofferdams, pipes, and pumps to divert streamflow, but does not know the level of flood protection because the size of the flood is not specified. Therefore, this provision is unbiddable. The term "proper" is subjective. What is considered proper to the contractor may not be considered proper to the engineer or to the owner. In fact, other subjective terms such as "good," "workmanlike," "adequate," and "enough" should also be avoided for similar reasons.

Avoidance of unenforceable requirements through good specification writing is discussed in Sections 15.9 and 16.2.

Inadequate Attention to Specification Production

The production of technical specifications for a project typically occurs near the end of the project, and not enough attention is given to its production (see also Section 14.4). Whatever the reason for this common practice—whether it is a resource issue, project budget issue, or sequence of construction document production—the lack of proper attention in preparing a set of well-written specifications may result in a host of problems. Some designers are anxious and enthusiastic in preparing construction drawings, but do not look forward to working on specifications. It is ironic that the document that receives inadequate attention during design receives precedence over the drawings in the event of a conflict. It is well known that courts generally rule favorably toward typed documents (i.e., specifications) over printed documents (i.e., drawings). With so much at stake for successful completion of a construction project, the design profession should at least give the same priority to specification preparation as to construction drawings and analytical work.

15.3 Philosophical Design Approach

This section presents a general design approach that has worked well in developing technical specifications for heavy civil construction projects. This approach bears some resemblance to the *partnering concept* that has been promoted by others, especially in public-sector work. It involves the disclosure of information in the construction documents, the sharing of risks among the parties, and fair treatment of the contractor, while protecting the best interests of the engineer's client—that is, the owner. But why does a design engineer need to adopt a philosophical design approach? Wouldn't technical design criteria and design assumptions be sufficient to meet the project goals and objectives? The recommended design approach is the guiding attitude toward the roles and responsibilities of the owner, engineer, and contractor, regardless of what the project goals, objectives, size, and complexity are. It encompasses the following:

- The three parties in a construction project—the owner, the engineer, and the contractor—are on the same team working toward building the project that is financed by the owner. Excluding the design-build arrangement, the engineer and the contractor have separate contractual agreements with the owner, each with unique team roles and responsibilities. Being on the same team mandates teamwork, honesty, and fairness among the team members. Whereas the legal and contractual arrangements between the owner and the contractor are contained in the construction contract, the engineer has the opportunity during design to assist the contractor by providing all the technical information he or she needs to build it. If there are still unknowns when a design project goes into construction, the engineer should disclose these unknowns and their associated risks to the owner and to the contractor, as well as how to resolve them both technically and financially. Most claims, disputes, and litigation in a construction project are caused by the inability of the three parties to work together, especially being fair to one another.

- The main role and responsibility of the engineer is to design and to resolve technical issues. To the extent possible, the engineer should resolve all design issues during the design phase and should not expect the contractor to complete the design during construction. The exception, of course, is in the case of performance specifications (see Section 17.3), when the contractor will provide the design to meet the specified design criteria and performance.
- The engineer should not treat the contractor as a potential adversary, as if he or she is trying to take advantage of the owner at every possible opportunity. Rather, the engineer should focus on providing clear and workable instructions to the contractor in the form of construction drawings and technical specifications, and then let the contractor build it. Dealing with poor construction and unqualified contractors is a totally different matter.
- Most construction claims and disputes revolve around financial compensation to the contractor, which is why it is important for the engineer to prepare clear and fair measurement and payment provisions in the specifications. Construction is a business, and the contractor is entitled to a fair and equitable profit for the work he or she performs. The engineer should not deliberately expose the contractor to unnecessary financial risk, and every effort should be made to compensate the contractor for all work within the scope of the contract.

The following is a detailed discussion of the main guiding philosophy for this approach:

Loss Prevention

Next to preserving public health and safety, one of the main responsibilities of a civil engineer is to protect and guard against losses to his or her professional license to practice and/or losses to his or her employer during performance of the work. There are numerous guidelines from professional societies and policies of engineering companies on loss prevention to limit professional liabilities in almost every engineering discipline, but none is more important than loss prevention in heavy civil construction work. Among the uncertainties and risks in heavy civil construction is the competence of the contractor, in the same way that the competence of the engineer affects the quality of the engineering design. Behind many successful construction projects are many competent contractors and good designs; likewise, behind many problematic construction projects are many incompetent and unqualified contractors and poor designs. In spite of some of the innovative procurement methods to select a qualified contractor (see Section 2.4), there is a chance that an owner may end up with a poorly qualified contractor in a competitive bidding situation. This is not to say that the lowest bidder is necessarily an incompetent contractor. However, because of this possibility, the main goal of the design engineer is to prepare a design that can be completed successfully even by a problematic contractor. When one assumes that a problematic contractor may be involved with the construction, there are certain loss-prevention measures that the designer should use during design to minimize liability exposure:

- There can be no obvious flaws in the specifications that the contractor can use as justification for claims. This step requires considerable experience in specification writing. There should be no technical inaccuracies (see Section 15.2). No ambiguous language should be used that will allow the contractor to take liberties in his or her own interpretation. There should be no conflicts within the documents (specifications and drawings) that the contractor can use to his or her advantage.
- Clearly spell out the duties and responsibilities of the contractor, such as submittal contents and schedule, quality control testing and frequency of testing, utility clearance, progress meetings, all safety issues, and progress payment requests.
- State all minimum qualifications and experience for specialty construction, such as rock blasting, posttensioned anchors, roller-compacted concrete, and foundation improvement. This protects the owner from getting inexperienced contractors and subcontractors that get the job through low bid.
- Use the submittal process to check the contractor's means and methods for difficult construction, such as dewatering of a permeable foundation, or braced excavation in a deep cut in soft ground that is adjacent to buildings that need to be protected. The submittal should clearly list the method, sequence, materials, and equipment that demonstrate to the engineer that the work can be performed safely while meeting the requirements in the specifications. The submittal process allows a direct dialogue between the designer and the contractor before the construction starts to address as many of the anticipated problems and concerns as possible ahead of time. Sometimes the submittal process many require several iterations in the case of an inexperienced contractor before all the issues are addressed and the engineer is satisfied.

The precautions listed here are nothing more than what the owner normally expects from the design engineer in preparing a good set of specifications. By maintaining this defensive approach throughout the preparation of design documents, the designer can guard against potential problems that could manifest themselves during construction.

In spite of the defensive design approach against potentially poor contractors, there is great integrity, professionalism, and expertise among most construction contractors, who frequently have to deal with difficult working conditions and risks to complete the work. A designer can learn a great deal from competent contractors, and the design profession should value contractors as a great resource for design and construction issues.

Sharing the Risk

Another one of the engineer's responsibilities is to protect the interest of his or her client, usually the owner. In heavy civil construction, there are many times when the engineer and the contractor have to deal with unknown conditions, such as inclement weather, differing geology and foundation conditions, groundwater inflows, surface runoffs and flooding, and stream diversion. One apparent way to protect the owner in these situations is to shift all the risk to the contractor, as in the following specifications:

> The Contractor shall provide whatever is deemed necessary for cofferdam protection, stream diversion, and dewatering so that all construction along the stream channel is performed in the dry. Damages to permanent construction caused by flooding shall be repaired at no additional cost to the Owner. It shall be the responsibility of the Contractor to determine the height of the cofferdam and size of the diversion facilities for his or her protection.

In this particular example, the unspecified requirement is the level of flood protection during construction. A bidder can bid no protection, or a bidder can bid protection for a 10-year storm. Even when the engineer provides the bidders with historical streamflow records and seasonal precipitation records, there is still considerable risk for the contractor to work in the stream channel. Bidding on unknown conditions and risky situations is difficult, and, as part of the bidding strategy, potential claims may have been prepared already by bidders. In general, unknown factors increase construction costs. If the increased costs are not manifested in the initial bid, they will most likely be manifested in change orders and claims during construction. Contractors are known to take risks, and some accept more risk than others. There is undoubtedly a cost difference in favor of the contractor who takes more risk, but the owner is ultimately at risk if a flood destroys the work during construction.

It is unfair for the contractor to assume all of the risk for unknown or unanticipated conditions. The owner should share appropriate risk with the contractor, whom the owner hires to help build his or her project. When an owner agrees to share risk, the contractor feels that he or she is being treated fairly and that he or she is included as a partner in the team. It promotes a mutually acceptable working relationship between the owner and the contractor, and also between the contractor and the engineer during construction.

Both sharing the risk and treating the contractor fairly require compensating the contractor for the costs and losses he or she experiences as a result of unpredictable conditions. To handle unknown situations during bidding, the bid documents can ask the bidders to put aside cost allowances, or some other uniform basis can be specified for bidding. In addition, the specifications should also allow the contractor to recuperate losses for documented unanticipated conditions through a negotiation process. When bidders enter their bids with the understanding that they will not need to absorb unnecessary losses, there will be fewer risk costs, and the bids will be more uniform and consistent. When a contractor starts construction with the understanding that he or she will be protected from losses caused by unknown situations, there will be less adversarial confrontation and more cooperation during construction.

For the example given above, the specifications can be rewritten to provide a more uniform basis for bidding and an avenue to compensate the contractor:

> The Contractor shall provide temporary cofferdam protection and stream diversion for construction in the stream channel. The required level of protection is elevation 362.0 feet. Temporary protection shall be earthfill cofferdams, sheet piles, bulkheads, or other approved water-retention barriers to prevent flooding of the new structure during construction. The Contractor shall provide a temporary diversion conduit with a shutoff valve under the cofferdam to drain the work area after flooding. Design and sizing of the conduit and valve shall be the responsibility of the Contractor.
>
> Damages to the permanent construction and temporary protection facilities caused by inadequate protection below elevation 362.0 feet shall be the responsibility of the Contractor. The Owner will negotiate with the Contractor in accordance with provisions in the contract documents to compensate for damages for floods that overtop the cofferdam above elevation 362.0 feet.

In the rewritten specifications, the owner and the contractor share the risk of flood protection. The engineer estimates that El. 362.0 ft is an acceptable level of protection for this construction, based on the duration of the construction work, and all bids for flood protection will be based on this level of protection. In fact, a bidder that provides no flood protection will be ruled nonresponsive and thus cannot use this tactic for cost advantage. Instead of specifying the frequency of the storm for flood protection, such as a 10-year storm, the engineer specifies a specific floodwater elevation, thus eliminating a common controversy on what sized storm actually occurred during the construction. When the bidders realize that they do not need to put aside any risk cost for large storms, the bids become more uniform, and the contractor's responsibilities are more clearly defined.

Fairness to All Parties

A fair specification treats all parties on the same basis. Each party has a certain responsible role, whether it is financial, design, testing, or construction. As designers, the engineer should take a lead technical role to provide the owner with the most cost-effective product that meets the project requirements. To the maximum extent possible, all of the design decisions and technical decisions should be made during the design phase, and not delayed until construction. One of the most common complaints from contractors is that they are asked to do too much engineering.

With some exceptions of specialty contractors, most contractors think that their main contribution to construction is to build, and not to design, for the owner. At the same time, owners pay engineers for their technical and design expertise, and a decision to delay a design issue to construction or to shift the design to the contractor should not be made, except under special circumstances. Special circumstances may include the following:

- Temporary construction features, which are usually designed by the contractor, such as dewatering, braced excavations, flood protection, stream diversion, access roads, and safety provisions;
- Need for additional foundation grouting, which is typically decided during construction, based on the geology, observed grout takes, and specified closure requirements; and
- Rate of fill loading on a soft clay foundation, which is controlled by the dissipation of excess pore-water pressure in the foundation, as monitored by piezometers.

The following are examples of some unfair and fair specification requirements. A commentary is provided (within brackets) for each example to further clarify the intent.

- Fair to all—"The Contractor shall submit test samples from proposed source for testing by Owner. If the test fails, the Contractor may submit a recheck sample for additional testing by the Owner. If the recheck sample fails, then the stockpile or proposed source shall be rejected. Testing for recheck sample shall be at the expense of the Contractor." (Commentary: The owner carries a testing budget to check whether the proposed material from the contractor's source meets specifications. However, when the first test fails, the specifications allow for a second test to account for variability but at the expense of the contractor. Both the owner and the contractor share the cost of testing—a fair arrangement.)
- Unfair to the contractor—"The Contractor shall be responsible for providing adequate quantities of structural fill from on-site borrow areas furnished by the Owner." [Commentary: It is the responsibility of the owner to ensure that the owner-furnished source has adequate material (see Section 3.4). A shortage of materials in the owner's borrow area should be considered a changed condition, and the contractor should not bear the additional cost of importing the material from off-site sources.]
- Fair to the contractor—"The Contractor agrees that, should he or she or any of his or her employees in the performance of this contract discover evidence of possible scientific, prehistoric, historic, or archaeological data, he or she shall notify the Contracting Officer immediately. Where appropriate by reason of a discovery, the Contracting Officer may order delays in time of performance, or

changes in the Work, or both. If such delays, or changes, or both, are ordered, the time of performance and contract price will be adjusted in accordance with the applicable clauses in the Contract." (Commentary: The discovery of buried archaeological artifacts during construction is considered an unforeseen field condition, even though the site has been surveyed and is known to contain these artifacts. If the discovery affects the construction, then the contractor is entitled to compensation for changes in contract price and schedule, which is allowed in the contract. These contract provisions are common in federal construction specifications.)

- Unfair to the contractor—"The Contractor shall perform all concrete and field density testing at a frequency as deemed necessary by the Engineer." (Commentary: The testing frequency is an open target, and it is impossible for the contractor to budget the testing cost in his or her bid.)
- Fair to all—"The Contractor shall perform concrete testing at a frequency of every 30 cubic yards of concrete placed. Field concrete tests shall include slump, temperature, and air content. The Engineer will perform all field density tests at least once every lift of earthfill placed, or more frequently, as deemed necessary by the Engineer. The test location in the fill will be determined by the Engineer." (Commentary: The contractor is responsible for testing the concrete, and the owner is responsible for testing the in-place earthwork. At a prescribed rate of 30 cubic yards per test, the contractor can estimate the number of tests required, and hence the testing cost. The contractor knows that the owner will test every lift of the earthfill placed, so there will be allowance for access by the testing personnel and work stoppage before the next lift is placed. The test location is not a cost burden for the contractor. If more earthwork testing is needed for each lift, that cost will be the responsibility of the owner, and not an open target for the contractor.)

15.4 Technical Correctness and Quality Control

The first responsibility of a specifier is technical correctness of the specifications. A set of specifications can be written in the most clear and concise language, but if the wrong materials or products are specified, or if the wrong standard references are cited, the specifications are defective. Examples of technical inaccuracies are illustrated in Section 15.2. Technical inaccuracies are considered design errors. Problems associated with design errors may or may not be readily revealed during construction.

Ensuring technical correctness is one of the main functions of the lead design engineer and represents part of the engineering process in a design. Regardless of what engineering discipline (e.g., structural, mechanical, or geotechnical) is involved, and without going into technical details in a particular discipline, there are a number of things a lead design engineer can do regarding technical correctness in specifications:

- The design analysis, whether hand-calculated or computer-assisted, should be checked for correct assumptions, criteria, methodology, and mathematics. Unchecked analysis is a poor engineering practice, and the direct implications of an error in specifications caused by unchecked analysis can be serious.
- When an old specification is to be reused for a current project, the engineer should try to understand what design criteria, site conditions, and other project-related background are associated with the old specification before it is marked up for the next project. Requirements in specifications were put in the previous project for a reason, and that reason may be different for other projects.
- Only factual field and laboratory data (such as drill logs, laboratory soil test data, concrete mix design study, and borrow-area test pit logs) should be included in the construction documents. The engineer's interpretation and evaluation, used in reports to his or her client, should not be used in construction documents. The contractor should provide his or her own conclusions and interpretations of these data.
- Heavy civil construction often involves many different engineering disciplines, and a designer of a particular discipline should resist practicing beyond his or her area of expertise without consulting with engineers from other disciplines (see Chapter 12). For example, a structural engineer should not prepare a foundation preparation specification of a clay shale foundation that has slaking deterioration potential if it is not adequately protected. A geotechnical engineer should not prepare a specification of mechanical gates and valves, especially for special applications, such as pinch valves, free-discharge valves, and radial gates.
- Specifying new products, new materials, and new construction methods that do not have adequate performance history or adequate testing should be resisted. An engineer should always be innovative and look for ways to reduce construction costs and to advance the state of the practice. On the other hand, a design engineer has a responsibility to minimize liability exposure for his or her company and himself or herself, and it is natural to take a fundamentally cautious approach in design. These two opposing considerations should be balanced on a case-by-case basis. A good example of being innovative in design is the use of articulated concrete block revetments to provide erosion resistance in hydraulic channels; this revetment system has been adequately tested in the laboratory, in full-scale models, and in actual applications. On the other hand, gabions (rock-filled wire baskets) have been promoted by manufacturers to provide the same erosion resistance in hydraulic channels, yet there are numerous failures reported for this application; in those cases, using the more traditional riprap is a more conservative approach.

- The designer should make it a habit to review the standard reference specifications referred to in the project specifications, especially when using a new or revised version in which subtle differences may exist (see Section 17.4). When products are specified from standard reference specifications, the availability of that product should first be verified with manufacturers and distributors.

The first responsibility of an in-house design reviewer is to check on the technical correctness of the specifications. If the primary role of the project manager of a design project is administrative because of a lack of design experience, that manager should not be the technical reviewer of the specifications (or the construction drawings). The same can be said about principals without design and construction experience. The review by a qualified technical reviewer is the last line of defense for quality control before the project goes into bidding and construction. According to the Construction Specifications Institute (2011), in addition to obvious graphical, dimensional, and typographical errors, the design reviewer should check the construction documents to eliminate the following problems:

- Omissions;
- Overlaps and duplications between disciplines;
- Noncompliance with laws and regulations;
- Conflicts and discrepancies with locations of equipment and components;
- Incompatible materials and components;
- Difficult or impossible construction methods;
- Inconsistent terminology and abbreviations;
- Inconsistent units of measure;
- Incorrect or unspecified materials, components, or equipment;
- Errors in defining areas of construction phasing;
- Errors in defining limits of work;
- Errors in identifying work by the owner or work not in contract;
- Errors in designating work of separate contract; and
- Inaccurate or unnecessary cross-referencing.

Typographical errors are another overlooked aspect of quality control of specifications. Typographical errors, if undetected, may result in serious problems in construction. An extra word (e.g., “shall not” versus “shall”) or different numbers may have significant cost implications associated with the error. Typographical errors, even though committed by the clerical staff, are the responsibility of the lead design engineer in the same way that technical errors committed by junior engineers are the lead engineer’s responsibility. Regardless of time constraints caused by a tight specification production schedule, it is the responsibility of the lead specifier to back-check all changes typed by the clerical staff and all cross-references to other specifications and drawings. This problem is particularly prevalent when an old specification from a previous project is used as a starting point, and the text is so voluminous that there is a tendency not to carefully read or understand all of the text.

15.5 Contractor's Means and Methods

The conventional approach in construction, whether civil or architectural, is to allow maximum flexibility to the contractor's means and methods that are not specified, as long as the final product or final results comply with the specifications. The reasons for this approach include the following:

- It allows the contractor to adapt his or her own equipment, crew, and procedure for the project.
- It encourages the contractor to be innovative and use his or her own experience and background.
- It alleviates the designer's liability on the construction method and allows the field quality control personnel to focus on the end product instead of the construction method.

A well-known application of this principle is site safety provisions, which are the sole responsibility of the contractor. Site safety is discussed in more detail in Section 15.12.

It is within the realm of the designer, however, to put restrictions on acceptable means and methods because of technical reasons or specific project requirements. These restrictions should not be considered a problem if they are known during bidding and construction. The following examples illustrate how limiting the contractor's means and methods actually results in a better product or performance, or improved safety, in some situations:

Soil compaction

- "Only vibratory rollers are allowed to compact the clean filter sand and gravel."
- "Only sheepsfoot rollers are allowed to compact the cohesive embankment fill in the dam. Smooth drum rollers are not allowed."

Drilling method

- "To avoid hydraulic fracturing, only drilling with hollow-stem augers and without drilling fluids is allowed in the embankment dam."
- "To avoid damaging the dam, only diamond-bit coring in the concrete dam shall be allowed."

Dewatering method

- "Well-point dewatering shall be required for excavation in the clean sand and gravel foundation. Foundation dewatering by sump-pumping alone shall not be considered adequate."

Construction sequence restriction

- "The Contractor shall first construct the new access road to allow local residents continuous access across the construction site."
- "To allow uninterrupted streamflow downstream, the Contractor shall install the new culverts before placing the temporary cofferdam."

In the examples above, the geotechnical designer has determined—based on the anticipated subsurface conditions, his or her understanding of material behavior, and his or her judgment—that certain construction methods are not acceptable. This engineering decision can be made during design or during construction. To the extent possible, the decision should be made during design to minimize changes in conditions and disputes during construction. By specifying these restrictions in the bid documents, the bidders can accommodate these restrictions in their bids. By delaying this decision until construction, the contractor may argue that these restrictions will result in additional costs to him or her. Both approaches may end up increasing the cost of the project (in the original bid or in change orders), but handling the changes during construction could lead to other problems, including delays or impacts to other related work, which then leads to additional cost increases.

15.6 Specifying Materials and Products

Even if the specifications are prepared by nontechnical personnel (e.g., in-house specifiers who are not professional engineers), the selection of a specified material or product should be the responsibility of the design engineer (see Section 15.1). Many factors—functional characteristics, practical concerns, material and installation costs, code requirements, compatibility with existing facilities, past performance, maintenance requirements and costs, and availability—contribute to the selection of a particular material or product. The Construction Specifications Institute has an excellent reference on product evaluation (2011).

The potential problems associated with product substitution are discussed in Section 15.2. In particular, the specification provision "or equal" is the center of most disputes regarding product substitution. Removing the "or equal" provision, as proposed by Rosen et al. (2010), is not the solution to this problem. In fact, for federal projects, this provision is mandated if proprietary products are used. Rather, if used appropriately, the provision "or equal" is an acceptable provision to allow a contractor to substitute a named product for another one.

Let us approach the problem from the standpoint of a contractor preparing his or her bid on a certain brand-name product with an allowance for substitution. Other than the brand name, no other properties and acceptance criteria are given in the specifications. To gain an advantage, the bidder does not use the specified brand name, but substitutes a less costly product. This bidder later is selected as the contractor, and when the contractor submits the cheaper product to the engineer for approval, the product is rejected on the grounds that it is an inferior product and is not equal to the specified brand name. Because the specifications for this product do not contain any other technical requirements and characteristics, the contractor chooses to argue with the engineer on the rejection, leading to delays, disputes, and claims.

Let us consider another scenario. This time, the specified brand name is accompanied by a list of relevant properties and performance criteria that are used to determine product equivalence. Under these conditions, the avenues of controversy are removed. Let us also assume that the contractor, in preparing his or her bid, has identified a cheaper product that satisfies all of the specified properties and criteria and has used that cheaper product in preparing his or her bids. During construction, the contractor submits a request for substitution, and the engineer accepts the substitution because it meets all required properties and criteria.

The latter approach contains two strategies in the use of the "or equal" provision:

1. It encourages competition, while it gives the engineer a contractual basis to compare equivalent products.
2. When a set of characteristic properties and criteria are specified with a named product, the additional information allows the bidder to look for equivalent, less expensive products for use in his or her bid. Without this information, the bidder is risking that his or her substitution will be rejected later.

Two examples of appropriate use of the "or equal" provision are provided below:

1. "Geotextile erosion protection mat shall consist of polymer nettings, with a fused, three-dimensional mat of sufficient thickness and void space to allow for soil filling. The material shall be ultraviolet stabilized with a minimum of 2 percent carbon black to resist sunlight degradation when exposed. The mat shall be resistant to biological and chemical degradation. Geotextile erosion protection mat shall be Tensar Erosion Mat TM3000, or approved equal."
2. "Steel sheet piles shall conform to ASTM A328-93 and shall have a minimum yield strength of 39,000 pounds per square inch. The minimum section modulus for each single section shall be 90 cubic inches, and the weight per square foot of pile shall be 35 pounds. The sheet piles shall be PZ35 as manufactured by Bethlehem Steel, or approved equal."

In these examples, the requirement of uniform bid basis is used to encourage competition. The characteristic properties given in the specifications allow the engineer to approve or reject any substitution without having to deal with any potential for claims.

Finally, the engineer should check on the availability of a brand-name product that is specified. Failure to do so during design may be justification for the contractor to request a price increase during construction for an alternate product to substitute for the unavailable product.

15.7 Contractor's and Manufacturer's Roles

Occasionally, a design engineer is faced with the need to use specialty construction (such as high-capacity posttensioned anchor installation, or a biopolymer slurry trench) or a new or specialty product (such as a fixed-cone valve or underwater epoxy coating) to meet project requirements. The design engineer can seek design and test data and performance history from his or her peers or from published literature. When these resources are not available, the engineer needs to consult with specialty contractors or product manufacturers to obtain additional design information and specification requirements. In heavy civil design, this type of interaction is quite common, and there are many advantages of doing so, namely,

- Specialty contractors can provide firsthand experience that is valuable in understanding the application, limitation, constructability, and cost.
- Specialty contractors and product manufacturers can provide valuable guidelines on practical considerations that should be incorporated into technical specifications.

Some advice is offered here to take advantage of this valuable design resource while keeping "an arm's length" from contractors and manufacturers to prevent any appearance of impropriety and claims of collusion:

- The suggestions and guidelines provided by contractors and manufacturers, including guide specifications, should be carefully reviewed and screened so that they do not favor the contractors or manufacturers that are consulted. Restricting the work to a particular contractor or a particular manufacturer not only discourages open competition, but also it is not allowed in federal construction. The engineer should disclose this intention up front, before consulting with these sources.
- The engineer should not put the contractors and manufacturers in a position that may exclude them from bidding on the project being designed. Improper involvement that may jeopardize the contractors and manufacturers includes disclosing too much project or "inside" information or referencing their names in construction documents.

15.8 Specifying Tolerances

Tolerances are allowable deviations from a specified value, such as thickness and grades. Tolerances also apply to the degree of compliance for a particular specified requirement, such as quality control testing for earthfill and concrete. These two types of tolerances have widely different meanings, and are therefore treated separately.

Dimensional Tolerances

Dimensional tolerances are used to give the contractor a range of acceptable finished dimensions, such as thicknesses, elevations, or verticality. Different practical tolerances are associated with different construction methods and different materials, and dimensional tolerance can be a constructability issue if not specified properly. For example, the finished elevation of the top of a concrete wall can be built to within 0.01 ft of accuracy using conventional forming and finishing methods, but the finished elevation of a soil foundation subgrade or fill can only be built to within 0.1 ft using conventional earth-moving equipment. That is not to say that tighter tolerances cannot be obtained. Tighter-than-normal tolerances require special construction methods that increase costs. For example, the finished elevation of a soil foundation subgrade or fill can be built to within 1/4 in. using hand tools, at a much lower production rate (cost per cubic yard) than using machinery. To ensure that the owner does not pay more than is necessary, it is important that tolerances are not specified tighter than necessary to accomplish the project design objectives.

When a specified tolerance is so tight that it cannot be met, it is considered unconstructable. An example of an unconstructable tolerance is the requirement of percussion drilling of a vertical hole to within 0.25° deviation from the vertical; a one-degree tolerance would be more appropriate for that particular drilling method. Unconstructable tolerance does not prevent a bidder from bidding on the work, and the contractor is likely to request a relaxation of the tolerance during construction. In such a case, tolerance relaxation should be granted by the engineer, unless there is a specific reason that the tight tolerance cannot be changed. In the example above, if tight tolerance is needed to protect an underground facility from being damaged by drilling, then a relaxation of the tolerance may put the existing facility in jeopardy. At this point, a different engineering solution or construction method (e.g., using a diamond-bit core drilling method instead of percussion drilling) may be needed, which usually implies a change order and delay. Another example of an unconstructable tolerance is to finish a dumped riprap layer to within 0.1 ft of the neat line, similar to a typical earthwork finish tolerance. The finish tolerance for dumped riprap rocks should be in the range of 3 to 6 in., depending on the maximum sizes of the rocks.

Construction experience is helpful in specifying constructable tolerances. Where necessary, consultation with specialty contractors is recommended during design and preparation of specifications.

Degree of Compliance

A 100% compliance of a specified material placement requirement, such as the minimum compacted density and moisture for an earthfill, or minimum concrete strength, is difficult to achieve, and the enforcement of such a requirement is frequently a source of disputes and claims during construction. A statistical quality control approach, which accepts less than 100% compliance, is becoming increasingly common in heavy civil construction projects. This approach uses a *running average* of all or part of the measured test values instead of the actual measured values at any given time. This statistical quality control approach thus allows some marginal cases to be accepted, with the understanding that the marginal cases are so insignificant that they will not affect the overall performance of the in-place materials. To prevent gross noncompliance, it is reasonable to specify an absolute minimum acceptance criterion. When a certain test value falls below that level, the work will be rejected, regardless of the running average. The running average method can also be used in conjunction with measurement and payment for that material. When the running average falls below a specified number, then the contract unit price will be reduced by some pay factor, depending on the degree of noncompliance. This statistical quality control has proved successful in many heavy civil construction projects in the area of earthwork, concrete, and pavements.

The following is an example of using a running average for quality control testing of concrete from the Colorado Standard Specifications for Road and Bridge Construction (CDOT 2011):

> The concrete will be considered acceptable when the running average of three consecutive strength tests is equal to or greater than the specified strength, and no single test falls below the specified strength by more than 500 psi. A test is defined as the average strength of three test cylinders cast in plastic molds from a single sample of concrete and cured under standard laboratory conditions prior to testing.
>
> When the average of three consecutive strength tests is below the specified strength, the individual low tests will be used to determine the pay factor in accordance with Table 601-2. The pay factor will be applied to the quantity of concrete represented by the individual low test.

15.9 Engineer's Discretion and Control

Many years ago, construction was completed with minimal drawings and specifications, and the engineer played a vital role during construction, including significant day-to-day engineering decisions being made and exercising significant discretion and control over the contractor's work. That was before litigation became a preferred way to settle claims and disputes made during construction. Now, construction documents become voluminous, even for small projects. The contractor determines his or her means and methods, and the engineer is discouraged from "directing the contractor" during construction. Specification provisions such as "as directed by the Engineer," "as determined by the Engineer," or "to the satisfaction of the Engineer" are treated as taboo because of fear that these provisions imply that the engineer is overstepping his or her bounds, or that the engineer is imposing an open target whereby the contractor performs additional work trying to meet this target without being compensated. Some specification writers even suggest that these terms should be totally removed from specifications, thus taking away the ability of the engineer to make discretionary decisions during construction.

The main intent of these specification provisions is to give the engineer some discretion and control during construction when it is not possible to determine what decision is appropriate during design. Actually, the contractor has no problem working under the engineer's direction or doing work until the engineer is satisfied, as long as the contractor is compensated for his or her efforts. Most disputes occur when the contractor discovers that there are no provisions in the contract for him or her to be paid for additional work directed or determined necessary by the engineer. With that in mind, the following compromises are offered in lieu of a complete ban of the following phrases:

"As directed by the Engineer"—The specified work that is directed by the engineer should not apply to contractor's means and methods, and it should not give the impression that the engineer is creating new work for the contractor outside of the original contract scope. Some examples of situations in which "as directed by the Engineer" can be used effectively are the following:

> The Contractor shall clear and grub all trees within the limits of disturbance shown on the Drawings, except for six large trees to be protected. The Contractor shall mark the trees to be protected, as directed by the Engineer.
>
> The Contractor shall overexcavate soft foundation subgrade and backfill with compacted structural fill, as directed by the Engineer. Approved and authorized overexcavation and backfilling shall be paid in accordance with applicable provisions in the measurement and payment clauses for Unclassified Excavation and Placing Structural Fill.

"As determined by the Engineer"—The specified requirement that is determined by the engineer should stay within the context of the contract scope of work, and the outcome for the engineer's field decision should not affect the contractor's work or compensation. Some examples of situations in which "as determined by the Engineer" can be used effectively are the following:

> The Contractor shall be responsible for testing the in-place density and moisture contents of the embankment fill. Two tests shall be performed for each compacted lift. The locations of the tests for each lift shall be as determined by the Engineer.
>
> The Contractor shall excavate 10 additional test pits in Borrow Area 5B during construction. The test pits shall be at least 20 feet long by 10 feet wide and 15 feet deep, and will be logged by the Engineer. The locations of the test pits shall be determined by the Engineer during construction. Payment for the additional test pits shall be in accordance with unit price per each test pit bid in the schedule.

> The Contractor shall drill and grout the voids outside the 48-inch concrete pipe. The primary drill hole pattern is as shown in the Drawings. The need for secondary and tertiary drill holes shall be determined by the Engineer based on actual grout takes in the primary holes. The locations and pattern of secondary and tertiary drill holes, if necessary, are shown in the Drawings. Payment for drilling and grouting secondary and tertiary holes shall be in accordance with the unit prices per linear foot bid in the schedule.

"To the satisfaction of the Engineer"—This provision should be used sparingly and only for unscheduled repair work when the contractor is clearly in the wrong, such as when he or she accidentally damages an existing structure to be protected. Because scheduled work should be based on specific acceptance criteria or other specific standards, this provision generally should not be used for scheduled work. In addition, because the extent and scope of unscheduled work is not known during design, the acceptance criteria cannot be determined during design. Examples of "to the satisfaction of the Engineer" being used effectively are the following:

> The Contractor shall protect existing benchmarks during site excavation. Damages to the existing benchmarks by the Contractor shall be repaired by the Contractor to the satisfaction of the Engineer at no additional cost to the Owner.

> Protect excavated subgrade. Subgrade damaged by the Contractor shall be repaired by the Contractor as directed by the Engineer and to the satisfaction of the Engineer. Repair may include excavation of disturbed soil and replacing the excavation with compacted fill. The Contractor shall not be entitled to compensation for repair work from damaged subgrade.

15.10 Handling Unknowns and Changed Conditions

Heavy civil construction always carries a certain risk and uncertainty of changed conditions, in spite of the best efforts on the part of the designer to characterize the project site. Chapter 3 covers the subject of an adequate site characterization to manage and reduce that risk and uncertainty. Section 15.3 discusses the design approaches of disclosing uncertainties and sharing the risk. Encountering changed conditions and unknowns that are not accounted for in the design may potentially affect the original design as well as the schedule and cost of the construction. Unknown conditions in heavy civil construction can be grouped into the following four categories:

1. Unanticipated field conditions—These are relevant field conditions that may affect the design, such as differing foundation conditions. For example, a soft foundation not known to contain cobbles and boulders may encounter so many pile-driving obstructions in some locations that it would be impossible to drive the specified pile foundation at those locations, and the pile layout would have to be modified where piles cannot be driven.

2. Excessive plan quantity variation—These are conditions that do not affect the design, but would have an effect on the payment of scheduled work. Examples of excessive plan quantity variation include work on foundation excavation, grouting of foundations, and demolition of buried structures.
3. Acts of God—These are natural conditions that could affect the construction working environment; they include conditions that are so out of the ordinary that the changes cannot be considered or assumed during design and bidding.
4. War, terrorist sabotage, etc.—When these human-caused events occur, not much can be done by the owner, engineer, or contractor, except to take steps to protect the safety of all parties involved, and, if necessary, demobilize all field equipment and personnel until the situations are stabilized for safe construction.

Unknown and changed conditions can be handled during design and construction in the following manners.

Unanticipated Field Conditions

Unanticipated field conditions may be the result of inadequate site investigation, or when the geology and subsurface conditions are so complex that it is not practical to completely explore all possible scenarios. Regardless of whether the engineer is at fault, if the designer determines that the field conditions are different from those he or she assumes in the design, then the design needs to be changed. Design changes caused by unanticipated conditions should be handled through contractual procedures in the general conditions on change orders that will most likely result in redesign, schedule delay, and an increase in project cost.

One of the design approaches discussed in Section 15.3 is for the engineer to disclose the uncertainty in the site conditions and how that may affect the design. An example is given below of a posttensioned rock anchor project in a competent granite bedrock foundation. Although all of the boreholes at the project site show that the granite foundation is competent, geologic site reconnaissance indicates that potentially soft, decomposed diabase dikes could be encountered within this geologic setting, even though the possibility is quite remote. As a precaution, the following specification clauses were prepared to handle the potential changed conditions in the bedrock:

> Unforeseen foundation conditions shall correspond to one or more of the following conditions in the foundation bedrock:
>
> 1. A rock type other than granite is encountered, with mechanical properties that are significantly weaker than those encountered in the borings performed for this project. The unconfined compressive strengths of the weaker rock shall be no more than 25 percent of the average unconfined compressive strengths of the granite tested for this project.

2. A highly fractured zone more than 5 feet thick, with rock quality designation (RQD) less than 10 percent, is encountered.
3. A shear zone more than 5 feet thick, with unconfined compressive strength of less than 1,000 pounds per square inch is encountered.

If these conditions are suspected in the foundation, the Contractor shall obtain NX-size cores of the foundation bedrock and perform laboratory tests to demonstrate to the Engineer that unforeseen conditions exist. If unforeseen conditions exist, then the Contractor will be compensated for the sampling and testing of the rock. If the data do not prove the existence of the unforeseen conditions, then the sampling and testing costs shall be the responsibility of the Contractor.

The Contractor shall be entitled to additional compensation for additional anchor materials and installation costs if unforeseen foundation conditions exist.

There are several elements in the example specifications above that are appropriate to handle potential unanticipated field conditions:

- The criteria to define a changed condition are quantified to the extent possible to avoid subjective interpretations on the part of the designer and contractor. Parameters such as unconfined compressive strength, rock quality designation (RQD), and thickness of soft zones are preferred over qualitative terms such as "soft rock," "highly weathered," "significantly different," or "as determined by the Engineer."
- In terms of testing costs and compensation for the anchor installation in the event of an unforeseen foundation condition, this specification is fair to the contractor, which is in the spirit of the design approach recommended in Section 15.3. This specification is also fair to the owner because it protects the owner from trivial claims that arise from a liberal interpretation of what "unforeseen conditions" are.
- The design engineer has not ignored the remote possibility of an unforeseen foundation condition and therefore has installed a mechanism in the contract documents for an orderly way to properly handle a surprise.

The example above was an actual case history. As it turned out, the soft diabase dike was not encountered during construction, and the anchors were completed as designed without incident.

When the changed field conditions affect the contractor's means and methods and hence his or her costs, the contractor may file claims on the grounds of differing site conditions. Disputes arise when the engineer and owner disagree with the contractor's claim, which may or may not be justified. Has the contractor misinterpreted the site data furnished to him or her and thus decided to use the inappropriate means and methods? Some construction contracts contain provisions to handle disputes, such as dispute resolution through mediation, which may or may not be binding. In the worst-case scenario, litigation is used to settle construction disputes.

Excessive Plan Quantity Variation

Plan quantity is the quantity shown on the bid schedule for a particular unit price item, and it is used as a basis for bidding. Variations in plan quantities during construction are related to measurement and payment (see Chapter 19). As discussed in Chapter 23, the unit price of a particular work item is affected by the quantity of work to be performed; therefore, significant changes in plan quantity affect the contractor's cost to perform work. General conditions in construction contracts typically contain provisions to handle this payment issue. However, these provisions are useless if the bid schedule is not set up to handle unanticipated variation in plan quantities. For example, if the exact length of an end-bearing pile is not known during design, then the pile should be paid for on a per-linear-foot basis. If the exact dimensions of a buried structure to be demolished are not known, then the demolition should not be paid as a lump sum item. If a mixed soil and hard-rock excavation are anticipated, then the excavation should not be paid for as one single "Unclassified Excavation" item. When a contractor knows that he or she will be paid for work that involves some unknown conditions and does not have to bear all of the risk involved, there will be a decreased likelihood of disputes and claims. Furthermore, bids will be more representative of the work required.

Excessive variations in plan quantities are caused by the following problems:

- Inadequate quantity estimate effort—The quantity can be underestimated or overestimated by a significant amount (e.g., 10% or more) if the geometry of the design layout is complicated and there is an insufficient number of cross sections taken to support the calculations. To correct this problem, the estimator should evaluate the variability of the paid item in question in each cross section already prepared and decide whether additional cross sections are needed to represent the variations. If additional cross sections are needed, they should be drawn to scale and then included in the backup calculations.
- Poor quality control effort—The person checking the quantities should evaluate the accuracy and assumptions used in the original calculations and not just check the mathematics. When the quantities were estimated using CAD software, these quantities should be checked also, whether by hand or by another computer-aided tool, and not taken for granted that they are correct. Not checking quantities is a poor design practice and is considered to be a design error and omission.
- Changes in field conditions—Changes in subsurface conditions are inherent in heavy civil construction, but they can be minimized by a good effort in site characterization (see Section 3.3). Sometimes it cannot be avoided because of

complex geology and subsurface conditions, in spite of a good effort to characterize the site. That is one of the reasons why an allowance for construction contingency is necessary for heavy civil construction (see Section 24.3).

Acts of God

The contractor should be compensated for additional construction costs and delays associated with the so-called "acts of God" events during construction. An "act of God" is a legal term for events outside human control, such as natural disasters for which no one can be held responsible. Such natural disasters include large floods, large earthquakes, excessive snowfall or rainfall, unusually cold weather, hurricanes, and tornadoes. No contractor will be expected to account for these unusual conditions in his or her bid. At the same time, the owner should not expect the engineer to include allowances in his or her estimate for these conditions. When these conditions occur, the owner would ultimately bear the additional cost. Such is the risk inherent in heavy civil construction. To a limited extent, there are some precautions that can be done during design to minimize the occurrence of "acts of God" during construction:

- Schedule the construction for certain times of the year during which damaging weather is less likely. For example, flooding along a stream bank worksite can be minimized by scheduling work in the dry fall season, and not during spring runoff.
- Provide adequate guidelines in the specifications on what work will be allowed under extreme weather conditions, such as cold weather placement of concrete and earthfill. Work should be shut down during unacceptable conditions.

The dividing line between what is considered normal conditions and "acts of God" could be a subject of disputes and litigation. It may be relatively simple to declare a 500-year flood an act of God, but is a 100-year flood considered the same?

Some construction contracts contain a *force majeure* clause to handle unknowns that are beyond the controls of the owner or the contractor. The term "force majeure" is French for "superior force" and is commonly used in contracts that free both parties from an extraordinary event or circumstance such as war or "acts of God." It should be pointed out that the force majeure clause does not necessarily prevent a dispute because both parties would still need to agree that the unknowns are indeed beyond the controls of either party.

15.11 Owner-Furnished Equipment and Materials

Occasionally, the contractor is required to install equipment and materials furnished by the owner. Some of the reasons for which an owner would furnish his or her own equipment and materials include the following:

- The project schedule is so tight that there is not enough time for the contractor to go through a normal equipment procurement process. For example, specially fabricated mechanical gates and valves may take several months for shop drawing preparation, approval, and fabrication, and these items are needed at the beginning of the project.
- The owner can obtain the materials at a lower cost than purchasing them through the contractor, either through an existing purchase agreement with a local supplier, or merely through savings in contractor's markup.

When an owner furnishes his or her own equipment or material, he or she bears the responsibility for the quality of the equipment or material, and the contractor is only responsible for installation. When an owner designates his or her own borrow site for a fill, he or she is responsible for the material characteristics and adequate quantity required for completing the work. It is not fair to ask the contractor to comply with the material specifications of an owner-designated borrow site. Material specifications for owner-furnished equipment and materials should state explicitly so. All of the inherent properties and characteristics of the owner-furnished equipment and materials should still be included in the product specifications for the following reasons:

- The contractor needs this information for installation. Information that will be helpful to the contractor includes shop drawings from the manufacturers, product data sheets, testing, and operation and maintenance manuals. All of the design criteria for each piece of equipment should also be listed if they are critical for the installation and performance of other related work that is the responsibility of the contractor.
- The significant properties of earthfill material should be included because these properties would allow the contractor to select the proper equipment and how the fill will be placed to meet placement requirements. For example, if the fill is a clay, then a sheepsfoot roller or a tamping roller is more appropriate than a vibratory roller for compaction. The converse is true if the fill is a clean sand and gravel material.

During installation of owner-furnished material and equipment, the contractor is only responsible for complying with the specified installation requirements and procedures. For example, for earthfill placement, the contractor is responsible for meeting the in-place moisture and density, as demonstrated by field testing. In the case of installing equipment such as mechanical gates and valves, the contractor is responsible for complying with all manufacturer instructions and recommendations, as demonstrated by field operation testing and/or pressure testing.

15.12 Construction Site Safety Issues

This section pertains to safety issues on the construction site and not to safety issues of the end-users of the new facilities. Although the design engineer often designs a new facility that meets all applicable industry safety guidelines on operation and performance, frequently the site considerations of constructing his or her design are ignored in the design process. Construction site safety is one of the most important topics in construction management, but it is beyond the scope of this book. An excellent discussion on construction site safety can be found in Fisk (1992). Because the contractor exercises direct control over his or her own equipment, workers, and means and methods of construction, construction safety is the sole responsibility of the contractor. It is his or her responsibility to comply with state and federal safety regulations, such as those stipulated by OSHA (2015). When an accident occurs during construction, the owner and the engineer are frequently involved in litigation to sort out who is liable for damages, regardless of whether the owner or engineer bears any part of the responsibility. Therefore, the key to construction safety is to prevent accidents before they occur.

What can engineers do during design to address construction safety? It is suggested that the best time for designers to get involved with safety is before construction, during planning and design (Gambatese 2000). Gambatese suggests the following practice during design to reduce the risk of construction safety problems:

- Decrease the amount of scheduled night work and overtime. It should be noted that restricting the contractor's schedule may take away some of the contractor's flexibility in performing the work and may result in higher construction cost.
- List hazardous materials and note their locations on the site.
- Locate underground utilities and other below-grade features.
- Design site grades to minimize the amount of work done on steep slopes.
- Incorporate safety issues as part of the constructability review during design.

All of these suggestions are excellent. In addition, the following elements should be included in the specifications regarding site safety:

- Compliance with OSHA construction regulations (2015)—Besides being legally obligated, the contractor is made contractually obligated to provide a safe working construction environment.
- Health and safety plan—Requiring the contractor to prepare and submit a health and safety plan forces him or her to address safety issues before they occur.
- Minimum safety provisions—It is within the realm of the owner's rights to request certain minimum safety provisions on a construction site, such as warning signs, hard hats, steel-toe boots, safety fences, first aid kits, fire extinguishers, working telephones, and a designated safety officer.
- Work-stoppage provisions—The contract should contain provisions for the field engineer to stop work for imminent hazards or dangerous conditions. Work stoppage always implies delays and claims, and it should therefore be exercised

with prudence and judgment by the field engineer. However, in the event of a serious or fatal injury, the financial consequences from a lack of action on the part of the owner's field representative could be significantly higher than those associated with a temporary work shutdown to correct safety deficiencies.

Exercise Problems

15.1 The following specifications contain ambiguous requirements. Identify the ambiguity and provide a remedy to remove the ambiguity.
   a. "Remove large rocks on existing ground surface before stripping topsoil."
   b. "Do not place roller-compacted concrete (RCC) in cold or hot weather."
   c. "Do not remove concrete forms until the concrete has achieved 75 percent of the design 28-day strength."
   d. "Protect clay shale subgrade from slaking deterioration as soon as possible after excavation."

15.2 The following situations are about specifications that contain conflicting requirements. Identify the conflict and provide a remedy to remove the conflict.
   a. Stainless steel "Johnson screens" are specified in the technical specifications for a new pumping well. The construction drawings call out perforated PVC pipes.
   b. A construction sequence for cofferdam installation is contained in both specifications and drawings. In the specifications, the cofferdam is required to be installed during Stage 1 Demolition, but in the drawings, the cofferdam is shown as being installed during Stage 2 Demolition.
   c. A descriptive approach is used in specifying the installation procedure to place a fill by requiring a lift thickness of 18 inches and four passes of a 10-ton vibratory roller. The contractor provides the specified equipment and effort, but density tests by the owner indicate that the in-place density is between 92 and 94% compaction, which is below the designer's intent of 95%.
   d. A riprap material quality specification requires a minimum specific gravity of 2.65, a minimum L.A. abrasion soundness of 30%, while also meeting all the requirements for riprap in the Colorado Standard Specifications Road and Bridge Construction. In the Colorado highway specifications, the minimum specific gravity for riprap is 2.5, while the minimum L.A. abrasion soundness is 50%.

15.3 Unconstructable specifications may be a result of an inexperienced specification writer or inadequate design effort on the part of the designer. Explain why the following specifications are unconstructable and how to avoid this problem:
   a. Placing a layer of compacted fill directly over a very soft subgrade without any foundation treatment. The minimum percent compaction is 98 percent.

b. Requiring a 56-day compressive strength of 2,000 pounds per square inch in a soil–cement mix in which the soil aggregate from the Owner-furnished borrow source contains a significant amount of clay fines.
c. In order to avoid drilling into an existing pipe, the two new drain holes adjacent to the existing pipe are required to have zero deviation from the vertical. The depth of the drain holes is 100 feet.

15.4 Which of the so-called "unenforceable specifications" provisions are likely to cause disputes and problems with the contractor?
a. "Testing of in-place density and moisture contents of compacted fill shall be the responsibility of the Contractor. The frequency and location of the tests will be determined by the Engineer."
b. "Testing of in-place density and moisture contents of compacted fill will be the responsibility of the Owner. The frequency and location of the tests will be determined by the Engineer."
c. "Finish the concrete floor slab as a nonskid surface and to the satisfaction of the Engineer."
d. "Protect the existing benchmarks outside the limits of excavation. Benchmarks damaged by the Contractor due to his or her operations shall be repaired or replaced by the Contractor at no cost to the Owner and to the satisfaction of the Engineer."
e. "Perform test pits in the borrow area to explore the limits and quantity of available clay fill. The locations and depths of the test pits shall be determined by the Engineer."
f. "Perform 12 test pits 10 feet deep in the borrow area to explore the limits and quantity of available clay fill. The locations of the test pits shall be determined by the Engineer."

15.5 Shifting risk to the contractor to address unknown factors is not a recommended practice in civil design. Of the following design strategies, which ones are considered to be shifting risk to the contractor?
a. Requiring the contractor to provide flood protection for work adjacent to a stream, but the level of flood protection will be left to the contractor.
b. The construction contract contains no provisions for work stoppage, delays, and compensation in an environmentally sensitive work area where buried cultural artifacts are known to exist.
c. When the work includes a deep excavation at the downstream toe of a high dam with a full reservoir pool, the designer decides to provide a deep-well dewatering system in lieu of a contractor-designed dewatering system.
d. When the work includes a deep excavation adjacent to a busy rural highway that will not be shut down during construction, the designer decides to provide a multilevel tieback bracing system in lieu of a contractor-designed temporary support system.

15.6 The correct way to handle product substitution is the incorporation of key product characteristics in the provision "or approved equal." Product characteristics typically are based on manufacturers' marketing and technical brochures and designers' criteria and experience. Based on the abbreviated manufacturers' product brochures provided below, specify a list of key product characteristics that are important for the engineer to have to evaluate a contractor's proposed product substitution:

a. A geogrid will be used to provide temporary reinforcement of a soft subgrade during construction. There are many manufacturers for this product, and the engineer is familiar with the performance of the geogrid product manufactured by Tensar from previous projects. Use the abbreviated product data in Fig. 15P-1 to prepare the list of key characteristics.

- The product designation is Tensar TriAx Geogrid.
- The geogrid is manufactured from a punched polypropylene sheet, which is then oriented in three substantially equilateral directions so that the resulting ribs shall have a high degree of molecular orientation.
- The nominal dimensions:
  - Longitudinal—1.6 in.
  - Diagonal—1.6 in.
- Load transfer capability, 93% of ultimate tensile strength, ASTM D6637-10
- Radial stiffness @ 0.5% strain: 225 kN/m, ASTM D6637-10
- Resistance to ultraviolet light and weathering: 70%, ASTM D4355-05

Fig. 15P-1. Example of Key Characteristics for a Geogrid

- The product designation is Adeka Ultraseal P-201.
- P-201 is a water-swelling, single-component, elastic sealant packaged in 10.8-oz cartridges.
- P-201 can be placed on damp or uneven surfaces and functions in a wide range of temperatures and groundwater conditions.
- P-201 will expand up to 100% by volume in the presence of water. It will expand in the direction of least resistance. When expansion is inhibited, the product will produce expansion pressure against the resistance substance, thus effectively sealing off water penetration.
- Color: grey
- Use in below-grade, cast-in-place concrete joints. Can replace conventional waterstop in nonmoving joints.
- P-201 is an excellent product to seal pipe penetrations, precast concrete segments, and sheet pile interlocks.

Fig. 15P-2. Example of Key Characteristics for a Water-Swelling Elastic Sealant

- Concrete panels are made of vibrated concrete produced in a concrete mixing plant.
- Concrete should have a 28-day compressive strength of 4,000 lb per square inch.
- Concrete reinforcement is placed in accordance with project drawings.
- The exterior face of the panels is uniform and does not show significant variations from one panel to the other.
- Tie strips are plain flats of Grade 250 supplied prebent and hot-dip galvanized.
- Tie strips are bolted to the concrete panels.
- Dowels and tubes are cast into the concrete panels for alignment. Dowels are rigid plastic bar 18 mm in diameter. The tube is rigid plastic, inside diameter 30 mm.
- Bolts and nuts are strength Grade 8.8 to BS 3692 or equivalent.
- Backfill is a selected granular sand and gravel material, free from organic or other materials. The angle of internal friction of a saturated soil specimen by direct shear test should not be less than 36 degrees.

Fig. 15P-3. Example of Key Characteristics for a Mechanical Stabilized Earth (MSE) Wall

b. A water-swelling elastic sealant will be used as a waterstop between precast concrete members in a hydraulic structure. There are many manufacturers for this product, and the engineer is familiar with the performance of the sealant product manufactured by Adeka from previous projects. Use the abbreviated product data in Fig. 15P-2 to prepare the list of key characteristics.

c. A mechanical stabilized earth (MSE) wall will be used to construct a 20-foot-high vertical wall for a highway in England. For long-term stability, the engineer excludes MSE wall systems that do not use metal tie strips. There are many manufacturers for this product, and the engineer is familiar with the performance of the MSE product manufactured by Reinforced Earth Company from previous projects. Use the abbreviated product data in Fig. 15P-3 to prepare the list of key characteristics.

CHAPTER 16

Good Specification-Writing Practices

16.1 Literary Style

The writing style for technical specifications is interesting: the document is a legal document, yet it is written in a simple and brief style. Perhaps the reason is that technical specifications are directions for contractors, material suppliers, and product manufacturers. They are not written for literary scholars, and they are certainly not written for lawyers. Technical specifications are not expected to win any literary awards. In fact, most good contractor-preferred technical specifications contain few multisyllabic words, have brief sentences, and perhaps are considered boring to read by most standards. Yet, this simple, well-planned document allows contractors to understand exactly what materials they need and how to install them. Coincidentally, this is also the type of technical writing style preferred by engineers in engineering reports.

The first requirement in technical specifications is to communicate the technical information to the builder. Significant technical and design issues pertaining to specifications are discussed in detail in Chapter 15. When a set of specifications is technically correct, the next responsibility of a specification writer is to convey this information quickly to the contractor, without ambiguity or delay. This chapter explains how some general guidelines can facilitate such communication. There will be no English or grammar lessons here. It is assumed that the specification writer has the basic writing skills and vocabulary that he or she needs for any technical writing. For more detailed guidelines on specification language (e.g., spelling, sentence structure, capitalization, punctuation, and grammar) the reader is referred to an excellent treatment on this subject by the Construction Specifications Institute (CSI 2011).

16.2 Recommended Guidelines

When a set of specifications is technically correct, the project probably can be built—even if the language is poorly written—but the engineer may need to clarify and explain the intended meanings during construction. When a set of specifications contains technical errors and design flaws, though, the best written language that follows every rule and guideline can still result in claims, disputes, and even litigation. Therefore, in the interest of giving the utmost attention to technical content, less emphasis is put on the importance of language that is considered good for specification writing. It is with this caution that the following guidelines are recommended to form the literary basis for an all-around well-written specification.

Use Imperative Mood

Instructions given to contractors are in the imperative mood and are written in one of two ways:

1. The Contractor shall coat the handrails in two 10-mil layers of brown paint.
2. Coat the handrails in two 10-mil layers of brown paint.

The two instructions are exactly the same and are both acceptable. The latter is the preferred format of the Construction Specifications Institute (CSI) (see Chapter 18). In general, actions of the contractor are given by using *shall* (absolute), and the actions of the owner and engineer are given by using *will* (optional), as follows:

> The Engineer will perform field density testing of the in-place compacted fill. If the tests indicate that the compacted fill does not comply with the specifications, the Contractor shall rework failed materials until the specified density is met. Reworking may include removal, recompacting, or reconditioning, or combinations of these procedures.

Avoid Repetition

There is a guiding principle related to specification writing: *Say it once, and say it right.* Each requirement has its own logical place and should not be repeated elsewhere. All references to a particular requirement can be made by citing the appropriate article, paragraph, or subparagraph. For example, it is determined that a Type-II low-alkali cement is required for a project that has several different types of concrete—cast-in-place structural concrete, cast-in-place lean concrete backfill, precast concrete, and mortar grout, all of which require the use of cement. The cement specification is contained in one place (e.g., paragraph 2.1 of Section 033000: Structural Concrete). The cement specification of the other three concrete mixes (backfill concrete, precast concrete, and mortar grout) in other specification sections for that project is then referenced to paragraph 2.1 of Section 033000. Any necessary changes for the cement can be made in only paragraph 2.1, and not in three other places.

Avoid Abbreviations and Symbols

To avoid potential ambiguity and misunderstandings, the use of abbreviations and symbols is not considered good practice in specification writing. There is another guiding principle related to specification writing: *When in doubt, spell it out.* Consider the following examples:

- Recommended: "Variation of the overall slope line from a straight line shall not exceed 12 inches in 100 feet, 3 inches in 30 feet, and 1 inch in 10 feet."
- Not recommended: "Variation of the overall slope line from a straight line shall not exceed 12 in. in 100 ft., 3 in. in 30 ft., and 1 in. in 10 ft."

As a minimum, if abbreviations are used in specifications, they should be clearly defined the first time they are used, as illustrated in the following example:

> "The 90-day compressive strength of the roller-compacted concrete shall be 2,000 pounds per square inch (psi). Additional strength requirements shall be as follows:
>
> 7-day compressive strength: 500 psi
>
> 28-day compressive strength: 1,500 psi"

Definitions of abbreviations should only apply to a particular section and should be repeated in other sections when the same abbreviations are used. Also, a listing of abbreviations should be included in a drawing or a specification section.

Although abbreviations and symbols are routinely used to shorten callouts or labels in construction drawings, they are not recommended in specifications. When abbreviations and symbols are used in construction drawings, they are defined in the drawings. Use of symbols, with or without definitions, is discouraged in specification text. For example, the following symbols should be spelled out in their entirety:

%	percent
°	degree
C	Centigrade
F	Fahrenheit
@	at
/	per
+	plus
–	minus

Abbreviations and symbols, however, are acceptable in tables and schedules in specifications with limited space.

Avoid Highlighting Text

Specification text should not be bold, underlined, italicized, or placed in quotations. Text that is highlighted in some way suggests to the contractor that it is more important than other parts of the specifications. The contractor should consider the entire specification to be equally important.

Avoid Irrelevant Text

A common practice in specification writing is to edit a specification section used in a previous project. There is nothing inherently wrong about this practice, except that irrelevant text and requirements should be removed to avoid confusion. For example, if the current project does not have fill density testing, then all references to fill testing standards should be deleted from the earthwork specification. If the current project does not have waterstops in the concrete joints, then all references to waterstops should be deleted from the concrete specification. If the current project does not have slotted drainpipes, then all references to slotted pipes in the drainpipe section should be deleted. Irrelevant text and requirements only confuse the contractor, and it should not be the contractor's responsibility to guess where these unnecessary requirements apply in the project.

Avoid Long, Blocky Text

Long, blocky text should be broken up into shorter, separate paragraphs for the following reasons:

- A long, blocky paragraph most likely contains more than one directive or requirement. Each directive or requirement deserves a separate paragraph or subparagraph.
- When a long, blocky paragraph is being referenced from other sections or during construction, it is not immediately clear what portion of the requirement is being referenced without further explanation.

Consider the following blocky text that is common in some federal agencies' specifications:

> C. Excavation and bedding—When the surface of roadway embankment in which a pipe culvert will be placed has reached an elevation approximately one-fourth the diameter of the pipe above the prescribed elevation of the invert of the pipe, the embankment material shall be excavated carefully to the established lines and grades to provide a firm and uniform bearing for the entire length of the pipe. In original ground, the trenches for pipe shall be excavated to a bottom width equal to the diameter of the pipe plus 1 foot and to slopes of 1H:1V (horizontal:vertical). The trenches in which pipe will be laid shall be excavated carefully to the established lines and grades to

provide a firm and uniform bearing for the entire length of the pipe. Where rock is encountered in the bottom of a trench, the trench shall be excavated to a depth of 6 inches below the grade established for the bottom of the pipe, and this additional excavation shall be backfilled with approved material, which shall be tamped thoroughly in place before the pipe is laid. Where the character of the material at any point in the bottom of the trench is such as might cause unequal settlement or provide unequal bearing for the pipe, as determined by the Engineer, the unsuitable material shall be removed to such depth as may be directed and the additional excavation shall be backfilled with approved material, which shall be tamped thoroughly to ensure an even and unyielding foundation for the pipe.

The above text can be improved by using shorter paragraphs, as follows:

3.3 EXCAVATION AND BEDDING

A. When the surface of roadway embankment in which a pipe culvert will be placed has reached an elevation approximately one-fourth the diameter of the pipe above the prescribed elevation of the invert of the pipe, the embankment material shall be excavated carefully to the established lines and grades to provide a firm and uniform bearing for the entire length of the pipe.

B. In original ground, the trenches for pipe shall be excavated to a bottom width equal to the diameter of the pipe plus 1 foot and to slopes of 1H:1V (horizontal:vertical). The trenches in which pipe will be laid shall be excavated carefully to the established lines and grades to provide a firm and uniform bearing for the entire length of the pipe.

C. Where rock is encountered in the bottom of a trench, the trench shall be excavated to a depth of 6 inches below the grade established for the bottom of the pipe, and this additional excavation shall be backfilled with approved material, which shall be tamped thoroughly in place before the pipe is laid.

D. Where the character of the material at any point in the bottom of a trench is such as might cause unequal settlement or provide unequal bearing for the pipe, as determined by the Engineer, the unsuitable material shall be removed to such depth as may be directed, and the additional excavation shall be backfilled with approved material, which shall be tamped thoroughly to ensure an even and unyielding foundation for the pipe.

Use Streamlined Format

The streamlined format is effective for listing multiple requirements. It is important that every item that is listed is assigned a subparagraph number for referencing. An example of streamlining is shown as follows:

2.2 CONCRETE MATERIALS

A. Cement: ASTM C150, Type II, gray.
B. Fine and coarse aggregates: ASTM C33.

C. Water: Clean and potable and not detrimental to concrete.
D. Compressive strength at 28 days: 3,000 pounds per square inch.
E. Maximum water to cement ratio: 0.45.
F. Slump: 2 to 4 inches.
G. Air entrainment: 4% to 6%.

Exercise Problems

16.1 Specifications are primarily instructions to the contractor and can be expressed either in imperative mood or by using the directive "The Contractor shall." Either writing style is acceptable. Convert the following specification directive to the imperative mood:

a. "The Contractor shall remove rocks more than 3 inches in diameter and strip the top 12 inches of topsoil at the borrow area."
b. "The Contractor shall compact the aggregate base course with 3 passes of a 10-ton vibratory roller."
c. "The Contractor shall not disturb the two existing masonry monuments adjacent to the entrance gate."
d. "The Contractor shall install the geotextile fabric under the revetment, as shown in the Drawings."

16.2 Specification text should not be abbreviated, underlined, or bolded, so that all text should be treated with equal importance. Correct the following specifications text to comply with this recommended writing style:

a. "Compressive strength @ 28 days: 4,000 psi."
b. "**Do not use** large roller for compaction adjacent to the existing conduit."
c. "Payment to the Contractor for all structural concrete shall be based on the unit price per CY bid in the schedule for <u>Furnishing and Placing Cast-in-Place Concrete</u>."
d. "Compact the embankment fill to a minimum of 95% maximum dry density in accordance with ASTM D698. The in-place water content shall be within + or –2% of the optimum water content."
e. "Maximum allowable in-place temperature: 70°F."
f. "Piezometer pipe: 3" dia. (ID)."

16.3 Long, blocky text in specifications is tedious to read and confusing because it contains multiple directives and requirements. Break up the following blocky specification text into a streamlined list of shorter individual requirements and directives:

a. "Slotted PVC drainpipes, fittings, and couplings—6-inch nominal diameter, unplasticized polyvinyl chloride (PVC) plastic gravity sewer pipe with integral wall bell and spigot joints, Standard Dimension Ratio (SDR) 26, and meeting ASTM D3034. The pipe joints shall have provisions for contraction and expansion with a rubber ring. The slot width shall be 0.06 inch. The minimum inlet open area shall be 20 square inches per linear foot of pipe. All fittings and accessories shall be as manufactured and furnished by the same pipe supplier."

b. "Inspection and testing of the in-place drainpipes shall be conducted by pulling a torpedo-shaped rigid plug through the drain segment, or by a method approved by the Engineer. The torpedo-shaped rigid plug shall be tapered on both ends. The diameter of the plug shall be 1 inch less than the inside diameter of the drain to be tested. The length shall be sufficient to eliminate the possibility of wedging the plug in the drain by tipping. The maximum pull allowed shall be 150 pounds of steady pull with no jerking. The line used to pull the plug shall be free of any protrusions that could snag the tubing or joints."

c. "Embankment fill shall be a mixture of clay, silt, sand, and gravel with a maximum particle size of 2 inches, a minimum of 35 percent passing the No. 200 sieve, a minimum plasticity index of 10, a maximum plasticity index of 45, and a maximum liquid limit of 60. Embankment fill shall be classified as either clayey sand (SC), or clay (CL, CH), in accordance with the Unified Soil Classification System. Embankment shall be free of peat and other organic materials, debris, and trash."

d. "Fabricate structural steel and miscellaneous metal items to straight lines and true curves. Drilling and punching shall not leave burrs or deformations. Continuously weld permanent connections along the entire area of contact. Exposed work shall have a smooth finish with welds ground smooth. Joints shall have a close fit with corner joints coped or mitered and shall be in true alignment. Unless specifically indicated in the Drawings, there shall not be bends, twists, or open joints in any finished member nor any projecting edges or corners at intersections."

CHAPTER 17

Types of Construction Specifications

17.1 General Considerations and Types

There are many ways for a design engineer to specify construction products, materials, testing, and installation. In general, the design engineer chooses—based on one or more of the following goals and considerations—the best method to specify a certain feature of the design:

- To yield the best product made with skill and efficiency from a technical and performance standpoint.
- To encourage the best price competition.
- To incorporate the advantage of the contractor's experience, special expertise, and innovation.

Different types of specifications are available to achieve the goals and considerations of the designer. They include descriptive (or method) specifications, performance specifications, standard reference specifications, and proprietary specifications. For a given set of project specifications in heavy civil construction, it is common for all four types of specifications to be used. In this chapter, each of these types of specifications is described, and examples are given to illustrate each type and its advantages and disadvantages.

Many public agencies (e.g., county engineering departments, state transportation departments, and certain federal agencies) have their own standard specifications for the type of work these agencies typically perform. Because they are so similar to each other among the states, some of these *agency specifications* are also discussed in this chapter, with an emphasis on standard transportation department specifications. When a design firm is contracted to perform design work for these agencies, the agencies require that their own specifications be used, and certain procedures and protocols are used by the design firm to satisfy specific project requirements.

The formats and design principles of writing technical specifications for federal agencies are the same as those for the private sector, except that a number of unique issues need to be considered. These issues include the general and supplemental conditions, use of restricted proprietary specifications, ways to specify foreign products, and terminologies for the parties involved, all of which are discussed in this chapter.

17.2 Descriptive Specifications

Descriptive specifications give the properties of a material, product, or equipment without mentioning a brand name or without specifying the end result. Descriptive specifications are also used in installation, in which the method of installation or placement is specified. The performance or end result of the material, product, or equipment is the responsibility of the design engineer. When a contractor is asked to furnish something or install something based on a descriptive specification, he or she is not responsible for the performance of that product or material, as long as it meets the specification requirement. Examples of descriptive specifications include the following:

> *Fill material*—"The fill shall be a mixture of clay, silt, sand, and gravel with a maximum particle size of 3 inches, a minimum of 200 percent passing the No. 200 sieve, a minimum plasticity index of 10, and a maximum liquid limit of 40. The fill shall be classified as either clayey sand (SC) or sandy clay (CL), based on the Unified Soil Classification System. The fill shall be free of peat and other organic materials, debris, and trash."
>
> *Mortar mix*—"The mortar mix shall consist of two parts ASTM C33 fine aggregate and one part ASTM C150 Type I cement, with enough water added to obtain a workable consistency."
>
> *Threaded fasteners*—"Structural threaded fasteners shall conform to ASTM A325-93. Connections shall be bearing types."
>
> *Metal pipe*—"Metal pipe shall be round corrugated galvanized steel pipe, 18 inches nominal diameter conforming to the requirements of AASHTO M36-90, minimum 16 gauge."
>
> *Fill compaction*—"Compact the fill with at least two passes of a vibratory plate compactor with a minimum dynamic force of 3,000 pounds. No testing of the fill is required."

When an engineer uses descriptive specifications for a material or product, he or she is reasonably confident that the end result or design intent will be obtained. In the examples given above, if the contractor furnishes and places the specified fill material, the in-place material should provide the minimum strength and watertightness that are required in the design. Or, when the strength of the mortar specified above is not critical, then—provided the contractor achieves the consistency that is needed for workability—the mortar mix is considered adequate.

Because the contractor is not liable for the performance of the material or product, assurance of the end result should not be the responsibility of the contractor. For example, if the contractor compacts the fill with the required two passes of a piece of approved equipment, then he or she is not responsible for the density of the fill. The engineer may still want to test the density of the fill after compaction for record purposes, but not for acceptance criterion of the in-place material. If the density of the fill is inadequate after two passes, the engineer can issue a field order to increase the number of passes, with an associated increase in payment to the contractor for increased effort.

A descriptive specification is straightforward and requires little risk on the part of the contractor. Because of low risk, the prices for items based on descriptive specifications are generally very competitive and consistent among all of the bidders. For these reasons, use of descriptive specifications should be encouraged as much as possible. This method uses the technical know-how and experience of the engineer. Because of the higher risk imposed on the engineer, inexperienced design engineers should be careful in using descriptive specifications, especially when the descriptive specifications are simply copied from a previous project.

17.3 Performance Specifications

A performance specification gives the end result or end product without mentioning the means and method to achieve the requirement. When this method is used, the burden of performance is on the contractor, and therefore, the contractor assumes a significantly higher risk. There are several reasons for which performance specifications are appropriate:

- This method encourages the use of a contractor's innovation, experience, and technical know-how and may result in an improved product.
- This method allows the contractor to use the means and methods most cost-effective for the contractor and may result in a cost saving to the project.
- Certain construction products and methods are so specialized that it is not possible for an engineer to use descriptive specifications at all.

Examples of performance specifications include the following:

Concrete strength—"The specified 28-day compressive strength of concrete shall be a minimum of 4,000 pounds per square inch (psi). Concrete materials shall consist of ASTM C150 Type I, ASTM C33 coarse aggregate size 67, ASTM C33 fine aggregate, 2-inch to 4-inch slump, and a maximum water–cement ratio of 0.45" (Commentary: The engineer specifies the design strength and quality of the materials, but leaves the concrete mix design to the contractor, who is responsible for proportioning the batch weights of the concrete materials and testing the concrete cylinders to verify the specified strength. This method is very cost-effective for ready-mix concrete.)

Percent compaction—"The fill shall be compacted in maximum 12-inch loose lifts to at least 95 percent of the maximum dry density in accordance with ASTM D698-78 within plus or minus 2 percent of the optimum water content." (Commentary: The contractor determines the type of compaction equipment, how much water to add to the fill, and the number of passes required to achieve the specified percent compaction. Field testing of the in-place fill density and moisture content by the engineer is essential to verify compliance with the specifications.)

Anchor design strength—"The contractor shall determine the bonded length of the anchor and diameter of the anchor drill hole to achieve a design strength of 100 tons. The anchor materials shall meet the requirements of paragraph 2.3.A and applicable standards of the Post-Tensioning Institute." [Commentary: Based on the foundation conditions given in the construction documents, the contractor is required to furnish 100-ton anchors by sizing the drilled holes, the design bond stress, the bonded length, and the method of installation. Verification of design strength occurs through a series of tests for anchors that may include performance testing, proof testing, and liftoff testing. Industry practice for anchor materials and installation is determined by the Post-Tensioning Institute. Unless it can be proved that there is a change in foundation conditions (see example in Section 15.10), the contractor is responsible for correcting problems associated with failed anchors not meeting the design strength.]

Precast concrete box culvert—"Precast concrete box culverts shall be reinforced concrete conforming to ASTM C789-87b, 4-foot span and 3-foot rise internal dimensions, and with a wall thickness of 5 inches. The minimum 28-day compressive strength shall be 4,000 pounds per square inch. Precast concrete sections shall be designed for a minimum earth load of 30 pounds per square foot, and a hydrostatic load of 10 feet of water." (Commentary: The contractor's responsibility here is to design the reinforcements for the culverts to meet standard ASTM specifications for the specified loads. Verification of compliance is usually handled through submittal of shop drawings and certification from the precast concrete supplier concerning the material types and strength.)

A set of performance specifications should contain three main components:

1. Requirements—The performance, end product, or end result should be expressed in properties that can be quantified and verified by testing. In the example of the concrete mix, the requirement is the 4,000-psi strength. In the example of the anchors, the requirement is the 100-ton design load.
2. Criteria—The contractor is required to comply with one or more design criteria. In the example of the concrete mix, the criteria are the water–cement ratio and the slump. In the example of the precast concrete, the criteria are the soil load and hydrostatic load. In the example of soil compaction, the criteria are the compaction effort in accordance with the ASTM D689 compaction standard and the acceptable in-place moisture content.

3. Testing—Verification of performance and of the end result is obtained through testing. Testing can be performed by the engineer, by the contractor, or both.

Requirements and criteria should be achievable based on project site conditions and current technology and construction methods. If the engineer is uncertain as to whether the required performance or end result can be achieved, he or she should consider performing full-scale testing during the design phase to obtain design parameters and to verify constructability before construction, and the test information should be furnished to the bidders during bidding as part of the reference data. Sometimes testing during design only provides enough information to ensure a uniform bid basis, and additional field testing is needed during construction to finalize the design parameters and the procedure and method of construction. A good example is the use of roller-compacted concrete (RCC) to construct concrete gravity dams. One of the key performance criteria for RCC is the design strength. During design, laboratory testing is performed to investigate the quality and durability of the aggregate and the strength of the RCC for a range of trial mixes. During construction, an RCC test fill is performed using on-site materials, full-scale mixing, and placing equipment to produce and construct the RCC. The final design mix and the contractor's equipment and method are then approved and used for the production placement in the dam.

17.4 Standard Reference Specifications

Reference specifications are publications that contain established standards of material and product quality, design standards, quality of work and installation, test methods, and codes. This information is used to represent standard of quality, accepted methodology, uniformity, and minimum standards. When a standard reference specification is used in a project specification, that standard reference becomes part of the construction document. Using standard reference specifications offers many advantages for establishing minimum quality, bid uniformity, and uniformity of construction testing and acceptance. It also reduces the need for the engineer to prepare a lengthy text on the technical requirements.

The following is a partial list of reference standard agencies that may be of interest to civil designers:

American Society for Testing and Materials (ASTM). ASTM provides the most widely used standards for materials and test methods of products that include iron and steel, alloys, concrete, soil and rock, geotextiles, pipes, plastics, and rubber.

American Concrete Institute (ACI). This organization publishes standards on the properties and applications of concrete. Essentially all concrete placement specifications and work quality issues can be addressed using ACI standards.

American Institute of Steel Construction (AISC). This organization is a nonprofit, technical-specifying, and trade organization for the fabricated steel industry in the United States. AISC provides specifications and codes for the design of fabricated steel.

American Association of State Highway and Transportation Officials (AASHTO). This organization publishes standards on highway material specification and testing methods, including earthwork, asphalt, and concrete. Some of the AASHTO standards and ASTM standards are identical.

American Water Works Association (AWWA). This organization publishes standards on gates, valves, and pipes for the application of water control.

A standard reference specification requires the following designations:

- Name of the organization,
- Designation of the standard and year of issue, and
- Title of the standard.

The following are some examples of reference standards:

ASTM D698-12: Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort [12,400 ft-lbf/ft^3 (600 kN-m/m^3)].

ASTM C150-05: Standard Specification for Portland Cement.

ACI 306.1-90: Standard Specification for Cold Weather Concreting.

AWWA C560-14: Cast-Iron Slide Gates.

AASHTO T-102-09: Standard Method of Test for Spot Test of Asphaltic Materials

It is important that the engineer who references a standard reference specification be familiar with that specification. If the engineer is unfamiliar with the specification, serious problems may arise:

Duplication or contradiction within the construction documents—Requirements in standard reference specifications should be checked for any duplication or contradiction within the requirements in the drawings and technical specifications. For example, if the design loads for a precast concrete culvert (ASTM C850) are specified, that project loading criteria should be checked against the standard design loads used in ASTM C850, which uses either HS20 or interstate loading.

Hidden choices—The reference specification may contain a number of choices of materials and products that are covered under that designation. If a particular type of material or product is not specified, the selection of that material is uncertain, and what takes place beyond this point is up to the contractor. The contractor may request additional information, or he or she may simply assume the cheapest one on the list during bidding, and then be compensated for additional costs for the more expensive item originally intended by the designer. Examples of reference specifications with hidden choices include ASTM C150 for the different types of cement, ASTM C33 for the different sizes of coarse aggregate, and ASTM C494 for the different types of chemical admixture.

Unavailable product—The reference specification contains a list of materials or products that are manufactured to comply with the requirements of that standard. If the specified properties fall outside of the list of products that are manufactured, specifying a product to meet that standard does not necessarily guarantee that this product will be available. It is not reasonable to assume that the manufacturer will specially fabricate that product solely for one project, especially in small quantities. When such a situation occurs, the contractor may request a substitution or an equivalent product, which may be more expensive and/or inferior to the originally specified product. As an example, a designer specifies a 12-in. PVC pipe with a standard dimension ratio (SDR) of 23.5, meeting ASTM D3034-89. Without reviewing the pipe dimensions table in this specification, the designer is unaware that SDR 23.5 for this type of pipe is available only for 4-inch and 6-inch diameters, but not for 12-inch diameter. To avoid this problem, the designer should always verify the availability either from manufacturers' catalogs or by contacting local distributors.

It is clear from this discussion that, as a general rule, the designer should carefully read all of the contents of a reference specification before adding it to his or her project specification. A hard copy or electronic copy of each reference specification should be included in the project file during design and at the project site during construction. It should be noted that the contractor is only required to comply with the particular version (year of issue) in the specifications. Updates of the reference specification issued after award of the contract have no relevance to the contractor, and new or changed details cannot be required of the contractor.

17.5 Proprietary Specifications

A proprietary specification calls out a brand name, model number, manufacturer of a product, or a product or method of construction that is usually patented. A specification is also considered to be proprietary when the product is available from only one source, even though the manufacturer's name is not specified. Proprietary specifications are used for the following reasons:

- The design engineer is familiar with the good performance of certain products, either from past experience or from reported literature.
- The named product is compatible with an existing project component that is being rehabilitated or replaced.
- The owner prefers the named product over other products.
- No generic product is available to satisfy the technical intent for a particular project.

- The brand name or manufacturer is called out to assist the contractor in identifying the source or sources of his or her suppliers, especially for very specialized items that are relatively new to the market.

Examples of proprietary specifications are the following:

Mechanical gate—"Contractor shall furnish and install one cast-iron sluice gate, 48-inch by 48-inch nominal dimensions, with hydraulic operator control system. The gate materials shall conform to the requirements of paragraph 2.3.A. Acceptable gate manufacturers include Rodney Hunt, Hydro Gate, Waterman, or approved equal."

Concrete revetment system—"Contractor shall furnish and install Tri-Lock Model Number 4015, 6-inch thick precast concrete blocks, supplied by the American Excelsior Company, or approved equal."

Coatings—"The hydraulic pumping unit base, tubing, and accessories shall be painted as follows:

- Surface Preparation: SSPC-SP-6.
- First Coat: Epoxy Coating (Amercoat 370), 5.0 mil thick.
- Second Coat: Epoxy Coating (Amercoat 370), 5.0 mil thick.
- Third Coat: Aliphatic Polyurethane (Amercoat 450HS), 2.0 mil thick."

The most restrictive type of proprietary specification specifies a single product or manufacturer and allows no substitutions. This method allows the engineer to have direct control over the specified product, but it also represents the least price-competitive method. Therefore, from a cost standpoint, this method should be used only when there is no other choice available in the market, or a very particular need of the owner is mandated.

It is common for an engineer to specify a proprietary product with more than one available source, such as the mechanical gate example listed above. This allows the contractor to substitute a similar product that is not listed in the specifications. This method gives the engineer some assurance of the quality of the product and offers the advantage of price competition. When this method is used, a list of product properties and criteria should be added to the specification for two reasons:

1. They allow the contractor to shop for the least expensive product meeting these requirements.
2. They form the contractual basis for the engineer to review a substitution for approval or rejection (see Section 15.6). To avoid disputes, the contract should state that the engineer's approval or rejection of a product substitution is final and is not subject to appeal.

Most proprietary specifications are based on guide specifications furnished by the product manufacturer. Unless a restricted proprietary specification is intended with no substitution allowed, the manufacturer's guide specifications should not be used verbatim. If open competition is allowed for the proprietary products, then the engineer should review the guide specifications carefully to remove any provisions that will restrict other manufacturers from competing on this product. For example, the technology of cure-in-place pipe liners is a proprietary process used in repairing defects in underground pipes. Several of these systems are available in the United States, and all of them are somewhat similar, but the curing temperatures of the liner resin for each system differ somewhat from one another. If a proprietary specification for pipe repair is based on a particular guide specification, the curing temperature that is unique to that particular system may prevent other competitors from bidding on the project. In this case, the designer should research the range of curing temperatures and specify an acceptable range. A better way to handle the different curing temperatures is to use the phrase "as required by the liner supplier."

17.6 Agency Specifications

Some county, state, and federal agencies have their own standard technical specifications for construction. These agencies include county engineering departments, state transportation departments, and some federal agencies, such as the Federal Highway Administration, Natural Resources Conservation Service (formerly the Soil Conservation Service), and the U.S. Army Corps of Engineers. The technical content of these specifications depends on the type of work these agencies normally do and is too diverse to list here. By far, the most prevalent and widely used agency specifications in heavy civil construction are the state highway department specifications.

Every state in the United States has its own standard highway specifications, and they are all available to the public. The name of these specifications varies somewhat from state to state. For example, they are called *Standard Specifications for Road and Bridge Construction* in Illinois and Colorado, and *Standard Specifications for Highway Construction* in Oregon and Oklahoma. For simplicity, the generic name of *standard highway specifications* is used here for discussion. Regardless of the title, all of these standard state highway specifications are formatted similarly to match the federal highway specifications, and they all contain work requirements related to highway construction and maintenance:

- Earthwork, landscaping, and erosion control;
- Subgrade, subbase, and base course;
- Bituminous surfaces and pavements, concrete pavements and sidewalks, pavement rehabilitation, and shoulders;
- Bridges, culverts, and sewers;
- Drainage, lighting, and safety provisions;

- Materials and equipment specifications; and
- Reclamation and seeding.

These standard highway specifications are used mainly for highway construction and maintenance work by each state's highway department. However, the use and application of these standard specifications go far beyond individual highway departments:

- Local sand and gravel manufacturers use these specifications to make concrete aggregates, base courses, riprap, and other materials.
- The local paving contractors use these specifications for placing unpaved roads, asphalt pavements, and concrete pavements.

Because local material suppliers and contractors follow state highway specifications, it is logical for an engineer to specify materials and placement procedures based on state highway specifications that are local to the project. Indeed, this practice has been widely used in the heavy civil construction industry, regardless of whether the work has been intended for private-sector, municipal, county, state, or federal agencies. It is not surprising that state highway specifications are frequently used in heavy civil construction in much the same way that standard reference specifications (see Section 17.4) are used. When state highway specifications are used for a project, these specification sections are made a part of the project specifications. Using state highway specification provisions has the following advantages:

- The specified standard materials are most likely to be available locally and do not need to be specially manufactured.
- The local contractors are familiar with the requirements, and thus are more likely to be proficient in that work.
- The pricing is more competitive.

Examples of standard highway specifications being used in project specifications include the following:

Aggregate base course—"Aggregate base course shall conform to Standard Specifications for Road and Bridge Construction, Colorado Department of Transportation, 1991, Section 703.03: Aggregates for Bases, Class 4 Aggregate Base."

Bituminous pavement materials—"The asphalt cement shall be viscosity grade AC-20 in accordance with Massachusetts Department of Public Works Highway Specifications, 1988, Designation M3.11.06: Bituminous Materials."

Riprap bedding—"Riprap bedding shall be free-draining, sound, and durable cobbles and gravels or manufactured crushed rock meeting the soundness and durability requirements of Colorado State Department of Transportation, Standard Specifications for Road and Bridge Construction, 1991, Section 703.09, Filter Material, Class A."

Because the federal highway specifications do not comply with the Construction Specifications Institute (CSI) format (see Chapter 18), the highway specifications of all the states likewise do not conform with the CSI format.

17.7 Considerations for Federal Projects

A number of issues should be considered when an engineering firm is engaged by a federal agency to prepare construction documents. Issues concerning fee schedules, design criteria, contract administration, and submittal review, though all important, are outside the scope of this book. The following is a discussion of issues concerning preparation of technical specifications for federal projects:

- All federal construction is contracted using Federal Acquisition Regulations (FAR), which represent all front-end documents for bidding and contracting. These FAR documents are similar to the bidding documents, general conditions, and supplemental conditions in the private sector. The engineering firm is asked to prepare the technical specifications, but the front-end documents are prepared by government personnel (specifically, the contracting officer). It is important that there is coordination between FAR requirements and technical requirements, especially for Division 1 (general requirements). To accomplish this goal, an engineer can review all applicable FAR clauses that will be used, or the government agency can review all technical specifications for coordination with the FAR requirements. The latter approach is preferred because most engineers are unfamiliar with FAR.
- Use of restricted proprietary specifications is generally not allowed when there is no competition for a particular product. The reasoning for this requirement is to encourage free competition in federal procurement. That does not mean that proprietary specifications cannot be used. When proprietary specifications are used, the named product should be accompanied by a list of basic properties and criteria by which equivalent or equal substitutions can be evaluated (see Section 15.6).
- When a specified material or product is made outside of the United States, a similar material or product should also be available in the United States. This is a direct requirement from the federal Buy American Act of 1933. This law gives U.S. manufacturers an advantage by imposing restrictions on the use of foreign products. Specifying a foreign product without a U.S. counterpart is generally not allowed, except under special circumstances in which domestic products cannot meet the required project criteria, or when the U.S.-made product is more than 6% higher than the cost of the foreign equivalent.
- The names of the parties involved in construction and frequently used in specifications (the owner, engineer, and contractor), are somewhat different. The term *contractor* remains unchanged. The term *owner* becomes *Government,*

and the term *engineer* becomes either *contracting officer* or *contracting officer's representative*, depending on the circumstances. For matters of administration and contract-related issues, such as measurement and payment, impact to schedule, or other contract changes, the term *contracting officer* should be used. For matters related to technical issues, submittal review and approval, or field inspection and approval, the term *contracting officer's representative* should be used.

CHAPTER 18

Construction Specifications Institute Format

18.1 Historical Perspective and Overview

The Construction Specifications Institute (CSI), in association with Construction Specifications Canada, is a leader in North America in developing and updating guidelines to the structure and formats of construction documents. The CSI format for technical specifications has been widely adopted in the architectural engineering and construction professions in the United States, including some state and federal agencies.

In this chapter, the CSI format for technical specifications is introduced and discussed, with emphasis on heavy civil construction projects. When a set of project specifications is written in CSI format, it implies that the recommended formats are followed. Even though this is the chapter in which the CSI format is formally introduced and discussed, all of the example specifications in previous chapters and indeed in this entire book are based on this format. Historically, the CSI is deeply rooted in the building construction industry, and understandably, most of the CSI format and guidelines are for architectural construction. Because this book is intended for civil engineers dealing with heavy civil construction projects, architectural elements of the CSI are deliberately deemphasized, and only elements related to heavy civil construction are highlighted.

CSI specifications are organized by divisions, which represent primarily different engineering and architectural products and construction methods in the building industry. Each division is divided into various sections. Each section is divided into three parts, but historically, a section used to contain four parts. Each part is divided into articles, paragraphs, and subparagraphs. The numbers and titles of the divisions and sections are provided in the CSI program *MasterFormat*. The general guidelines of the contents in the three parts of each section are provided in the CSI program *SectionFormat*. The formatting of each page in a particular section, including the hierarchy of articles, paragraphs, and subparagraphs, are provided in the CSI program *PageFormat*. Together, these three formats (Master, Section, and Page) constitute the CSI format. Formats of the CSI specifications have been revised about every 10 years, with the revisions dated 1995, 2004, and 2014. Much of the revision was focused in the *MasterFormat* program, with little changes in the *SectionFormat* and *PageFormat* programs since 1995. If the reader is interested in a historical development of specification formats, a good reference can be found in *Construction Specifications Writing: Principles and Procedures* (Rosen et al. 2010).

18.2 MasterFormat

Before 2004, most CSI specifications used in the industry contained 16 divisions, as provided in the 1995 edition of *MasterFormat* (CSI 1995). A major reorganization in the divisions took place in 2004, when the number of divisions expanded from 16 to 50 (CSI 2004), including the addition of a Division 00: Procurement and Contract. The number of divisions in the 2014 *MasterFormat* (CSI 2014) is decreased from 50 to 48.

Table 18-1 is a summary of the 16 divisions in the 1995 *MasterFormat*. It is necessary to include the 1995 *MasterFormat* in this chapter, not only because it is of historical significance, but also because it is still being used by some owners and federal agencies. The subject matter and types of construction for the divisions are self-explanatory for some divisions (e.g., Divisions 3, 4, 8, and 16), but are not so obvious for others (e.g., Divisions 10, 11, and 13). It is clear based on the division titles that the master format is organized for the building industry. Nevertheless, all of the work from heavy civil construction can be logically fit into this format.

The division numbers and titles in the 2004 and 2014 *MasterFormats* are similar to each other, as far as heavy civil design and construction are concerned, and thus are both summarized in Table 18-2. Compared to the 1995 *MasterFormat,* the major changes in the 2004 and 2014 *MasterFormat*s, as far as heavy civil construction is concerned, are the following:

Table 18-1. 1995 CSI *MasterFormat*

Division	Subject	Division	Subject
1	General Requirements	9	Finishes
2	Site Construction	10	Specialties
3	Concrete	11	Equipment
4	Masonry	12	Furnishings
5	Metals	13	Special Construction
6	Wood and Plastics	14	Conveying Systems
7	Thermal and Moisture Protection	15	Mechanical
8	Doors and Windows	16	Electrical

Table 18-2. 2004 and 2014 CSI *MasterFormat*: Applicable Divisions for Heavy Civil Projects

Division	Subject	Division	Subject
00	Procurement and Contract	11	Equipment
1	General Requirements	12	Furnishings
2	Existing Conditions	13	Special Construction
3	Concrete	14	Conveying Equipment
4	Masonry	26	Electrical
5	Metals	31	Earthwork (2004) Earthwork Methods (2014)
6	Wood, Plastics, and Composites	32	Exterior Improvements (2004) Bases, Ballasts, and Paving (2014)
7	Thermal and Moisture Protection	33	Utilities
8	Openings	35	Waterway and Marine Construction
9	Finishes		
10	Specialties		

- Addition of Division 00 (Procurement and Contract)—The scope of this division includes solicitation and invitation to bid, instructions to bidders, scope of work, schedules, existing conditions and data, bid forms, contract forms, bonding, general conditions, and supplementary conditions. This division also includes requirements of measurement and payment for unit price items, which were formerly under Division 1 in the 1995 *MasterFormat*.
- Shifting of most earthwork and foundation work, including site excavations, from Division 2 to a new division (Division 31). In the 2014 *MasterFormat,* base course and aggregates are part of Division 32 (Exterior Improvements), which is somewhat confusing.
- Electrical work is shifted from Division 16 to Division 26.
- New titles—In 2014, the title of Division 2 (Site Construction) is renamed Existing Conditions. The title of Division 6 (Wood and Plastics) is renamed Wood, Plastics, and Composites to include new composite materials. The title of Division 8 (Doors and Windows) is renamed Openings. The title of Division 31 is renamed Earthwork Methods. The title of Division 32 is renamed Bases, Ballasts, and Paving.
- Reserved divisions—Several of the divisions have no contents or titles. These are numbers reserved for future expansions in contents.

Each division is divided into sections. CSI has specific guidelines and recommendations for the subject matter, numbering system, and format for the sections. In the 2014 *MasterFormat,* each section has a six-digit number and a title. For comparison, each section in the 1995 *MasterFormat* had a five-digit number. In the new six-digit system, the first two digits of the section number (ranging from 00 to 48) refer to the division number and, therefore, are fixed for a given division. The third and fourth digits are "level 2" numbers (ranging from 00 to 99) that are assigned by CSI based on the type of construction and products. Some of the last two digits (ranging from 00 to 99) are assigned by CSI, with gaps that can be assigned by individual users for nonstandard titles that are not on the CSI *MasterFormat* list.

The following are examples of section numbers assigned by CSI in the 2014 *MasterFormat*:

013300	Submittal Procedures
014500	Quality Control
015700	Temporary Controls
017400	Cleaning and Waste Management
023200	Geotechnical Investigations
024100	Demolition
032000	Concrete Reinforcing
033900	Concrete Curing
055000	Metal Fabrications
099000	Painting and Coating
311100	Clearing and Grubbing
312316	Excavation
312323	Fill
313700	Riprap
321100	Base Courses
323100	Fences and Gates
324600	Subdrainage
329200	Turf and Grasses
352016	Hydraulic Gates
353119	Revetments
357300	Embankment Dams

Based on the section titles assigned by CSI in the 2014 *MasterFormat*, the following is a discussion regarding the application of each division to heavy civil construction work:

Division 1 (General Requirements)—This division contains general and administrative requirements, mobilization, procedural requirements (e.g., submittals, quality control, quality assurance, and closeouts), temporary facilities and controls, product storage and delivery, waste management, and construction layout and surveying. All of these requirements are stated once in this division, and they apply broadly to the work in the remaining divisions. Sections in Division 1 should be written broadly enough to apply to all sections in Divisions 2 through 48. Provisions in Division 1 should be an extension of the general and supplemental conditions, but should not be a repetition or contradiction to those conditions.

Division 2 (Existing Conditions)—This division contains subsurface investigation data, including geotechnical and geophysical data, survey data, environmental assessment, hazardous materials, demolition, and site remediation. Much of the traditional Division 2 work, such as earthwork, excavation, and foundations, is now located in Division 31.

Division 3 (Concrete)—All of the work items in this division are applicable for heavy civil construction, including concrete foundations, bridges, spillways, outlet works, tunnel linings, pipes, and manholes. This division includes cast-in-place concrete, precast concrete, grouts, shotcrete, and mass concrete work. A relatively new concrete technology is the roller-compacted concrete (RCC), which has been used worldwide in the application of water resources and pavements (Hansen and Reinhardt 1991). Another construction method similar to RCC is soil-cement, which has been used in wave protection, bank protection, and soil stabilization for many years.

Division 5 (Metals)—The applicable work in this division includes metal fabrication, metal stairs, railings, and gratings.

Division 9 (Finishes)—The applicable work in this division includes painting and coating, and special coatings such as epoxy coating.

Division 31 (Earthwork Methods)—This entire division is applicable to heavy civil work. It includes not only earthwork, but also most of the work in foundation and geotechnical engineering. Earthwork includes clearing and grubbing, stripping and stockpiling, grading, subgrade preparation, erosion and sediment control, excavation, dewatering, fill placement and compaction, and riprap. Foundation improvement processes include soil stabilization, rock stabilization, soil reinforcement, and slope protection. Foundation engineering work includes shoring and underpinning, excavation support and protection, cofferdams, slurry walls, piles, caissons, anchors, and tunneling.

Division 32 (Bases, Ballasts, and Paving)—This division covers the work of flexible paving (asphalt) and rigid paving (concrete), as well as the underlying base course and aggregate foundation. Other construction that is not obvious to the division title includes fences and gates, retaining walls, wetlands, plantings, turf, and grasses.

Division 33 (Utilities)—The applicable work in this division includes monitoring wells, relief wells, culverts, subdrainage, subdrainage piping, and ponds and reservoirs and their liners.

Division 35 (Waterway and Marine Construction)—Most of the waterway and marine construction listed in this division, such as shoreline protection, seawalls, bank protection, revetment systems, scour protection, and underwater work, is applicable to construction work for dams and reservoirs, natural streams and rivers, canals and artificial channels, and levees. This division also includes requirements for hydraulic and mechanical control equipment such as gates and valves.

The *MasterFormat* is intended as a guideline only. Depending on the size and nature of a project, individual subscribers to this format exercise considerable freedom to choose the applicable divisions and section numbers. At the same time, the selection of division and section numbers should be kept within the general framework of the

CSI *MasterFormat.* There are cases in which the selection of a division can be left to the individual users. For example, granular filters for foundation drainage can logically fit into either Division 31 or Division 33. A flexible, prefabricated concrete revetment system can logically fit into either Division 3 or Division 35.

18.3 SectionFormat

The standard CSI *SectionFormat/PageFormat* (CSI 2009) consists of three primary parts:

Part 1—General,
Part 2—Products, and
Part 3—Execution.

Part 1 contains administrative and procedural requirements specific to a section. Part 2 contains requirements for materials, products, equipment, or fabrication. Part 3 contains installation, placement, and testing requirements. This three-part section format is a revision of a previous version, which contained an additional part, Part 4—Measurement and Payment. Under the current *MasterFormat,* measurement and payment provisions are now under Division 00. In any case, even though the current standard contains three parts, some owners still prepare specifications in four parts.

The CSI section format is a guideline of where information should be shown. How the information is presented in each of three parts (e.g., articles, paragraphs, subparagraphs, numbering, margins, and capitalization) is contained in *PageFormat,* which is discussed in Section 18.4.

The following is a discussion of the items recommended in a CSI specification section. These items represent the articles that are major headings under particular parts. Articles should be numbered for references (e.g., 1.1, 1.2, 2.1, 2.2, 3.1, 3.2). The numbers of the articles in the discussion below are arbitrary, and the actual numbers should be determined for a particular project. Note that the article headings should be all capital letters.

Articles for Part 1—General

1.1 SUMMARY

This is an outline of the scope of the section. The scope should only contain major work items, but not incidental work (e.g., preparation, coordination with other work, and cleanup). The outline should be brief, and each item on the list should be limited to one sentence or one phrase if possible. For example:

1.1 SECTION INCLUDES

A. Furnishing and installing reservoir staff gauge.
B. Furnishing and installing piezometers.
C. Furnishing and installing survey benchmarks.

1.2 PRODUCTS SUPPLIED BUT NOT INSTALLED

This is a list of products or materials that are specified in Part 2 of a section, but the installation or placement specifications are not included in that section. If the products are installed for the project, then the section number containing the installation specifications should be referenced here. Otherwise, no other reference is needed. Two examples are given below that illustrate when the materials and installation are specified separately in different sections.

> Foundation anchor project—In this project, steel bars are grouted into the ground with cement grout. The cement grout material and the steel bars are specified in separate sections in Division 3 for cement and concrete reinforcements, respectively, and the placement of the grout is specified in a foundation anchor section in Division 31 (Earthwork Methods).
>
> Concrete revetment project—In this project, a concrete revetment is used to provide scour protection in a hydraulic channel. The precast concrete for the revetment is specified in Division 3 (Concrete), while the installation of the revetment is specified in a revetment section in Division 35 (Waterway and Marine Construction).

1.3 PRODUCTS INSTALLED BUT NOT SUPPLIED

This article lists the products that are installed based on specifications in Part 3 of a section, and using products specified elsewhere or furnished by the owner. If the products are specified in other sections, those sections should be referenced here. The same examples used above for "Products Supplied but Not Installed" are applicable here.

1.4 RELATED SECTIONS

This is a list of sections that contain work directly related to the work in a section. This listing should contain the section numbers and the complete section titles. For example, a section on cast-in-place structural concrete may contain the following related sections:

> 1.4 RELATED SECTIONS
>
> A. Section 031113: Structural Cast-in-Place Concrete Forming
> B. Section 031513: Waterstops
> C. Section 032111: Plain Steel Reinforcing Bars
> D. Section 033500: Concrete Finishing
> E. Section 033913: Water Concrete Curing

1.5 MEASUREMENT AND PAYMENT

This article contains measurement and payment clauses of paid items whose work requirements are specified in the section. It should be noted that it is not always possible to match work requirements in a particular section with the entire scope requirements of a particular paid item. In those cases, the measurement and payment clauses for a particular paid item will be in more than one section, which may cause confusion. For example, the work requirements for the paid item "Cast-in-Place Concrete" are contained in several sections, including cast-in-place concrete, reinforcement, concrete joints, forms, and curing. This article can be omitted in lieu of a single section in Division 1 that contains the measurement and payment clauses of all of the paid items.

1.6 REFERENCES

This is a list of standard reference specifications (see Section 17.4) that are used in a CSI section. With this reference list in Part 1, any reference to these standard specifications can be abbreviated, which shortens the length of the specifications. This reference list should contain only those specifications actually used in this section, rather than a complete "shopping list." It should be noted that the applicable date of each standard specification (e.g., ASTM C33-13) should be included in the reference, where the suffix "-13" refers to the latest year of issue, in this case 2013. Then, when that specification is cited elsewhere in the specifications, it is not necessary to include the date, that is, the suffix "-13" is not needed for ASTM C33. All standard specifications are updated from to time to time, and the updated year for a particular specification should be shown in one place only but not at every place where it is cited in the project.

1.7 DEFINITIONS

This article contains definitions of special or unusual terms. Examples of terms that can be defined here are *passes, percent compaction, rock excavation, unclassified excavation, refusal,* and *tempering time.*

1.8 DESIGN CRITERIA

When the contractor is required to design a particular feature of a project in a performance specification (see Section 17.3), the performance and design criteria are listed here. For example, the design criteria for a contractor-designed cofferdam may contain the following requirements:

1.8 COFFERDAM DESIGN CRITERIA

A. Temporary cofferdam shall be earthfill or rockfill embankments.
B. The crest of the cofferdam shall be at Elevation 2,150.0.
C. The crest width shall be at least 25 feet to allow equipment travel.
D. The embankment slopes shall be no steeper than 2H:1V (horizontal: vertical).

1.9 SUBMITTALS

The contractor submittal requirements are listed here. The contractor submittal is a process in construction that allows the engineer to review the proposed materials, products, procedures, sequence, etc., in advance before delivery or execution. Submittals can include materials data and samples, product data, shop drawings, proposed method and sequence, etc. The general procedure of the submittal process is contained in a section in Division 1, namely 013300: Submittal Procedures. When a submittal is required from the contractor, the following minimum information should be specified explicitly, regardless of the nature of the submittal:

- Title of the submittal (e.g., Dewatering Plan, Structural Concrete Mix, or Health and Safety Plan).
- Schedule of submittal related to other parts of the work (e.g., "Sediment and erosion control plan shall be submitted 21 calendar days before any excavation work." To avoid ambiguity, "calendar days" should be used instead of "working days" or just "days."
- Detailed list and requirements of submittal contents.

1.10 TESTING RESPONSIBILITIES

The article should clearly define the testing responsibilities of the contractor and the owner. The procedure of the testing process should be referenced to the general quality control requirements in Division 1, namely Section 014500: Quality Control. Detailed testing requirements should be located in Part 3. Some specifications do not contain owner testing requirements because they do not concern the contractor. However, adding that information is preferred for the following reasons:

- It allows the contractor to anticipate what tests will be performed by others so that proper and timely coordination can be arranged in advance.
- The design engineer preparing the specifications may not be involved during construction.
- Responsibility and cost of retests can be defined if the contractor's work does not pass the testing by the owner.
- There is a procedure to correct failed tests.

1.11 RESTRICTIONS

This article alerts the contractor of the restrictions that could affect his or her work. Examples of project restrictions include daily work schedule, traffic, working room, and noise. Reference to drawings may be required.

1.12 PROTECTION

Existing or new facilities that should be protected should be listed here. Protected items may include trees, wetlands, cultural resources, threatened or endangered species, streams, buried utilities, benchmarks, and adjacent properties. Typical specifications require the contractor to be responsible for any damage to the protected items, including repair of any damages.

1.13 PREPARATION AND SEQUENCE

This article contains a list of preparatory work that should be in place before performing work required in a particular section. Care should be taken not to use this article to limit the contractor's means and methods. Rather, the purpose of this article is to convey the designer's intent on a workable and constructable sequence. Through the submittal process, the contractor should be allowed to use a different sequence or preparation procedure that will accomplish the same result. For example,

1.7 CONSTRUCTION SEQUENCE

A. Erosion and sediment control shall be in place and approved by the engineer before stripping and excavation.
B. The temporary cofferdam shall be constructed before removing the existing structure.
C. The foundation subgrade shall be adequately dewatered and prepared before placing any fill.

Articles for Part 2—Products

2.1 MATERIALS AND PRODUCTS

More than one article may be required to list all the materials or product specifications, with one article for each material. When a material or product is specified here, the material or product name should match exactly the name used in the drawings and on the bid schedule. For example,

2.1 VENT PIPE

A. Steel pipe and fittings for vent pipe shall be 6-inch nominal diameter, schedule 40, conforming to ASTM A53, Grade B.
B. Vent pipe shall be standard weight and galvanized.

2.8 DRAIN GRAVEL

A. Drain gravel shall be hard and durable natural stone meeting the requirements of Illinois Standard Specifications for Road and Bridge Construction, 1997, Section 1004: Coarse Aggregate, Class A quality, Size CA-15.

2.2 EQUIPMENT

More than one article may be required to list all the equipment, with one article per piece of equipment. A descriptive specification, performance specification, or proprietary specification (see Chapter 17) can be used to describe the equipment. For example:

2.8 COMPACTION EQUIPMENT

A. Compaction equipment for drain sand and aggregate base course shall consist of self-propelled vibratory rollers and vibratory plate compactors. Vibratory rollers shall be approved by the Engineer and shall have a minimum static weight of 1,800 pounds per foot of compaction drum length, a minimum dynamic force of 8,000 pounds per foot of compaction drum length, and an applied force of not less than 3,000 pounds per foot of compaction drum length.
B. It is anticipated that vibratory plate compactors will be required for special compaction and in tight, restricted, or steep areas not accessible by vibratory rollers. Vibratory plate compactors shall be approved by the Engineer and shall have a minimum static weight of 270 pounds and a minimum dynamic force of 1,000 pounds.
C. Smooth rollers shall not be allowed for the compaction of embankment fill. Compaction equipment for embankment fill shall be a sheepsfoot roller or tamping roller or approved equal. The weight of each roller shall not be less than 4,000 pounds per foot of drum length. Compaction equipment for embankment fill shall be approved by the Engineer.
D. It is anticipated that smaller rollers may be required for special compaction and in tight, restricted, or steep areas not accessible by larger rollers. Smaller rollers shall be approved by the Engineer.

2.3 MIXES

Materials formed by mixing more than one ingredient in a plant or in the field are considered manufactured products. Proportions, ingredients, and procedures are specified here. Mixes commonly used in heavy civil construction include ready-mix concrete, bituminous concrete, mortar, grout, roller-compacted concrete, and soil-bentonite. For example,

2.3 RCC MIX PROPORTION

A. 9 percent portland cement, in percent of dry weight of aggregate
B. Optimum water content plus or minus one percent, in accordance with ASTM D1557.

2.4 FABRICATED PRODUCTS

Fabricated products require both written specifications and drawings for a complete description, and they generally require submittals for material compliance and shop drawings. Written specifications include material requirements, design criteria, performance criteria, and workmanship requirements. Graphical fabrication requirements such as dimensions and locations of materials are shown on the drawings, and should be referenced accordingly. Work quality requirements should be specified in Part 3. Commonly used fabricated products in heavy civil construction include reinforcing steel bars for structural concrete and fabricated metalwork (e.g., trash rack, ladder, grating, vent pipes, handrails, and gates).

Articles for Part 3—Execution

3.1 PLACEMENT AND INSTALLATION

The placement or installation requirements and procedures for the specified materials, products, equipment, mixes, and fabricated products are included here. For an orderly presentation and quick location, it is recommended that the procedures follow the same order in which the materials or products are listed in Part 2. Placement or installation procedures for materials or products that are specified elsewhere in another section are also located here. For example,

3.4 PLACING AGGREGATE BASE COURSE

A. Place aggregate base course in maximum 12-inch-thick compacted lifts, and in accordance with paragraph 3.5.B.
B. Rework materials that have not been placed in accordance with these specifications. Reworking may include removal, recompacting, reconditioning, or combinations of these procedures, as required by the Engineer.

3.8 INSTALLATION OF SLUICE GATES

A. Sluice gates and accessories shall be installed in accordance with the gate manufacturer's recommendations.
B. Provide the manufacturer's recommended water-resistant lubricants.
C. The gate lift and stem guide shall be installed as shown in the drawings using the size and type of structural fasteners recommended by the sluice gate manufacturer.

3.2 FABRICATION REQUIREMENTS

This article contains work quality requirements for specified fabricated products. For fabricated metalwork, these requirements pertain to qualifications of welders, welding standards, and special project requirements. For example:

3.3 FABRICATION AND ERECTION

A. Except as otherwise specified, the fabrication and erection of structural steel and miscellaneous metalwork shall conform to the requirements of the AISC "Manual of Steel Construction—Allowable Stress Design," latest edition.
B. Fabricate structural steel and miscellaneous metal items to straight lines and true curves. Drilling and punching shall not leave burrs or deformations. Continuously weld permanent connections along the entire area of contact. Exposed work shall have a smooth finish with

welds ground smooth. Joints shall have a close fit with corner joints coped or mitered and shall be in true alignment. Unless specifically indicated in the drawings, there shall not be bends, twists, or open joints in any finished member nor any projecting edges or corners at intersections.

3.3 TESTING REQUIREMENTS

Field testing to verify compliance with design is stated here. Testing requirements include procedure, reference testing standards, data reporting, and acceptance criteria. For example:

3.5 COMPACTION MOISTURE AND DENSITY REQUIREMENTS

A. Structural fill shall be compacted in place to at least 95 percent of the maximum dry density and within minus one (1) percent and plus three (3) percent of the optimum water content, when tested in accordance with ASTM D698.

3.4 TOLERANCES

This article contains tolerance requirements that include thicknesses, deviation from design lines and grades, and angular deviation. Different tolerances are needed for different materials and construction methods. For example:

3.14 TOLERANCES FOR EARTHWORK

A. All earthwork except riprap shall be finished to within an allowable tolerance of plus or minus 0.10 foot from the grades shown in the Drawings.
B. Construct the riprap within a tolerance of three (3) inches above and 1 inch below the neat lines shown in the Drawing.

Not all sections require all three parts. As a minimum, Part 1 should always be used. When Part 2 or Part 3 is not needed for a section, the part title is still listed with the phrase “Not Used” under it.

18.4 PageFormat

The guidelines for arrangement of text on each page of the specification section are shown in the CSI *PageFormat* (CSI 2009). The guidelines include margins, page arrangement, section heading and ending, page header and footer, designations of articles, paragraphs, and subparagraphs. When these guidelines are followed, the text is presented clearly and facilitates easy reading.

The most unique feature of the CSI *PageFormat* is the organization in which information is presented and referenced. Text information is organized in the following hierarchy:

SECTION (six-digit section number plus section title)
  PARTS (three parts with standard part numbers and titles)
    ARTICLES (major subject titles with article numbers)
      Paragraph (article requirements with letter designation)
        Subparagraph (subordinate to paragraph with numbering)

The numbering system is important because it is used for referencing texts within the specifications. An article number includes a prefix for the part number, a decimal point, and one or two digits beginning with "1." The article title should be capitalized. An example of an article number is the following:

3.1 PLACING STRUCTURAL FILL

A paragraph number consists of an article number plus an upper-case letter, starting with "A." A paragraph may or may not require a heading, such as:

3.1 PLACING STRUCTURAL FILL

A. Place structural fill in maximum 9-inch loose lifts and compact to at least 98 percent of the maximum dry density in accordance with ASTM D698 within plus or minus 2 percent optimum water content.

The full paragraph designation for the example above is paragraph 3.1.A.

A subparagraph is used to elaborate on further requirements under a paragraph. Further subdivisions under subparagraphs are also called subparagraphs. A subparagraph number consists of an article number plus a letter designation plus a number starting with "1." A subparagraph may or may not require a heading, such as the following:

2.4 CONCRETE MIX

A. Provide structural concrete for required structures with the following characteristics:
   1. Minimum compressive strength (28 days): 4,000 psi.
   2. Slump: 3 inches ± 1 inch.
   3. Maximum water–cement ratio: 0.45.

Three subparagraphs are shown in the example above, with designations of 2.4.A.1 for the compressive strength, 2.4.A.2 for the slump, and 2.4.A.3 for the water–cement ratio. Further subdivisions are allowed by CSI, but are not recommended. Further subdivisions of a subparagraph (which are also called subparagraphs) can use alternating lower-case lettering and numbers, such as 2.4.A.1.a or 2.4.A.1.a.1, etc. Excessive use of subdivisions beyond the first subparagraph level is not recommended.

CSI *PageFormat* also contains guidelines for section headings, endings, and page footers:

Section heading and ending: The first page of each section should have the section number and title centered at the top. The section title should be in all capital letters.

The end of the section should be designated with “END OF SECTION.” Some specification writers prefer to use “END OF SECTION” followed by the section number. No further text is allowed beyond this designation. Any tables, schedules, forms, etc., should precede the page containing this end designation.

Page header and footer: The page header is optional and is not a mandatory CSI requirement. When a page header is used, some of the following information can be used: project title, solicitation number, division number, and division name. The minimum information in the page footer should include the section title and page number. The page number starts with “1” and contains a prefix, which is the section number. For example, for Section 015100 (Temporary Utilities), the pages are numbered 015100-1, 015100-2, and so on. Therefore, every page on a set of specifications is unique, and can be referenced accordingly without ambiguity. Other optional information includes the project name, date of the specifications, and the electronic file name.

Exercise Problems

18.1 The outline of the technical specifications document can be started at the 30% design stage during final design (see Chapter 2, Table 2-1). Many of the specification divisions and sections can be identified from the work items on the bid schedule (see Section 19.2). Based on information from the following bid schedules, identify the divisions and sections, in 2014 CSI *MasterFormat* (Note: the 2014 *MasterFormat* outline can easily be downloaded from the Internet):

a. Work item descriptions of Bid Schedule A: see Fig. 18P-1.

b. Work item descriptions of Bid Schedule B: See Fig. 18P-2.

1. Demolishing and Removing Existing Concrete Structure
2. Stripping and Stockpiling Topsoil
3. Dewatering Foundation
4. Preparing Subgrade for Structure Foundations
5. Unclassified Excavation
6. Borrowing and Placing Embankment Fill
7. Furnishing and Placing Filter Sand
8. Furnishing and Placing Structural Fill
9. Furnishing and Installing Precast Concrete Manholes
10. Furnishing and Placing Cast-in-Place Concrete Structures
11. Furnishing and Installing Steel Handrails
12. Seeding and Reclaiming Disturbed Areas

Fig. 18P-1. Work Item Descriptions of Bid Schedule A

1. Sediment and Erosion Control
2. Temporary Earthfill Cofferdam Protection
3. Soil Excavation
4. Foundation Rock Excavation
5. Foundation Treatment and Preparation
6. Foundation Grouting
7. Furnishing and Placing Roller-Compacted Concrete
8. Furnishing and Installing 36-inch Hydraulic Gates
9. Furnishing and Installing 8-inch Drainpipes
10. Furnishing and Placing Aggregate Base Course for New Access Road
11. Furnishing and Installing New Chain Link Fences

Fig. 18P-2. Work Item Descriptions of Bid Schedule B

SECTION 106: SCOPE OF WORK

DESCRIPTION

106.1 This Contract includes the construction of two embankments and appurtenant structures as part of the South Yampa Court Dam. Major items of work include:

1. Site preparation including clearing, sediment and erosion control, and surface and groundwater controls.
2. Foundation excavation for embankments and appurtenant structures.
3. Constructing East and West Embankments.
4. Constructing a combined low-level outlet works and service spillway structure under the East Embankment, with all associated gates, pipes, and metalwork.
5. Constructing an emergency spillway structure in the left abutment of the West Embankment, with all associated metalwork.
6. Installing dam instrumentation.

106.2 Access to Site: Contractor shall limit operations to the area designated on the design Drawings. Other areas shall not be used by the Contractor unless authorized by the Owner in writing.

106.3 Health and Safety Requirements: The Contractor shall assume full responsibility for the health and safety of all of his or her on-site personnel and the protection of all equipment and materials.

106.4 No construction activity will be permitted until required submittals, if applicable, for that activity have been accepted by the Owner and Notice-to-Proceed has been issued for the applicable phase of the project.

106.5 A geotechnical data report for South Yampa Court Dam was prepared. The report contains results of the field investigations, subsurface conditions of the dam foundations, and limited data on the fill borrow area in the pond area. The geotechnical data are available from the Engineer upon request.

MATERIALS

(Not Used)

CONSTRUCTION REQUIREMENTS

(Not Used)

Fig. 18P-3. Example of a Non-CSI Specification Section for Scope of Work

18.2 Most modern specifications are in CSI format, but some organizations (notably the state highway departments) still use specifications that are not in CSI format. Convert the following non-CSI specifications into CSI format:

a. This non-CSI specification section contains the summary of work to construct a new dam consisting of two embankments and appurtenant structures. There are no materials requirements or installation requirements. When converted to CSI format, the section will contain Part 1 only; see Fig. 18P-3.

b. This non-CSI specification section contains general and material requirements for an owner to procure a new mechanical gate. This gate will be furnished to a contractor later for installation. When converted to CSI format, the section will contain Part 1 and Part 2, but no Part 3 (see Fig. 18P-4).

SECTION 722: SLUICE GATE

DESCRIPTION

722.1 Provide all labor, materials, equipment, tools, and services necessary to furnish a cast-iron sluice gate. This section includes requirements for materials of a cast-iron sluice gate conforming to AWWA C560 and as supplemented herein.

722.2 Submit shop drawings; certificate of compliance with AWWA C560; dimensional drawings, manufacturer's catalog data, and descriptive literature; calculations showing lift and stem sizing; manufacturer's installation instructions; and manufacturer's operation and maintenance manual.

722.3 Design criteria for sluice gate:

a. Sluice gate and appurtenances shall comply with AWWA C560.

b. The sluice gate shall be designed for a minimum seating head of 37 feet and a minimum unseating head of 10 feet.

c. Provide nonrising stem and manual lift.

MATERIALS

722.4 Materials of construction shall be as listed in AWWA C560.

722.5 The sluice gate slide shall be of one-piece construction.

722.6 Stem threads shall be machine cut or rolled and of the square or Acme type. The stems shall be supported with adjustable stem guides such that the l/r ratio (as defined in AWWA C560) does not exceed 200. Gate stem diameter shall be a minimum of 2 inches.

722.7 Provide a cast-iron floor box mounting for gate lift. The floor box shall have a lockable latching cover designed to be tamper resistant.

722.8 Floor box shall be supplied with a counter indicator for gate position. The lift nut in the floor box shall be 2 inches square.

722.9 Provide a manual gate lift conforming to AWWA C560. A maximum effort of 40 pounds shall be required to operate the gate at the specified operating head.

722.10 Provide a T-wrench for operation of the lift nut mounted in the floor box. Cross bar of the T-wrench shall be a maximum of 30 inches long. Bottom end of T-wrench shall be furnished with a 2-inch square socket to fit over the lift nut inside the floor box.

722.11 A cast iron wall thimble shall be provided by the sluice gate manufacturer for thesluice gate. The downstream flange of the wall thimble shall be drilled and tapped to match the mating pipe flange. The wall thimbles shall be E-type, circular, conforming to AWWA C560.

722.12 Bolts shall be stainless steel conforming to ASTMF593 or ASTM F594, alloy group 1 or group 2.

CONSTRUCTION RQUIREMENTS

(Not Used)

Fig. 18P-4. Example of a Non-CSI Specification Section for Sluice Gate

c. This non-CSI specification section contains excavation requirements. When converted to CSI format, the section will contain Part 1 and Part 3, but no Part 2. See Fig. 18P-5.

SECTION 213: EXCAVATION

DESCRIPTION

213.1 Excavation in the foundation for constructing the low-level outlet works structures and seep collar cutoff in the left abutment for constructing the emergency spillway structure; for constructing PVC toe drainpipe and other drainage facilities; and in borrow area.
213.2 Other excavation incidental to the work as specified herein and shown on the Drawings.
213.3 Disposal of all excavated materials that are not suitable for construction.
213.4 All excavations for this work shall be unclassified. This shall include excavation in soil, trench excavation, and excavation in bedrock.
213.5 Comply with all safety requirements of OSHA.
213.6 Protect existing structures, facilities, and instrumentation designated to be protected and any such facilities under construction during excavation. Damage to structures, facilities, and instrumentation designated as protected resulting from the Contractor's excavation activities shall be repaired by the Contractor at no cost to the Owner and to the satisfaction of the Engineer.
213.7 Protect existing trees, shrubs, and other vegetation as shown on the Drawings.
213.8 Blasting shall not be allowed for this work.
213.9 When excavating, dust shall be controlled within safe hygienic limits (less than 10 milligrams per cubic meter) as specified in "Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment," published by the American Conference of Governmental Industrial Hygienists.

MATERIALS

(Not used)

CONSTRUCTION REQUIREMENTS

213.10 Identify required excavation lines, levels, contours, and data, as shown on the Drawings.
213.11 All excavation shall be performed in the dry.
213.12 Excavate to the lines and grades as shown on the Drawings.
213.13 The Contractor shall assume all responsibility for deductions and conclusions as to the nature of the materials to be excavated and the difficulties of making and maintaining the required excavations.
213.14 The Owner reserves the right, during the progress of the work, to vary the slopes, grades, or the dimensions of the excavations from those specified herein. Where the Engineer determines that foundation material is unsuitable through no fault of the Contractor, additional excavation and backfill will be ordered in writing.
213.15 Take all necessary precautions to preserve the material below and beyond the established lines of all excavation. Any damage to the work or the foundations due to the Contractor's operations shall be repaired as directed by the Engineer at the expense of and by the Contractor.
213.16 Do not excavate in frozen materials, except with written approval of the Engineer.
213.17 Side slopes of all earth excavations shall be no steeper than shown on the Drawings. In all cases, excavations shall conform with all safety requirements of OSHA.
213.18 All excavations in the borrow area shall be in the dry, unless authorized in writing by the Engineer. Provide drainage in the borrow area for surface water runoff.
213.19 Stockpile excavated material suitable to be reused as embankment fill.
213.20 Stockpile materials within limits of site disturbance, in staging and stockpile areas, or other areas approved by the Engineer.
213.21 Excavated materials that are not suitable for embankment fill shall be disposed of.

Fig. 18P-5. Example of a Non-CSI Specification Section for Excavation

CHAPTER 19

Measurement and Payment Provisions

19.1 Importance of Payment Provisions

In heavy civil design, financial compensation of the contractor is handled through the bid schedule and the associated measurement and payment provisions in the specifications. The role and importance of the bid schedule and measurement and payment provisions frequently are overlooked by both owners and designers, yet these matters are the grounds for most construction disputes and claims. After the construction contract is awarded, the bid schedule becomes the payment schedule, and, together with the measurement and payment provisions in the specifications, defines how the contractor will be compensated. To account for a variety of field conditions and risk and unknown factors, most heavy civil construction projects—unlike building construction projects—are bid with a combination of unit-price items and lump sum items. Determining what work should be paid as unit-price items and what work should be paid as lump sum items requires careful consideration of the risk involved, uncertainties, unknown conditions, fairness to all the parties involved, and judgment. This chapter contains a discussion of preparation of bid schedules containing unit-price items and lump sum items, methods of measurements for unit-price items, payment of lump sum items, provisions for changed conditions and/or excessive changes from bid schedule quantities, and common sources of payment disputes and claims.

As discussed throughout this book, particularly in Chapters 3 and 15, heavy civil design projects inherently contain many conditions that are not apparent until construction is under way. Most of these conditions are related to excavation, earthfill, foundations, groundwater, buried structures, and other site work that is common to all heavy civil construction. Associated with these conditions is the risk to be taken by both the owner and the contractor. This chapter also discusses how the financial effects caused by uncertainties and unknowns can be minimized through careful consideration in selecting and formulating bid items in the bid schedule. It is fair to say that most construction disputes and claims are directly related to costs incurred by the owner and compensation to the contractor. When an owner, understanding the risk involved, feels that he or she is not overpaying the contractor for work within the contract scope, that owner is less likely to withhold payment to the contractor. When a contractor understands that he or she will be compensated for risk taken for work within or even beyond the contract scope, he or she is less likely to file claims.

It should be pointed out that there are other methods to compensate the contractor besides an agreed upon payment schedule, such as the force account and the cost-plus methods:

- *Force account* is a payment method used for extra work if the contractor and the owner cannot agree on a unit price or a lump sum price. Force account payments cover labor, equipment, and materials plus a certain percentage for overhead and profit.
- *Cost-plus* is a cost reimbursement payment method where a contractor is paid for all of its allowed expenses to a set limit plus additional payment for a profit.

When the payment schedule method with agreed upon prices is compared with force account or cost-plus contracts, it is obvious that there is more risk involved on the part of the contractor; however, the price schedule method also has the potential of more profit margin instead of a fixed percentage. An owner can engage a contractor very quickly, for example in an emergency situation, through force account or cost-plus arrangements and even without any detailed construction documents such as drawings and specifications. Some owners actually prefer using force account or cost-plus contracts even for a well-developed design with detailed drawings and specifications because they are protected from exorbitant change order costs.

19.2 Bid Schedule and Bid Strategies

A bid schedule is a breakdown of construction work items that the contractor uses when submitting his or her prices during bidding. The bid prices then become the basis for compensating the contractor for actual work completed during construction, and the approved bid schedule then becomes the payment schedule in the contract. Each item on the bid schedule contains a measurement and payment provision. A bid schedule is incomplete without the associated measurement and payment provisions that are typically included in Division 1 of the CSI technical specifications. For the following reasons, the proper time to start a bid schedule in a final design project is at the beginning of the design:

- The bid schedule contains the work items that will be used in construction drawings and technical specifications. The same terminology used in the bid schedule should also be used in the drawings and specifications. Establishing the bid schedule at the beginning of design defines the work items for the design team, improves coordination, and minimizes subsequent changes.

- Items in the bid schedule quickly lead to the outline of the required specification divisions and sections. This outline allows the specification writer to initiate the specification writing process early in the project.
- Formulation of the bid schedule provides an opportunity for the engineer to discuss with the owner various parties' shared risk and unknown conditions associated with each work item. Such dialogue between the owner and the design engineer should be started at the beginning of the project, rather than near completion.

Fig. 19-1 is an example of a bid schedule for a dam rehabilitation project. Some of the items in this example will be used for discussion in this chapter. The example is used to illustrate some key elements of a bid schedule:

Item No.	*Item Description*	*Quantity*	*Unit*	*Unit Price*	*Total Cost*
1	Mobilization/Demobilization	1	Lump Sum	________	________
2	Clearing	1	Lump Sum	________	________
3	Foundation Dewatering	1	Lump Sum	________	________
4	Sediment and Erosion Control	1	Lump Sum	________	________
5	Stripping and Stockpiling Topsoil	4,600	Cubic Yard	________	________
6	Demolition	1	Lump Sum	________	________
7	Diversion and Temporary Cofferdam	1	Lump Sum	________	________
8	Unclassified Excavation	10,000	Cubic Yard	________	________
9	Borrowing and Placing Embankment Fill	34,000	Cubic Yard	________	________
10	Furnishing and Placing Filter Sand	1,270	Cubic Yard	________	________
11	Furnishing and Placing Aggregate Base Course	100	Cubic Yard	________	________
12	Furnishing and Placing Riprap	660	Cubic Yard	________	________
13	Furnishing and Placing Riprap Bedding	350	Cubic Yard	________	________
14	Outlet Works Modifications	1	Lump Sum	________	________
15	Service Spillway Structure	1	Lump Sum	________	________
16	6-Inch PVC Slotted Drainpipe	600	Linear Foot	________	________
17	Concrete Sill for Emergency Spillway	1	Lump Sum	________	________
18	Instrumentation	1	Lump Sum	________	________
19	Reclamation of Disturbed Area	6.5	Acre	________	________
Total Items 1–19					________

Fig. 19-1. Example Bid Schedule

Key Elements of a Bid Schedule

Item Number

The item number is important for cross-referencing with the measurement and payment provisions and also for quick referencing during evaluation of the contractor's progress payment requests during construction. The order of the items in the schedule is not important; however, there are two common ways to list the items:

- In approximate chronological order in which the work will be performed or
- In order of increasing CSI section numbers.

In the example shown, the first item is mobilization and demobilization, and the last item is seeding for reclaiming the disturbed areas at the end of the project. It is preferable to list the bid items in the chronological order in which the work is being performed.

Item Description

The description should be chosen carefully and should be as short as possible. The item descriptions in the bid schedule and in the measurement and payment provisions in the specifications should match word for word. In addition, the names of the materials used in the item description (e.g., "filter sand" in Item 10, or "riprap bedding" in Item 13 in Fig. 19-1) should be exactly the same as those used in the construction drawings and technical specifications. The item description also can indicate what the work scope entails. For example, in Fig. 19-1, Item 9 "Borrowing and Placing Embankment Fill," it is clear that the embankment fill material will be obtained from an owner-furnished borrow site and is not an import material. It is also clear that the bid item includes all activities from borrow-pit development to final in-place fill after compaction. In another example, in Fig. 19-1, Item 12 "Furnishing and Placing Riprap," it is also clear that the riprap will be imported from off site, and the material source is the contractor's responsibility. That bid item includes all costs of purchasing the riprap, hauling it to the site, stockpiling if necessary, and placing it.

Quantity

The quantities indicated on a bid schedule are also referred to as *plan quantities* or bid quantities, which are the basis for the bid. The plan quantities are based on the engineer's best estimate of the work scope and are used for unit-price items. Quantity calculations during design are discussed in Section 22.2. When the actual construction quantities differ significantly from the plan quantities, the contract usually allows the contractor to renegotiate the unit-bid price (see Section 22.5). The procedure and criteria for price adjustment for differing quantities are contained in the general conditions and supplemental conditions of a contract and can be different for different owners and agencies. The quantity for lump sum items, of course, is unity.

Unit

The unit is used for measurement for payment of a unit-price item. Units should be carefully selected and should be practical, meaning that the quantity can be readily measured or calculated. For example, most excavation and earthwork are measured in cubic yards, pipes are measured in linear feet, and fabric materials such as geotextile fabric are measured in square yards or square feet. The location of measurement should be defined in the measurement clause in the specifications. For example, earthfill can be measured in the stockpiles, but most often they are measured in place, that is, after compaction. The location of measurement is important particularly for earthwork because of the volume changes from excavation, hauling, stockpiling, and compaction.

Unit Price

Unit prices are submitted by a bidder and should include all costs as defined in the payment clause in the specifications. The costs may include materials, delivery, labor, equipment, and the contractor's overhead and profit. For unit-price items, the unit price is the cost that is prorated over the bid quantity. The unit price for a lump sum item is, of course, also the lump sum price. Estimating construction costs during design is discussed in Chapter 23.

Total Cost

The total cost of each item is the product of the plan quantity and the unit or lump sum price.

During design, it is the design engineer's responsibility to discuss the bid schedule, measurement provisions, and payment provisions with the owner, and the final version of the bid schedule should be agreeable to both parties. Most owners may not be interested in design criteria and details, but they are always interested in how the construction will be paid. Obtaining a concurrence from the owner on the bid schedule during design is particularly advantageous in the event of measurement-related or payment-related disputes with the contractor during construction. The engineer only needs to concentrate on dealing with the contractor and does not need to explain his or her position to the owner.

Bid Strategies

Several bid strategies can be used to prepare a bid schedule that provides the best price for the owner and fits within the owner's construction budget. Before discussing the bid strategies, the following terms are defined:

Base bid—The base bid is a compilation of contract work items that the owner will be obligated to award to the winning contractor. All bidders are required to bid on the base bid.

Bid alternative—A bid alternative is an alternative work item to replace one or more related work items in the bid schedule. When bid alternatives are used for a work item, only one of the alternatives will be awarded. Each bidder should only bid on one of the alternatives.

Bid additive—A bid additive is an optional work item in addition to the base bid work, and this optional work may or may not be awarded, depending on the owner's available budget. At the owner's discretion, a bid additive might be added to the base bid work. More than one bid additive can be used, and the bidders are required to bid on all of the bid additives.

A bid alternative is used when the design engineer feels that there is more than one technical solution to a particular feature in the project. The best price or the preferred solution may be determined by the bids received during bidding. By allowing the contractors to bid on an alternative, the designer is soliciting the experience and technical expertise from the contractor to determine what is most cost-effective for the project. It should be pointed out that the designer should provide the design of all bid alternatives, including the drawings and specifications, in equal levels of details. In addition, all the alternatives should be technically equivalent, allowing an "apples-to-apples" comparison during bid evaluation. Two examples of this strategy are given below.

Dam Drainage Gallery

Several methods (conventional forming, precast concrete panels, and removable "balloon" forms) can be used to construct a drainage gallery in a concrete dam. Three acceptable methods are specified, and the bidders are invited to bid on any one of the alternatives for Bid Item 8:

Bid Alternative 8A—Furnishing and Installing Drainage Gallery with Conventional Forms.
Bid Alternative 8B—Furnishing and Installing Drainage Gallery with Precast Concrete Panels.
Bid Alternative 8C—Furnishing and Installing Drainage Gallery with Removable "Balloon" Forms.

Based on the bid prices, only one of the bid alternatives (8A, 8B, or 8C) will be awarded for Bid Item 8.

Concrete Culverts

New concrete culverts are needed on a small remote island for drainage improvement, and the island has no facilities for manufacturing concrete. All concrete will need to be shipped a short distance from mainland by boat. Two different methods of culvert design are allowed—cast-in-place concrete, and precast concrete—and the contractor is invited to bid on either one of the two alternatives for Bid Item 5:

Bid Alternative 5A—Furnishing and Installing 4 feet × 6 feet Cast-in-Place Concrete Culverts.
Bid Alternative 5B—Furnishing and Installing 4 feet × 6 feet Precast Concrete Culverts.

With a limited project budget, owners can use bid additives to solicit bid prices on construction work, and the owners are not contractually obligated to award bid additives work. Similar to bid alternatives, the designer should also prepare the design of all bid additives, so that they can be biddable and constructed if these work items are awarded. When favorable bid prices are received for base bid and bid additives that would fit within the project budget, some or all of the bid additives will be awarded along with the base bid. If high bid prices are received for a base bid and bid additives, then only the base bid work will be awarded and the bid additives are not added to the contract. This is the owner's way of "shopping around" for prices, and it is perfectly legal and ethical. An example is given below to illustrate this strategy.

Bituminous Pavement Repair

Two miles of a paved road are in need of repair, but the owner (county) only has funding to repair an estimated 1.5 miles of the road. A base bid is set up for 1.5 miles of road repair, with a bid additive for the remaining 0.5 miles of the road.

Base bid—Paving 1.5 miles of County Road 178 with Asphalt, Sta. 11+50 to 90+70.
Bid additive—Paving Additional 0.5 mile of County Road 178 with Asphalt, Sta. 90+70 to 117+10.

In this example, there were many bidders for the project, and the bids were much lower than the engineer's estimate. As a result, the owner was able to award the work in the bid additive.

19.3 Methods of Payment

For heavy civil construction, some work items are paid on a lump sum basis, and some work items are paid on a unit-price basis, and typically a combination of both methods is used to complete the project (see, for example, Fig. 19-1). The following are some guidelines on selecting an appropriate payment method for different types of work in heavy civil projects.

Unit-Price Method

The unit-price method is used when actual quantities are difficult to determine exactly during design. This method allows the contractor—without going through change orders—to be paid for the actual quantities encountered during construction. Typical work items paid using this method include clearing and grubbing, driven sheet piles, backfill concrete, foundation drilling and grouting, excavation, and earthwork. When a work item is paid by the actual quantity completed, the quantity must be measured for payment. The administration of construction for measurement and payment is beyond the scope of this book.

Lump Sum Method

The lump sum method is used when the work performed cannot be measured practically for payment purposes, or when the scope of work can be accurately defined. Typical work encountered in heavy civil projects that are difficult to measure for payment purposes include mobilization, demobilization, foundation dewatering, stream diversion, cofferdam protection, and demolition of existing structures. When the work scope and/or quantity can be accurately defined, the contractor can prepare an appropriate bid for all of the anticipated costs, and the work item can be performed on a lump sum basis. For example, if all of the dimensions of a new concrete structure can be identified during design, along with all of the appurtenant components, then this work can be performed using the lump sum method. An advantage for bidding such a structure as a lump sum work is that there is no need for measurement for payment. Another advantage is that it simplifies the bid schedule. When a work item is paid in lump sum, the contractor is entitled to progress payments for that work item, based on the estimate of percentage of the work completed during each pay period.

19.4 Definition of Measurement Methods

When a work item is specified as a unit-price paid item, the completed work will need to be measured for payment during construction. The measurements can be performed by the contractor or by the owner, depending on the provisions of the contract. It is important to include in the measurement provisions the units and level of accuracy that will be used for measurement. For example, if clearing is being paid by number of acres, will the area be measured to the nearest acre or to the nearest 0.1 acre? If earthfill is being paid in cubic yards, then where is the volume measured: in stockpiles or in place? To avoid disputes during construction, the specifications should state explicitly the method of measurement, as illustrated by the following measurement provisions:

Stripping and Stockpiling Topsoil will be measured for payment in cubic yards in the stockpiles after stripping, to the nearest cubic yard.

Embankment Fill will be measured for payment in cubic yards of fill in place at the locations and to the neat line shown on the Drawings, and measured to the nearest cubic yard.

Steel Sheet Pile Cutoff Wall will be measured for payment in square feet of wall driven at the locations shown on the Drawings, or as accepted by the Engineer, measured to the nearest square foot.

Backfill Concrete will be measured for payment in cubic yards of concrete in place and approved by the Engineer, and measured to the nearest cubic yard.

Grouting will be measured for payment in cubic feet of grout being pumped into the voids outside of the pipe, to the nearest cubic foot, and approved by the Engineer. Wasted grout not pumped through the grout nipples will not be entitled to payment.

19.5 Payment of Lump Sum Work

Because the information is important to the contractor for financing the construction and preparing the bid, the method of payment for lump sum work should be defined in the specifications. Some of these cost items, such as mobilization, demobilization, and large structures, can be a significant percentage of the project. The contractor is entitled to partial payment of lump sum items for work completed or for materials and equipment delivered to the site. A typical way to provide progress payment to the contractor for lump sum items is through milestone completion. When milestone completion is not specified for a lump sum item, an estimate of the percent completion for that item will be needed for payment purposes. Some examples of schedule of payment provisions for lump sum items are the following:

Schedule of payment for Mobilization/Demobilization shall be as follows:

1. The total amount of premiums paid by the Contractor to obtain performance and payment bonds will be paid at one time, together with the first progress payment.
2. When 5 percent of the total original contract amount is earned from other schedule items, 50 percent of the amount bid for Mobilization/Demobilization will be paid, less any amount already paid the Contractor for performance and payment bond premiums.
3. When 10 percent of the total original contract amount is earned from other schedule items, an additional 40 percent of the amount bid for Mobilization/Demobilization will be paid.
4. When the Contractor has demobilized from the site and the project has been inspected and accepted by the Owner, the balance of the amount bid for Mobilization/Demobilization will be paid.

Schedule of payment for Furnishing and Installing Pumping Wells shall be as follows:

1. After the pumping wells outside the drain walls have been installed and tested during Phase 1, 90 percent of the lump sum bid price will be paid.
2. After groundwater initial drawdown between Phase 1 and Phase 2, 5 percent of the lump sum bid price will be paid.
3. After all remaining work required for this item has been completed in Phase 2, the remaining 5 percent of the lump sum bid price will be paid.

In the two examples above, the payment schedules are somewhat arbitrary, but they appear to be fair to the contractor and have been used in many actual projects. Whether the specified payment schedule reflects the actual costs incurred by the contractor to reach a particular milestone is not as important as defining that schedule in the specifications during bidding. The bidder will account for any difference between the amount compensated by the owner and the actual cost as finance charges in the bid. When the payment schedule is clearly defined at the outset, there is no dispute during construction.

19.6 Writing Measurement and Payment Clauses

Measurement and payment clauses for paid items in the bid schedule are typically located in the technical specifications. In the latest CSI specifications format (both 2004 and 2014 versions), the price and payment procedures are assigned under Section 012000 in Division 1. It is recommended that the measurement and payment clauses of all paid items in the bid schedule be contained in a single section so that these provisions can be readily located. Regardless of where the clauses are located, measurement and payment clauses should accompany every paid item in the bid schedule. The following is a list of guidelines for preparation of these clauses:

- The same item number in the bid schedule should be used in the clauses, and the measurement and payment clauses should be listed in the same order as in the bid schedule.
- A consistent format should be used for each paid item. In particular, two paragraphs should be used: the first paragraph is used for measurement, and the second paragraph is used for payment. A measurement paragraph is suggested even for lump sum paid items for completeness and clarity, even though it appears to be trivial.
- The measurement provisions should state whether the paid item will be measured for payment. Lump sum items will not be measured for payment. Unit-price items will be measured for payment, and the unit, location, and the accuracy of the measurement should be specified.

- The payment provisions should list briefly all cost components that will be included under a particular paid item for both unit prices and lump sum price items, as well as exclusions of work not covered under this item.

The following are some example measurement and payment clauses using the example bid schedule in Fig. 19-1.

Item 3: Foundation Dewatering

a. Foundation dewatering will not be measured for payment.
b. Payment to the Contractor for dewatering work will be made at the lump sum price bid in the schedule for Foundation Dewatering. The price shall include all costs for providing materials, equipment, and labor to install, operate, and maintain all dewatering pumps, including pumps, piping, sump pits and backfill, and other facilities for the control, collection, and disposal of groundwater for the proper construction of all contract work; maintaining foundations and other parts of the work free from water as required; complying with all applicable environmental protection laws and permits, and requirements for operation of the dewatering system; and removing all components of the dewatering system after dewatering is complete.

Item 8: Unclassified Excavation

a. Unclassified excavation will be measured for payment in cubic yards, to the nearest cubic yard, of materials excavated in place to the limits of excavation shown in the Drawings, or otherwise approved in writing by the Engineer.
b. Payment to the Contractor for authorized excavation will be at the unit price per cubic yard bid in the schedule for Unclassified Excavation, which price shall include excavating, stockpiling of materials to be reused, and disposal of excavated materials not suitable or required for construction. Unauthorized excavation will not be paid for.

Item 11: Furnishing and Placing Aggregate Base Course

a. Aggregate base course will be measured for payment in cubic yards in place to the neat lines shown in the Drawings, to the nearest cubic yard.
b. Payment to the Contractor for aggregate base course will be at the unit price per cubic yard bid in the schedule for Furnishing and Placing Aggregate Base Course, which price shall include all costs for equipment, materials, and labor to purchase the material, delivering to the site, stockpiling, and placing the material.

Item 14: Outlet Works Modifications

a. Outlet works modifications will not be measured for payment.
b. Payment to the Contractor for outlet works modifications will be at the lump sum price bid in the schedule for Outlet Works Modifications,

which price shall include all labor, materials, and equipment to place the upstream concrete collar; grouting of the existing 36-inch pipe; new 24-inch PVC pipe; concrete pipe encasements and joints; concrete outlet basin; and all concrete testing.

Item 17: Concrete Sill for Emergency Spillway

a. Concrete sill for emergency spillway will not be measured for payment.
b. Payment to the Contractor for concrete sill will be at the lump sum price bid in the schedule for Concrete Sill for Emergency Spillway, which price shall include all labor, materials, and equipment to furnish and construct cast-in-place concrete sill wall, and concrete testing. Excavation to construct the wall will be separately paid for.

Exercise Problems

19.1 Recommend a bid item description to be used in a bid schedule based on the following construction work requirements:
   a. Purchase aggregate base course from a commercial sand and gravel pit, import it to the project site, and compact it as a cover material for a gravel road.
   b. Develop a borrow area provided by the owner to obtain a clay fill to be used as a storage pond liner.
   c. Clear a heavily wooded area, including removing the tree stumps and roots.
   d. Purchase 6-in. PVC pipes from a local distributor, send them to a machine shop for slotting, and then install them adjacent to a hillside for drainage.
   e. Reclaim and clean up disturbed areas at the end of construction, consisting of removing trash and leftover fill materials, grading, placing topsoil, and seeding the area with new topsoil.
   f. Install concrete forms and reinforcing bars, and then purchase and deliver ready-mix concrete to the site to place in the forms for new culverts.
   g. Fabricate a variety of metalwork, including handrails, gratings, trash racks, and air vent pipes.

19.2 Which payment method—unit price or lump sum price—should be used for the following work? Provide an explanation for the selection.
   a. Excavation for concrete footings.
   b. Concrete footings and walls for a house.
   c. Site demolition, including removing old concrete structures, buried pipes, chain link fences, and several timber outbuildings.
   d. Sheet pile cutoff walls, to be driven and keyed into a claystone bedrock. Boreholes indicate that the top of the rock is highly variable.
   e. Rock foundation preparation, consisting of removing highly weathered zones as needed, filling in low areas with dental concrete, and removing loose rock pieces.

f. A new hydraulic structure to be constructed with reinforced concrete, with a slide gate mounted on the upstream side to control water inflow and a chain link fence on top of the walls for safety and security.
g. Grouting the rock foundation under a concrete gravity dam through drilled holes.
h. Guardrails along the shoulders of a highway.

19.3 Write measurement and payment clauses to be included in the technical specifications for the following bid items. Use two separate paragraphs: one for measurement, and one for payment.

a. Unclassified Excavation (cubic yards)—Work includes excavating in foundation soil, rockfill, or highly weathered shale bedrock; stockpiling suitable excavated materials as backfill; and disposing of excess materials in on-site disposal area. Excavated materials will be measured in place from the existing ground surface to the limit of excavation shown in the Drawings.
b. Cast-in-Place Structural Concrete (cubic yards)—Work includes furnishing ready-mix concrete, forming, reinforcing, placing, finishing, and curing. Concrete will be measured in place to the neat lines shown in the Drawings.
c. Cofferdams and Stream Diversion (lump sum)—Work includes furnishing, installing, and removing upstream temporary sheet pile cofferdam, downstream earthfill cofferdam, 24-inch diversion pipe, and shutoff valves. This work will not be measured for payment.
d. Road Fill (cubic yards)—Work includes excavating fill materials from borrow area; moisture-conditioning and stockpiling if necessary; hauling to the road embankment; and spreading and compacting. Fill will be measured in place after compaction.
e. Riprap (tons)—Work includes purchasing riprap stones from off site, hauling to the designated stockpile area, and placing the riprap stones along the stream bank. The weight of the riprap will be based on weight tickets of the delivery trucks.
f. Precast Concrete Manholes (per each)—Work includes furnishing precast concrete manholes and manhole covers, access ladders, cast-in-place concrete bases, and gaskets. This work will be measured for each manhole completed.
g. Sediment and Erosion Control (lump sum)—Work includes furnishing, installing, and removing temporary hay bales, silt fences, and sediment collection ponds to control erosion and movement of sediments from surface runoff. This work will not be measured for payment.

CHAPTER 20

Presenting Reference Data

20.1 Technical Information from Design Investigation

Rarely are heavy civil construction projects constructed based on design drawings and technical specifications only. In most cases, data collected during the investigation and design phases are furnished to the contractor for his or her use. These data include topographic surveys, underground and existing structures and utilities, subsurface data, geologic data, laboratory and field test data, precipitation and weather data, and streamflow data. The importance of these data in heavy civil projects is discussed in Chapter 3. This chapter discusses how to incorporate these reference data in construction documents.

It is important to point out that, when data are included in the construction documents, these data become part of the contract, and as such, should be factual, accurate, and obtained with the same care and competency with which drawings and technical specifications are prepared. Any errors or omissions in these data are grounds for changed condition claims during construction.

Most of these data, such as subsurface data and test data, are obtained as part of the engineering investigations required for design. These data are typically summarized and presented in engineering reports. These reports also contain conclusions of findings, recommendations for design, and considerations for construction that represent interpretations, judgments, and evaluations by the engineer. Some owners and design engineers include these reports in their entirety in construction documents, with qualifications that the contractor should provide his or her own interpretations and evaluations on the data provided. This practice assumes that the contractor can separate factual data from the engineer's interpretations and evaluations. When the separation between data and interpretations is not straightforward and explicit, it is possible that the contractor will incorporate the engineer's interpretations and evaluations in planning his or her own work or preparing his or her designs (e.g., in performance specifications).

Construction documents furnished to the contractor should only contain factual data, not the engineer's interpretations, evaluations, and recommendations to the owner. When engineering reports contain site investigation data and test data that are relevant and important to the performance of the construction work, those data should be separated from the report before amending the construction documents. This chapter contains suggestions on presenting data in construction documents for heavy civil projects.

20.2 Reference Data

In general, reference data are any existing information that is relevant to the design and construction of the project. It is also referred to as available information. Most of the reference data contain site characterization information that represents the existing conditions of the site, such as site topography, geology, subsurface and groundwater conditions, prior use of the site, and environmental issues. In some cases, project permits are required from regulatory agencies for construction. A detailed discussion of site characterization and permits is contained in Chapter 3. In addition, because heavy civil construction is performed outdoors, and in many cases in or adjacent to waterways and other bodies of water, natural conditions of the site such as climate, precipitation, and streamflows also are relevant to the project. It is the responsibility of the engineer to obtain all relevant reference data for design and analysis and to provide the contractor with the appropriate factual data for construction.

The following is a list of data that are typically presented in construction documents for heavy civil projects. This list is not intended to be exhaustive, as each project may have other unique and special data requirements not included in this list.

Subsurface Data

Subsurface data include drill logs from boreholes, logs from test-pit excavations, field test data (e.g., standard penetration tests or field permeability tests), groundwater conditions in boreholes and test pits, observation-well installation and monitoring data, laboratory test data, and geophysical field investigation data. Some of these data can be conveniently included in construction drawings by using simplified graphic logs. In most cases, subsurface data cannot all be conveniently summarized graphically, and they should then be included as part of the technical specifications. Data that are commonly included in specifications include detailed field logs, field permeability values, water levels measured at the time of drilling (with an appropriate disclaimer clause), observation-well installation reports, and laboratory test reports.

Test Data

Results of field and laboratory test data collected during field investigations and laboratory testing are important information that the contractor needs for his or her work. For example, when an owner specifies that an earthfill borrow area should be used for a project, the engineer should furnish the relevant soil properties (e.g., natural water contents, plasticity, and compaction characteristics) to the contractor. Field permeability test results are useful to the contractor for planning his or her dewatering operations during foundation excavation. Field anchor test results for a clay shale foundation are useful to the contractor for designing the foundation anchors that are typically specified using performance-based requirements. Soil–cement mix design results are useful to the contractor for planning his or her material handling and mixing operations. When an owner-furnished quarry will be used as a source of riprap rock, the results of a test blast program will be useful to the contractor for planning his or her quarry blasting operations during production of the riprap.

Hydrologic and/or Climatic Data

All heavy civil construction takes place outdoors, and planning construction work to account for climatic factors (e.g., precipitation, freezing conditions, and storms) is just one of the risky elements inherent in this type of construction. In some cases, when work is at or near a stream, the risk of flooding at certain times of the year should be accounted for by the contractor. It is the owner's responsibility to gather as much of the climatological data as possible before construction and to provide these data to the contractor. However, some owners and engineers do not agree with this approach and would leave this type of information entirely to the contractor, thus requiring the contractor to absorb more risk.

Meteorological data can be obtained from the National Climatic Data Center of the National Oceanic and Atmospheric Administration. Information typically provided from this source includes mean maximum and minimum monthly temperatures, degree days, and precipitation records for the reporting station(s) close to the project site.

Streamflow records are available from the U.S. Geological Survey for the gauging station close to the project site. Streamflow records can be shown in graphical form, which is then inserted into the construction drawings set. It is preferable to present the data in table form in the specifications rather than in graphical form in the drawings to avoid any plotting errors introduced by the engineer. It is unnecessary to present both sets of duplicate information.

Records of Existing Structures

Many heavy civil projects involve rehabilitating or upgrading existing structures. Any available records on these existing structures furnished by the owner to the engineer for design should also be furnished to the contractor. These records are important to the design engineer for technical and constructability reasons, but they are also equally important to the contractor. If the structures will be demolished, that information would provide the contractor with the level of effort and equipment needed. If the structures are to be modified, that information would help the contractor understand how the new work would fit into the old structure, especially when some of the work would most likely be field-fitted. Equally important to the owner and the contractor is how the information is used to protect the existing structure that remains.

Frequently, records of existing structures include old record drawings. Old record drawings can be included in the construction drawings set to supplement data that are referenced in the specifications.

It is the responsibility of the contractor to review all of the reference data furnished by the owner. A contractor who fails to do so would lose his or her claim rights. Legally, contractors are held to the information and data in the specifications contained in the contract, regardless of whether they read them or not. This issue had been challenged in court and has been ruled in favor of the owner by the U.S. Court of Appeals (Loulakis and Gaba 2002). Therefore, contractors should be aware of the consequences of neglecting any of the relevant data in the contract.

20.3 Presenting Reference Data in CSI Format

The 2004 and 2014 CSI *MasterFormat* specifications have assigned the following sections under Division 00 to present available information:

Section 003100:	Available Project Information
Section 003119:	Existing Condition Information
Section 003121:	Survey Information
Section 003124:	Environmental Assessment Information
Section 003125:	Existing Material Information
Section 003126:	Existing Hazardous Material Information
Section 003131:	Geophysical Data
Section 003132:	Geotechnical Data
Section 003143:	Permit Application
Section 003146:	Permits

It should be noted that there are no sections assigned by CSI for hydrologic, precipitation, and climatic conditions, perhaps because these conditions are not critical to the building industry. However, these factors are very important for heavy civil construction. In the absence of CSI guidelines, the following sections can be used when needed:

Section 003210:	Hydrologic Data
Section 003220:	Climatological Data

Similarly, any relevant data that are not listed or discussed above can be added to Division 00 simply by adding new sections as deemed necessary by the designer.

PART 4

Cost Estimating

CHAPTER 21

Estimating and Funding Engineering Projects

21.1 Cost Estimating Process

In a broad sense, an engineer's construction cost estimate is a designer's prediction regarding the probable cost of a construction project. Traditionally, it has always been part of the engineer's responsibility to assist the owner to plan and budget the money needed for a construction project. Based on the engineer's estimate, the owner obtains the money necessary for construction. It is obvious that the engineer's cost estimate should be confidential before bid opening, and the information should not be shared with anyone interested in bidding on the construction of that project. Depending on a variety of factors that are discussed in the next few chapters, the actual construction cost may or may not be close to the engineer's construction cost estimate. Problems related to the accuracy of the engineer's estimates, between the project owner and the designer, occur from time to time. Now, liability-conscious design professionals and their legal advisors have stopped using the term *engineer's cost estimate* and replaced it with the term *opinion of probable construction cost* (Dixon 1998). Changing the way we label estimated construction cost does not make the problems go away or decrease the engineer's liability. What is important is for an engineer to perform this work in a professional and competent manner, similar to the work he or she has done in preparing the construction drawings and technical specifications. While the estimated cost of a construction project is really an engineer's professional opinion, there is nothing inherently wrong with the term "engineer's cost estimate" if the assumptions, guesses, and uncertainties are adequately discussed with the owner. In this book, the traditional term will be used for this process.

There are two separate steps in an engineer's cost estimate. The first step is estimating the quantities based on the design layout. Because they are calculated based on the layouts in the drawings (or plans), these quantities are also referred to as *plan quantities*. The second step is estimating the prices of construction work items, the so-called *pricing estimate*. The two sets of estimates—quantities and prices—are combined to obtain the total cost of the construction.

21.2 Levels of Estimate

Just as there are different levels of design (see Section 4.2), there are different corresponding levels of engineer's cost estimates. Because different contingency factors and unknowns are associated with each level, it is important to distinguish among various levels of a cost estimate. In the early phase of a project, an engineer's cost estimate is performed to compare costs of various technically feasible alternatives; this level of cost estimate is called a *planning-level cost estimate* or *feasibility-level cost estimate*. After a preferred alternative has been selected, an in-depth conceptual design is performed to obtain a *conceptual-level cost estimate* or *preliminary-level cost estimate*. Frequently, the owner uses the cost information and contingency factors recommended by the engineer at the conceptual level to obtain funding for the final design and construction.

The importance of a conceptual-level cost estimate cannot be overemphasized. The engineer only has limited design data and information to arrive at the funding-level cost estimate. It is at this level of cost estimate that the experience and judgment of the engineer play a significant role in the successful planning of the project. Because the design is conceptual or preliminary and nothing will be constructed from this design, many owners and design professionals underestimate the importance of using experienced designers for designing and estimating the cost of the project at an early phase. Inexperienced designers can commit significant errors because only limited analyses and site investigation are performed to support the design, and major cost items can be neglected in the cost estimate. Sometimes, these errors are not realized until final design, and sometimes they are not apparent until construction.

The following is an example of an engineer significantly underestimating the costs in conceptual design. A new high embankment dam will be built on Fort Union shale foundation, which is a clay shale with weak shear strength. Because of limited engineering budget at this early stage, the dam will be designed during conceptual design without the benefit of subsurface exploration, laboratory testing, and slope stability analysis. The designer, who is not a geotechnical engineer and who is not familiar with the engineering behavior of Fort Union shale, sized the embankment geometry by using the typical guidelines of a 3H:1V (horizontal:vertical) upstream slope and a 2.5H:1V downstream slope. During final design, the foundation was explored with drill holes and laboratory testing, and slope stability analysis was performed on the embankment slopes. In order to meet slope stability criteria, the upstream slope was found to require a minimum slope of 4H:1V, and the downstream slope was found to require a minimum slope of 5H:1V. The resulting embankment volume is about 50 percent higher than that estimated in conceptual design. On the other hand, an experienced engineer, especially if that engineer has a geotechnical engineering background, would have recognized that the weak clay shale foundation would control the embankment slope stability, and most embankment dams on similar foundations require very flat slopes. Therefore, a more conservative geometry should have been used in conceptual design, such as 5H:1V upstream and 5H:1V downstream.

The consequences of underfunding a construction project are more serious in federal construction projects than in private-sector projects. When underfunding for a federal project is discovered during final design, the project cannot go into bidding and construction. In such a situation, additional funding needs to be reallocated under the current budget, or it needs to be approved by Congress during the annual budgeting process, which results in long delays. Sometimes, designs must be revised to downsize the project in accordance with available funding. Neither prospect is attractive to federal agencies, and sometimes underfunded projects are simply terminated.

When a design concept goes into final design, plans and specifications are prepared, and a final-design-level engineer's cost estimate is prepared. Most projects then go directly into bidding, selection of a contractor, and construction. The engineer's cost estimate at this level serves many purposes:

- The engineer's cost estimate at this level is compared with the funding-level cost to evaluate whether adequate funding is available to complete the construction.
- The plan quantities on the bid schedule are used as a basis for bidding.
- The prices estimated by the engineer are used to evaluate the bids and/or negotiate with the contractor.

21.3 Roles and Responsibilities in Estimating

Estimating the cost of a construction project can be handled in at least three ways:

1. The engineer performs all of the cost-estimating work, including the pricing estimate.
2. A professional cost estimator performs all of the cost-estimating work.
3. A team of an engineer and a professional cost estimator shares the responsibilities of quantity estimate and pricing estimate.

The advantages and disadvantages of each arrangement are discussed below.

By Engineer Only

This arrangement is common in small to medium–sized firms that do not have their own in-house cost estimators. Typically, staff engineers calculate quantities, and more senior engineers estimate the prices. Historically, this approach has resulted in cost estimates that may vary widely compared with bids and actual construction costs. This problem is exacerbated when the project involves specialty construction, difficult site conditions, and a highly volatile bidding climate. Most engineers are not trained to estimate construction costs, and most of them lack the proper construction field experience to evaluate many different factors that will affect the cost of construction. These factors may include construction market conditions, the bidding climate, site remoteness, availability of local labor, production rates of crews and equipment, materials availability, and difficult site conditions.

When an engineer is uncertain about costs, the natural tendency is to be conservative. Although conservatism is essential for technical design and analysis, an overly conservative cost estimate is not always advantageous to the owner. An overly conservative cost estimate may have the following consequences:

- The owner's financial limitations may simply terminate the project.
- The fact that all of the bids are significantly lower than the engineer's cost estimate may raise some questions regarding the competency and credibility of the estimating engineer.
- Overfinancing of a project may cause financial problems for the owner.
- For state and federal projects, it may create problems allocating and managing all the money left over from overfunding.

When engineers perform the cost estimate, they can seek a second opinion (peer review) by engaging an outside professional construction cost estimator. This outside consultant essentially acts as a reviewer for the engineer and, in most cases, would make some contributions toward the quality of the plans, specifications, and constructability in addition to cost information. Given the consequences, an outside peer review is a good loss-prevention practice.

By Professional Estimator Only

Some large design firms are staffed with in-house professional cost estimators for the specific purpose of performing construction cost estimating. Many of these specialists are former contractors with field construction experience, and they may or may not have any technical training and background. The estimator can perform the work under two scenarios:

- The estimator is handed a set of plans, specifications, and a bid schedule, and he or she is required to perform all of the quantity takeoffs and estimate the prices of the items in the bid schedule.
- The estimator is handed a set of plans, specifications, a bid schedule, and plan quantities, and he or she is required to estimate the prices in the bid schedule.

Regardless of whether the estimator is given the quantities, he or she may approach the estimate in a similar manner as the bidders. The main difference is that he or she is not bidding on the project, so the objective is not to be the low bidder.

His or her goal is to target within the middle of the anticipated bid price range. In any case, the estimator works independently and usually is not involved during the design and, therefore, does not know the design intent, design criteria, site conditions, or site constraints. It is important that the cost estimator work with the design engineer to understand clearly the known and unknown design-related conditions and site constraints and limitations in order to prepare realistic unit prices or lump sum prices.

The use of professional estimators in cost estimating represents a significant improvement in the accuracy of the construction cost estimate, but that capability is reserved for a limited number of large firms with in-house estimators. The lack of a site visit by the estimators is a disadvantage, and the designers unintentionally may not give the estimator all of the necessary information to estimate effectively the cost of the construction.

Team of Engineer and Professional Estimator

The third working arrangement involves a cooperative effort between the design engineer and the professional estimator, and is the recommended arrangement. To use the expertise and knowledge of a professional cost estimator, an engineer should involve the estimator during design and then provide him or her with all of the pertinent information for the cost estimate. This cost estimator may be an in-house resource, or he or she may be an outside consultant. Specifically, the engineer should do the following:

- Allow the cost estimator to visit the project site—If bidders are given an opportunity to visit the site in a prebid meeting, why should the professional cost estimator be denied that opportunity?
- Provide pertinent information to the estimator—Pertinent information directly affecting the prices includes designer's assumptions on construction methods, sources of materials, preferred manufacturers and suppliers, owners' requirements (such as requirement of using union labor), and schedule of construction. Note that this information is privileged to the estimator only, but not to the contractors bidding on the project.
- Estimate and provide the quantities to the estimator—The quantities include both unit-price items and lump sum price items. Some construction cost estimators habitually check some of the key quantities independently, which results in improved quality control. The design engineer should provide a breakdown of quantities for lump sum items also, based on the payment provisions in the specifications. A good example is foundation dewatering work, which is typically paid in lump sum. For that bid item, the designer should provide the following breakdown to the cost estimator: method of dewatering (e.g., sump pumps or well points), duration when dewatering is required, and layout of dewatering equipment.

Based on the factors and considerations discussed above regarding the roles and responsibilities of cost-estimating personnel, it is clear that an adequate construction cost estimate should be performed with some level of involvement by a professional cost estimator. From a loss prevention standpoint, it is risky for the engineer to complete a construction cost estimate without the involvement of a professional cost estimator because most engineers are not adequately trained in estimating construction prices. Chapter 23 contains a more in-depth discussion on the problem of estimating construction prices by the engineer, including many uncertainties and complicated factors associated with estimating prices for heavy civil construction.

CHAPTER 22

Estimating Quantities

22.1 Units in Quantity Calculations

In heavy civil design and construction, quantities are estimated in units of length, distance, area, volume, or weight. The selection of units of measurement is based primarily on the ability to measure units practically and quickly during construction for payment purposes. When it is difficult or not practical to quantify the work with measurable units, such as foundation dewatering or site demolition, it is customary to use a lump sum method for payment (see Section 19.3).

Measurement of Length

Using length to represent work effort is suitable when the cross section is uniform along the limits of the work. The most common unit of length measurement is linear feet (LF). Examples of construction work that can be represented in linear feet are the following:

- Pipes (e.g., drainpipes, sewers, culverts, and storm drains);
- Drilling (e.g., drain holes or grout holes);
- Fence, guardrails, or handrails;
- Walls with uniform sections;
- Tunnels; and
- Pilings.

Measurement of Area

Using area to represent work effort is suitable when the thickness or depth is uniform within the limits of the work. The common units of area measurements are square feet (SF), square yards (SY), and acres (AC), depending on the total area involved. The use of square feet or square yards is a designer's preference, as the two units only differ by a factor of nine. When the anticipated quantity is large, say in the tens of thousands of square feet, it is more practical to use acres or thousand-square-foot

(MSF) as the unit of measurement. Examples of construction work that can be represented in areas are the following:

- Fabric (e.g., geotextiles, geomembranes, and erosion-protection mats) (SF or SY);
- Precast concrete panels (SF or SY);
- Shotcrete or gunite (SF or SY);
- Steel sheet piles (SF);
- Proof-rolling subgrade (SF);
- Pavement (SF);
- Clearing and grubbing (AC or MSF);
- Site grading (AC or MSF); and
- Reclamation of disturbed areas (AC or MSF).

Measurement of Volume

When the geometry is such that length and area are not suitable to represent the work performed, such as excavation and backfill, then it is best to use volume as a unit of measurement. Most volumes are measured *in place*, that is, after installation or placement. For example, excavation is typically measured as the difference between the existing ground surface before excavation and the limits of final excavation. Backfill is typically measured in place after compaction. When approval of materials in stockpiles is necessary, it is also customary to measure the materials in the stockpiles, such as stockpiles of topsoil that is stripped and the topsoil thickness is not uniform. To avoid disputes during construction, it is important to specify the location of measurement in the measurement and payment clauses (see Chapter 19) for earthwork. Section 22.4 discusses measurement and calculation of earthwork volume under different conditions.

The most common unit of volume in heavy civil construction is the cubic yard (CY). Smaller units, such as the cubic foot (CF), are used for mortars or grout. Examples of volume measurement are the following:

- Excavation, earthfill, aggregate base course, and riprap (CY);
- Conventional formed and unformed concrete (CY);
- Roller-compacted concrete and soil–cement (CY); and
- Grout and mortar (CF).

Measurement of Weight

Theoretically, volume and weight can be used interchangeably if the unit weight is known. When the material is transported by trucks, the weight is more readily available because the trucks can be weighed. The most common unit of weight is the ton (2,000 lb). Contractors typically purchase fabricated metals from fabricators in pounds. However, because the fabricated products usually are not weighed individually after installation in the field, the owner typically pays for the metals as lump sum items. When reinforcing steel is purchased separately, however, it is usually paid for in pounds. Riprap can also be measured and paid for in tons; in fact, contractors prefer to be paid this way because it eliminates the need for conversion from weight (easily obtained from truck scales in quarries) to bulked cubic yards in place. The issue of using weight or volume for payment of riprap is one of designer's preference.

Examples of weight measurement are the following:

- Riprap (tons);
- Asphalt (tons);
- Bulk cement and fly ash (tons);
- Cement for grouting (94-lb bags);
- Processed concrete aggregate (tons); and
- Reinforcing steel (pounds).

Other Units

Occasionally, construction work effort cannot be represented easily by length, area, volume, or weight. Examples of other units include the following:

- Per each (e.g., survey monuments, observation wells, anchors, and hookups for grouting);
- Hours (e.g., water-pressure testing, standby time, and crew and equipment time); and
- Days (e.g., pumping to remove water).

22.2 Quantity Calculations

Quantity calculation (also called *quantity takeoff*) is part of the engineering design process and, as such, should be performed with the same care and manner as other design documentation. It is suggested that the following general procedures be followed for quantity takeoff:

- The level of design, drawing revision number, bid item number, and date of calculation should be clearly stated on all calculation sheets.
- The method of measurement and calculation should be stated. When a planimeter is used, the data obtained from the planimeter should be recorded. When CAD software is used for quantity calculations, computer printouts should be attached and properly labeled.
- The same terminology used in the specifications and drawings should be used in the calculations. For example, if there are three different types of backfill

(e.g., select fill, general fill, and structural fill), each type of fill should be clearly differentiated and identified.

- The source of dimensions should be stated clearly. When dimensions are obtained directly from design drawings, the sheet number, cross-section designation, or stations should be referenced. When dimensions are assumed because they are not available in the drawings, the assumptions should be stated. This is particularly helpful for someone who is checking and reviewing the calculations. In fact, the person performing the calculations should always ask the following question: “Have I provided enough information for the checker?”
- When additional drawings or sketches are required to improve accuracy and resolution, the supporting drawings should be attached.
- Allowance should be made to account for unavoidable waste and overlap during construction. For example, when a geotextile fabric is installed, the panels are overlapped by an amount recommended by the manufacturer. The actual fabric area used is always larger than the finished area shown in the drawings. This quantity allowance is needed even if the fabric is measured as neat area without overlap.
- The estimator should refrain from excessive rounding of calculated quantities. In general, rounding should be performed at the end of calculation for a particular item, and not during intermediate steps. For example, it is appropriate to round off a number from 7908 CY to 7900 or 8000 CY, but not from 7122 CY to 8000 CY. Excessive rounding will increase the chance for a quantity to exceed the allowance during construction (see Section 22.5).
- Ample space should be reserved in the calculation sheets for the checker’s comments and additional calculations if necessary.
- Similar to checking other engineering calculations, the checker should use a pen of a different color to distinguish the original calculation from the checker’s comments. The checker should initialize and date the checked calculations for tracking and accountability.

Quantity calculations are required for all unit-price items on the bid schedule and may also be required to support some lump sum items. Examples of lump sum items that require quantity takeoff to support the pricing estimate include the following:

- Volume of concrete for a reinforced concrete structure, which should be broken down into footings, walls, and floor because each component has a different unit cost;
- Weight of fabricated metals;
- Breakdown of components for dewatering systems, stream diversion, cofferdam protection, etc.; and
- Breakdown of components for reclamation features, e.g., regrading area, topsoil quantity, seeding and mulching area, and pavement repair.

22.3 Methods of Computation

It is assumed that the reader is knowledgeable in basic mathematical skills and formulas to compute areas and volumes of commonly encountered shapes and geometric configurations. Mensuration formulas to calculate various geometric shapes, readily available in mathematics textbooks and other engineering handbooks, are not presented in this book. This section addresses the methodology of using information from design drawings in quantity computations and the tools used to complete such computations. In particular, this section discusses the method of estimating quantities of irregularly shaped geometrical design features, for which rigorous mathematical treatment is inappropriate or impossible, but which is common in earthwork calculations.

Length or Distance

Length or distance can be measured from the drawings with an engineer scale, or a map-measuring device. In design drawings, linear features—e.g., pipes, culverts, roads, and tunnels—are shown on plan views with control survey information, such as stations, curve lengths, northings, and eastings. When this type of information is shown in the drawings, it is recommended that the survey control data or dimension callouts should be used directly in the calculation of the quantities, rather than measuring the features. When depths of drill holes (for drainage or grouting) are shown in the drawings, the depths called out in the drawings should be used instead of direct measurement. Direct measurements are required when drawings are still in their feasibility or conceptual-design stages or in their early final design phase, when controls have not been established, and only a general layout is available for measurement.

Area Calculation

When an area to be calculated can be subdivided into regular shapes (e.g., triangles and trapezoids), the area is calculated using appropriate mensuration formulas. Again, dimensions directly called out in the drawings should be used and supplemented with other distances that can be measured with a scale. In most cases, however, areas are irregularly shaped in civil design and earthwork, and a planimeter can be used. A planimeter is a mechanical or electronic device that can be used to determine the area of any shape by tracing around the perimeter of the area. Although the accuracy of this instrument is independent of the irregularity of the area to be estimated, there is some difference in the result from different operators or even from different trials of the same operator. Therefore, it is recommended that each area should be traced at least twice, and the average of the measurements should be used to determine the area. Modern planimeters are electronic and have digital displays; they are capable of measuring areas in which the vertical scale is

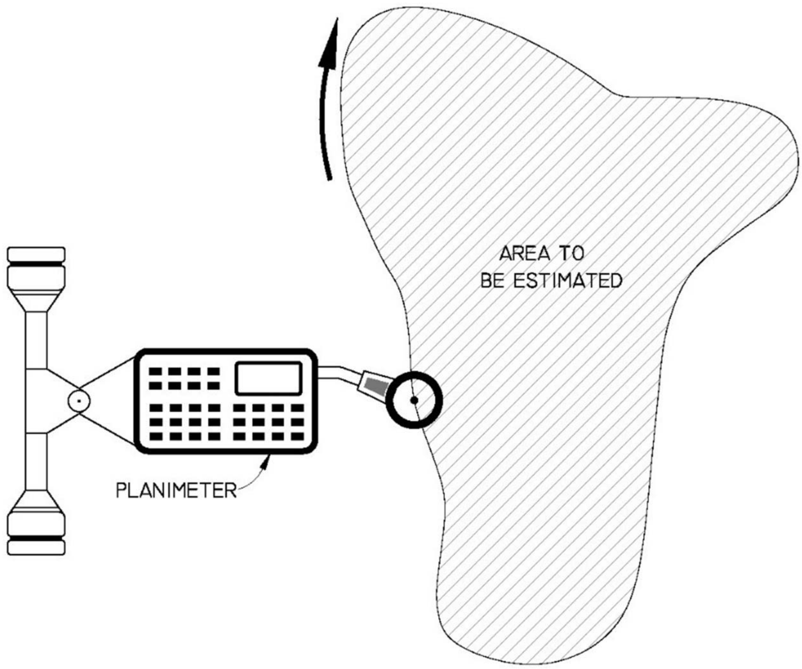


Fig. 22-1. Measuring Area with a Planimeter

different from the horizontal scale. Fig. 22-1 is an illustration of area determination using a digital planimeter.

When a drawing is drawn in CAD, areas can be determined with extreme precision using the computation capability of the software. As recommended in Section 22.2, all computer-determined quantities should be documented with a computer printout and checked by hand by the engineer, who also checks that the CAD drafter inputs proper area boundaries and scales. This check can be very coarse and is only for confirming the general value of the CAD printout data (±5% accuracy), unless the engineer checks the computer calculations using the same CAD program.

Volume Calculation

When a volume to be calculated can be subdivided into regular shapes (e.g., pyramids, cubes, or other prismatic components), such as for concrete and metal structures, the volume is calculated using appropriate mensuration formulas. Again, dimensions directly called out in the drawings should be used and supplemented with other distances that can be measured with a scale. For earthwork and excavations, however, volumes are irregularly shaped and other approximate methods of calculation are used. Methods to determine volume include the subdivision method, prismoidal method, average end-area method, and contour method. A comprehensive treatment of these methods can be found in Church's *Excavation Handbook* (1981).

By far, the *average end-area method* is most common to determine volumes for quantity estimates of earthwork and excavations. This method is popular because of its simplicity and acceptable precision for long structures (e.g., roads, levees, and pipelines). In this method, the volume of a three-dimensional object with parallel or near-parallel cross sections at each end is equal to the average of the cross-sectional areas at the two ends multiplied by the distance between the sections. Fig. 22-2 illustrates this method. Cross sections at some regular intervals, such as 50 ft or 100 ft, can be selected and drawn, and the areas of these cross sections are measured, most commonly with a planimeter (see the section titled "Measurement of Area" near the beginning of this chapter). Some useful guidelines for this method are given below:

- The number of cross sections required depends on the changes in cross sections of a particular feature. When the cross sections are relatively uniform, fewer cross sections are required. Sometimes, additional cross sections are required to characterize the change in cross sections. Most design drawings only contain a typical cross section that can be used to generate additional sections for quantity estimate. These additional sections do not need to be included in the design and construction drawings, but should be attached to the computation sheets for checking and future reference.
- The accuracy of this method depends on the distance between the cross sections. The smaller this distance, the more precise will be the volume estimate, but because more sections are involved, the effort will be more time-consuming. Therefore, the estimator will need to decide on a balance between precision required and the time and budget available for this work.

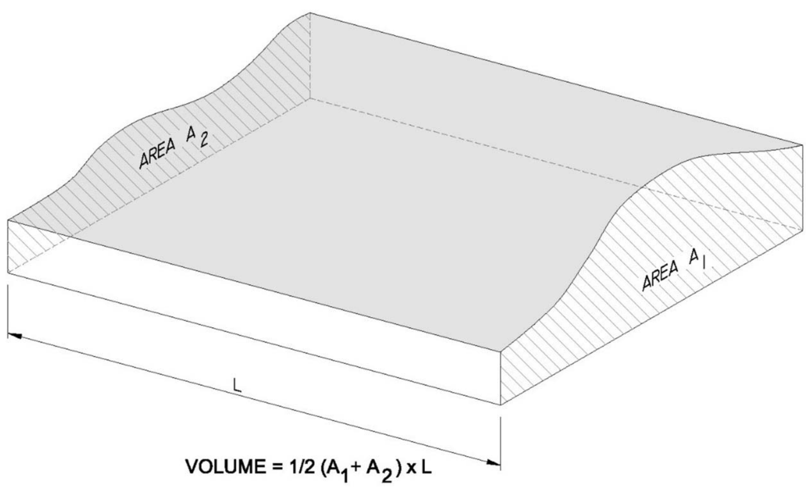


Fig. 22-2. Measuring Volume with the Average End-Area Method

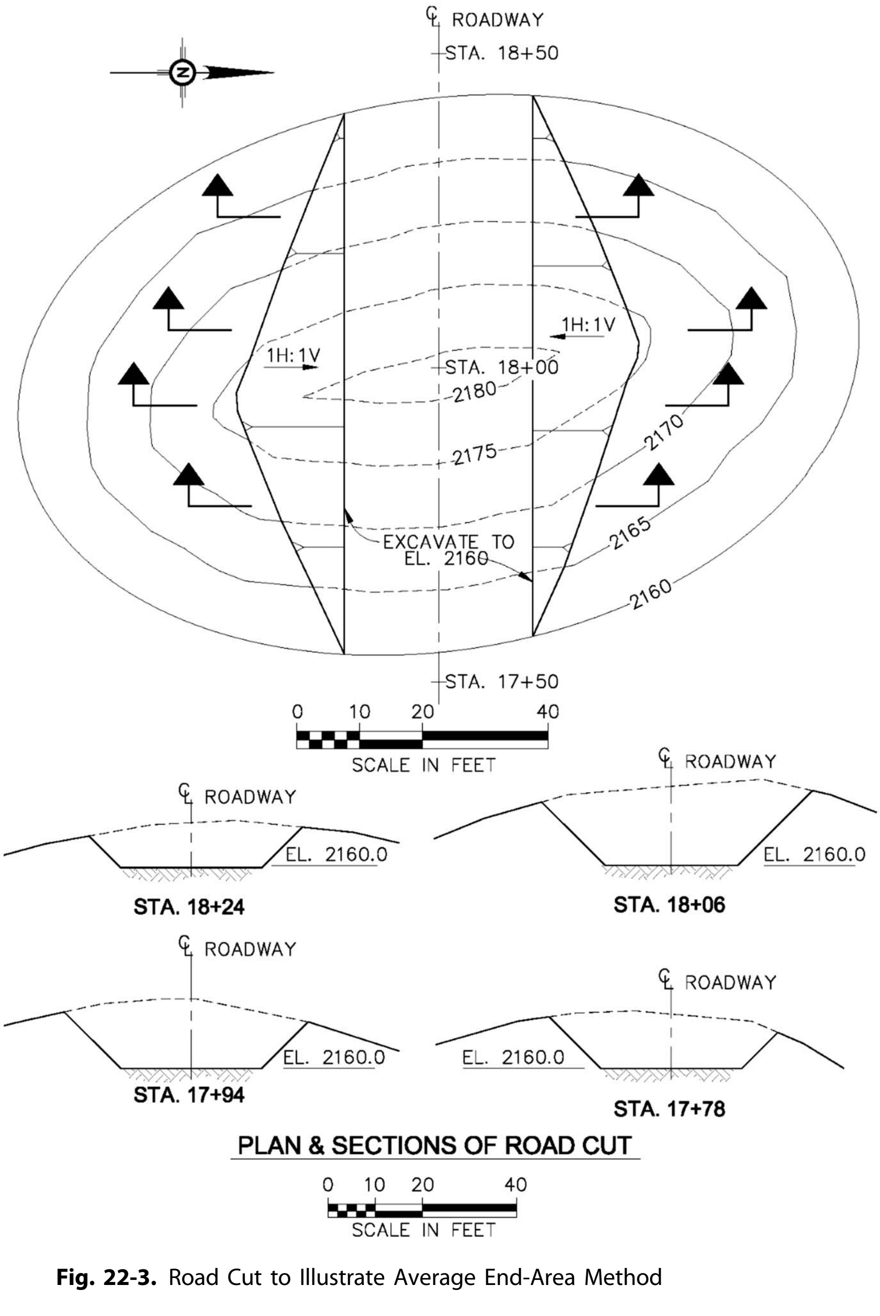


Fig. 22-3. Road Cut to Illustrate Average End-Area Method

As an example of the average end-area method, Fig. 22-3 shows a plan and cross sections for a road cut through a knob in the bedrock. Four cross sections are drawn, and the cross-sectional areas of the excavation are measured with a planimeter. The measured sectional areas and the calculations are shown in Table 22-1.

Table 22-1. Illustration of Average End-Area Calculation for Road Cut Excavation

Station	Areas (sq. ft)		Distance Between Sections (ft)	Volume (cubic yards)
	Section Area	Average Area		
17 + 60	0			
		203	18	135.3
17 + 78	406			
		581	16	344.3
17 + 94	756			
		810.5	12	360.2
18 + 06	865			
		562.5	18	375.0
18 + 24	260			
		130	13	62.6
18 + 37	0			
		Total Volume (cubic yards)		1,277.4

The estimated excavation quantity for the road cut in this example is 1,277 cubic yards, which can be rounded off to 1,280 cubic yards.

22.4 Earthwork Handling and Payment

Because the densities of earthwork materials change during excavation, handling, and placement, calculations related to earthwork—e.g., excavation, fill, and riprap—differ from quantity estimates for other materials, for example, concrete and steel, whose densities do not change. Regardless of the method used to compute the quantities, the following changes in volumes should be accounted for in earthwork calculations:

- Materials excavated from natural sources (so-called *bank-run* or *pit-run* materials) increase in volume in the haul trucks and/or in the stockpiles. This increase in volume is known as *swell*.
- Materials that are compacted by mechanical equipment decrease in volume when compared with loose stockpiles and sometimes when compared with bank-run materials. This decrease in volume is known as *shrink*.

When aggregates, filter materials, or riprap are paid for by weight in the payment schedule (see Section 22.1), conversion factors must be used to convert the in-place volumes into weights. Regardless of how these materials are paid, either the engineer or the contractor needs to use conversion factors for the following reasons:

- When materials are paid for by weight, the engineer needs to convert in-place volumes to weights. Because these materials are purchased and hauled based on weight, the contractor does not need the conversion process. The contractor prefers this method.
- When materials are paid for by in-place volume, the engineer does not need to use the conversion factors; that responsibility is shifted to the contractor. Not only does the contractor have to convert the materials from weights to volumes, he or she also must estimate the effects of swelling and shrinking during borrowing, stockpiling, and compaction and wastes during the handling process. The engineer prefers this method.

Swell factors and shrink factors can be used to account for changes in densities of excavated and compacted earthwork. Civil and mining engineers have used these factors for more than 100 years. A complete list of swell and shrink factors for a variety of materials, including soils, bedrock, ore materials, peat, and caliche, can be found in Church's *Excavation Handbook* (1981). Only factors related to soil materials, aggregates, and riprap commonly used in heavy civil construction are presented in this book.

Published swell and shrink factors are typically defined as follows:

$$\%\ \text{Swell} = \frac{(\text{bank run density} - \text{density in loosened conditions}) \times 100}{\text{density in loosened conditions}} \tag{22-1}$$

$$\%\ \text{Swell} = \frac{(\text{bank run density} - \text{compacted density}) \times 100}{\text{compacted density}} \tag{22-2}$$

The term "bank run" is an informal term used in heavy civil construction and the aggregate industry to denote natural state or composition of materials obtained directly from the ground without any processing. As defined in Eq. (22-1), the percent swell is generally a positive number, because most bank-run densities are higher than the densities in loosened or stockpile conditions. For soil materials, including clays, silts, sands, and gravels, the percent shrink as defined in Eq. (22-2) is generally a negative number, because the compacted density is generally higher than the bank-run density.

Current published tables of swell and shrink factors do not include conversion from loosened conditions (e.g., in stockpiles or in loaded trucks) to compacted condition. A third conversion factor, *compact*, is proposed for this scenario. The compact factor is defined as follows:

$$\%\ \text{Compact} = \frac{(\text{density in loosened conditions} - \text{compacted density}) \times 100}{\text{compacted density}} \tag{22-3}$$

As defined in this way, the percent compact can be calculated easily from the percent swell and shrink factors in published tables as follows:

$$\% \text{ Compact} = \frac{(\% \text{ Shrink} - \% \text{ Swell}) \times 100}{\% \text{ Swell} + 100} \tag{22-4}$$

For example, if the percent shrink is –10% and the percent swell is 35%, the corresponding percent compact is the following:

$$\% \text{ Compact} = \frac{(-10 - 35) \times 100}{35 + 100} = -33\% \tag{22-5}$$

Table 22-2 contains the percent swell, shrink, and compact factors for commonly encountered soil materials, including riprap. The table also contains conversion factors between weights and volumes.

The factors in Table 22-2 should be used with caution for the following reasons:

- By virtue of the different geologic formations, deposition methods, and soil compositions, bank-run soil materials are highly variable. The percent swell and percent shrink shown in the table are dependent on the bank-run conditions and represent only the average conditions.
- Loosened conditions are also highly variable, depending on a number of factors, such as method of excavation, moisture condition of the soil, and cohesion characteristics. The percent swell and percent compact in the table, which are dependent on the loosened conditions, represent only the average conditions.
- Compacted density is also highly variable, depending on a number of factors, such as the loose-lift thickness, size and type of the compaction equipment, and in-place moisture content. The percent shrink and percent compact shown in the table are dependent on the compacted density and represent only the average conditions.

In general, the factors in Table 22-2 are within the level of accuracy typically expected for an engineer's cost estimate. However, to better characterize the changes in densities of the various earthwork materials, a contractor planning his or her borrowing, stockpiling, hauling, and compaction operations—especially for large projects—should perform project-specific field and laboratory tests, such as test fills using proposed equipment and in situ density measurements of bank-run materials.

22.5 Allowance for Quantity Difference

This section discusses the contractual and cost implications of the difference between estimated quantity and the actual quantity required during construction. There are many reasons that the actual quantity of a particular work item can differ from the estimated quantity, such as the following:

Table 22-2. Earthwork Quantity Conversion Factors

Material	Unified Soil Classification	Volume Change Factors			Weight–Volume Conversion (ton/cu. yd)	
		% Swell	% Shrink	% Compact	Loose	Compacted
Gravel, clean, moist, poorly graded	GP, GP-GM, GP-GC	9	–7	–15	1.5	1.8
Gravel, clean, moist, well-graded	GW, GW-GM, GW-GC	9	–11	–18	1.6	1.9
Gravel, dirty, moist, silty fines	GM	9	–11	–18	1.5	1.8
Gravel, dirty, moist, clayey fines	GC	14	–9	–20	1.4	1.8
Sand, clean, moist, poorly graded	SP, SP-SM, SP-SC	10	–15	–23	1.4	1.8
Sand, clean, moist, well-graded	SW, SW-SM, SW-SC	9	–18	–25	1.4	1.9
Sand, dirty, moist, silty fines	SM	5	–16	–20	1.4	1.7
Sand, dirty, moist, clayey fines	SC	5	–15	–17	1.4	1.7
Silt, moist, low plasticity	ML	11	–9	–18	1.2	1.5
Silt, moist, high plasticity	MH	12	–10	–20	1.1	1.4
Clay, moist, low plasticity	CL	33	–8	–31	1.2	1.8
Clay, moist, high plasticity	CH	33	0	–25	1.2	1.6
Aggregate base course	GM, SM					
Dry		17	–18	–28	1.5	1.9
Moist		14	–16	–27	1.5	2.0
Filter/drain sand	SP, SW					
Dry		17	–21	–31	1.2	1.8
Moist		16	–19	–30	1.3	1.8
Topsoil	OL	50	–22	–48	0.8	1.6
Riprap						
D50 = 6 in.					1.45	
D50 = 9 in.					1.49	
D50 = 12 in.					1.50	
D50 = 18 in.					1.89	
D50 = 24 in.					2.20	

Note: D50 is the riprap diameter at which 50% of the total weight is finer.

- *Accuracy of the quantity estimating method*—The accuracy of different methods of quantity calculation varies. For example, areas and volumes determined with the planimeter method typically have an accuracy of ±0.5% to ±1.0%. Areas and volumes determined using CAD software yield better accuracy, but the results are only as good as the input data.
- *Errors in quantity calculations*—Errors can be committed by engineers and CAD drafters performing the calculations in many ways—e.g., inaccurate measurements, arithmetic errors, wrong equations, and wrong scales. As suggested in Section 22.2, all quantity calculations, hand calculations, and computer calculations should be checked to avoid errors. It is wishful thinking to assume that computer-generated calculations are always accurate and do not require checking.
- *Field conditions that differ from those assumed in design*—Field conditions that can result in different quantities of earthwork include different existing topography and different subsurface conditions that require different depths of excavation. This source of difference can be minimized by adequate site characterization effort during investigations and design. Some site work quantities, such as excavation, are based on the designer's assumptions regarding behavior of materials during construction. If the designer assumes that the ground can be excavated in a 1H:1V slope, but the actual ground is so loose and sandy that a 1.5H:1V slope is the steepest possible, then the quantity of excavation will be underestimated, as will the required backfill.
- *Design modifications during construction*—When design modifications are made during construction, quantities are usually affected by the change. Design changes during construction are handled through change orders.

Most construction contracts contain a provision to handle changes in quantities for unit-price work items. When the actual quantity of a particular bid item is within a certain percentage of the original bid quantity (or plan quantity), there is no change in the unit price for that item. When the actual quantity is less than or more than the allowable percentage, the contractor is entitled to renegotiate the unit price for the item. There is no fixed allowable percentage, and that number varies from contract to contract and from owner to owner. The Engineers Joint Contract Documents Committee general conditions (EJCDC 2013) defer that option to the Supplemental Conditions, and the Supplemental Conditions allow the owner to insert whatever percentage is appropriate. Typically, the allowable percentage ranges from 15% to 30%. Because of the inherent unknowns and risks, an allowable percentage of 25% is recommended for heavy civil construction.

When the actual quantity is significantly less than or more than the plan quantity, the contractor's cost to perform the work is expected to change. Generally, when the actual quantity is significantly less than the plan quantity, the actual unit cost to the contractor increases. The dependence of unit cost on the work quantity can be explained as follows. When a contractor bids on a unit-price work item, the cost is the sum of some fixed cost (e.g., mobilization, equipment finance, equipment rental, or insurance) plus production cost (e.g., operator, fuel, or parts), and the total cost is prorated over the plan quantity. If the actual quantity decreases significantly, then the prorated unit price increases because the fixed cost remains the same. The contractor is therefore entitled to renegotiate for a higher unit price than the bid price. For the same reasoning, when the actual quantity is significantly more than the plan quantity, the actual unit cost to the contractor decreases and the owner is therefore entitled to renegotiate for a lower unit price than the bid price. However, large increases in quantities can have an effect on construction schedules, and the contractor is also entitled to a schedule extension and related costs associated with delays. Although there is a contractual system to handle changes in quantities and unit price, renegotiation for unit prices should be kept to a minimum during construction. To minimize significant changes during construction, it is the responsibility of the design engineer to estimate the quantities as accurately as possible based on the design and site information before the start of construction.

22.6 Quantity Survey

When construction work is paid for by unit price, the actual quantities should be measured during construction for payment purposes. The limits of construction work for which the contractor is entitled to payment are shown in the drawings as *neat lines*. It is important to show neat lines in excavations and backfill. For example, when the contractor excavates beyond the neat line, the overexcavation is not entitled to payment, unless the engineer authorized it in advance or the engineer directs the overexcavation in the field because of unanticipated conditions, such as weak subgrade. The neat lines for concrete structures coincide with the dimensional limits of the structure.

A designer should be careful in calling out minimum dimensions, such as "5 ft minimum excavated width." The contractor could excavate 10 ft, which meets the design requirement, and then demand payment for 10 ft of excavation. If 5 ft is the intended excavated width, then that exact dimension should be called out to avoid paying the contractor for excessive quantity.

Typically, the contractor is responsible for surveying or measuring the completed work, and sometimes the owner also engages his or her own surveyor to check the contractor's quantity data. Quantity survey is time-consuming and disruptive to construction. Excessive effort to measure quantities for progress payment is also costly, regardless of who does it. Therefore, it is important during design to carefully select the units in the bid schedule and measurement and payment clauses to make quantity survey as simple and as quick as possible. Some examples illustrating this principle are given below:

- Stripping of topsoil is required, but the thickness of the topsoil is highly variable. Instead of measuring the actual thicknesses of the topsoil that were stripped, it is more practical to measure the topsoil in the stockpile for payment purposes.
- Reinforced concrete contains rebars, joint materials, waterstops, etc. Instead of measuring the volume of the concrete, weight of rebars, and lengths of the joint materials and waterstops and paying for them separately, it is quicker to measure the in-place quantity of the concrete in cubic yards only, and all embedded materials become incidental to the concrete item. Therefore, all the incidental items must be included in the concrete unit price by the contractor.
- When the design cross section is uniform, as it is in asphalt pavement, it is quicker to measure the linear feet of pavement completed than the area of the pavement.

Exercise Problems

22.1 Recommend the units for payment of the following work items:
   a. Clearing and grubbing trees.
   b. Drilling foundation drain holes.
   c. Placing shotcrete on an unsupported tunnel surface.
   d. Compacted clay reservoir liner.
   e. Stripping and stockpiling topsoil.
   f. Precast concrete box culverts.
   g. Asphalt surfacing of a county road.
   h. Proof-rolling foundation subgrade.
   i. Seeding, mulching, and fertilizing topsoil.
   j. Field testing service on an as-needed basis.

22.2 The plan and maximum section of a detour road embankment are shown in Fig. 22P-1. The footprint of the embankment is stripped 12 in. to remove the topsoil before the embankment fill is placed. The road embankment crest is protected with 12 in. of compacted aggregate base course as a driving surface. Temporary guardrails are installed along each shoulder of the road crest for safety. Compute the following quantities:
   a. Volume of topsoil that is stripped, in cubic yards.
   b. Volume of the aggregate base course, in cubic yards.
   c. Volume of the road fill, in cubic yards.
   d. Total length of guardrails, in linear feet.

22.3 The profile and typical cross section of a new buried culvert are shown in Fig. 7P-4 (see Chapter 7). The new cast-in-place concrete culvert is constructed in an open-cut excavation. After the concrete is placed, the culvert is covered with a compacted fill to the original ground surface. Compute the following quantities, from culvert station 12 + 00 to 12 + 70:
   a. Volume of earth excavation, in cubic yards.

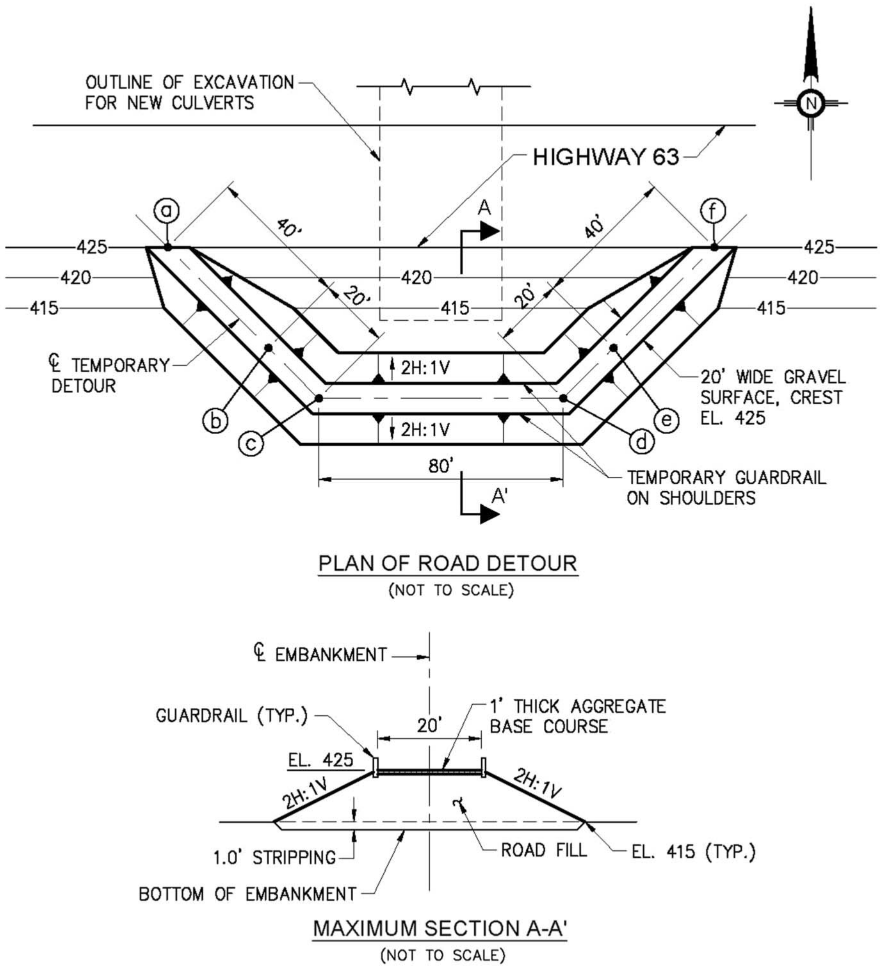


Fig. 22P-1. Plan and Section of Road Detour Embankment

b. Volume of cast-in-place concrete for the culvert, in cubic yards. Ignore "fillets" at the interior corners.

c. Volume of fill, in cubic yards.

22.4 Fig. 22P-2 shows the plan, profile, and section of a concrete stilling basin structure. Compute the concrete quantities of the structure, separating the floor slab from the walls (sidewalls and wing walls) because the pricing for the slab and for the wall is different.

a. Floor slab and footing volumes, in cubic yards.

b. Wall volume, in cubic yards.

c. Total volume, in cubic yards.

22.5 Calculated quantities need to be rounded off before the numbers are used in the bid schedules. How the numbers are rounded off depends on the total

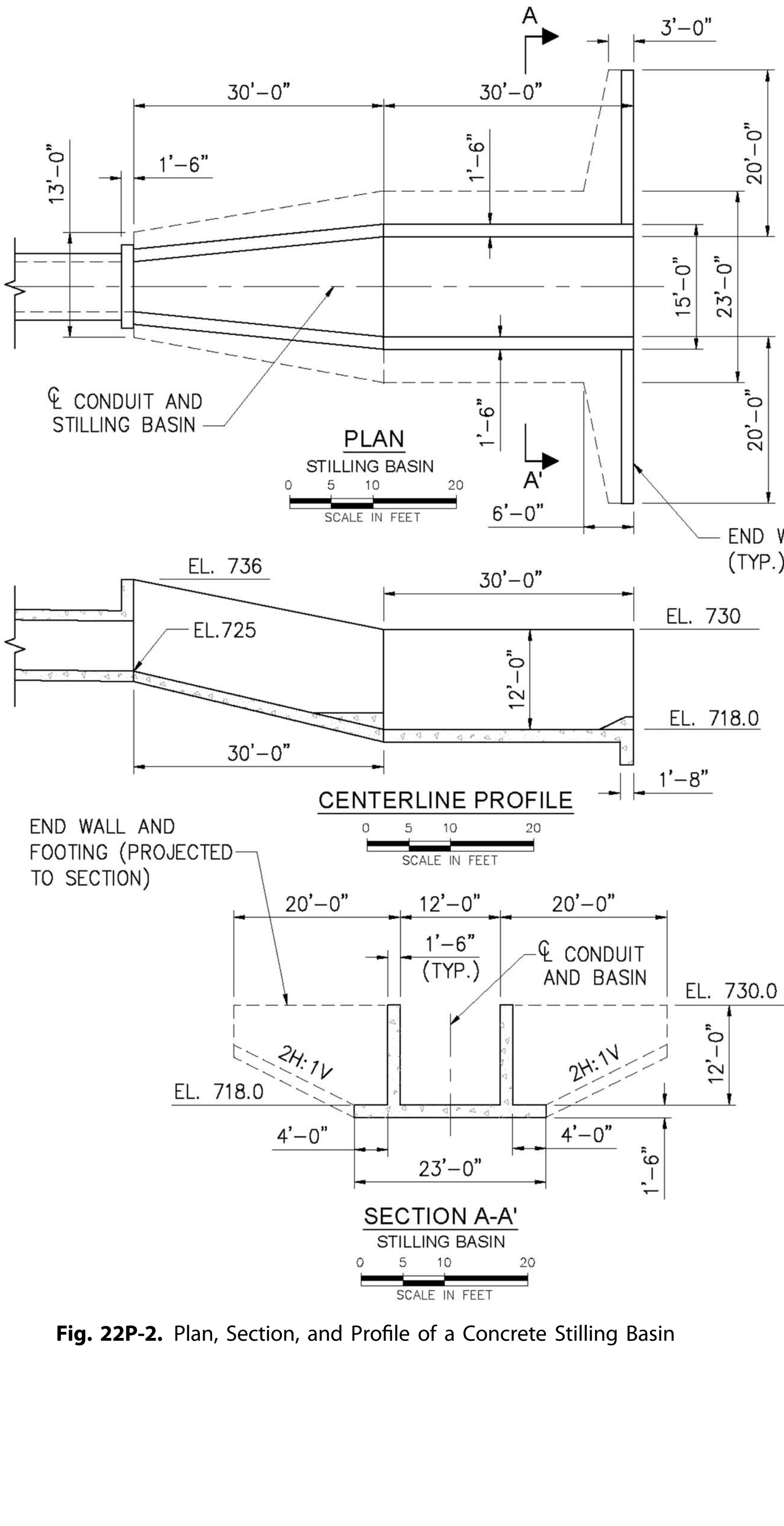


Fig. 22P-2. Plan, Section, and Profile of a Concrete Stilling Basin quantity involved, the degree of accuracy needed, and the uncertainties that are inherent in the work items. Round off the following calculated quantities to be used in the bid schedules as "plan quantities":

a. Excavation, calculated quantity = 23,987 cubic yards
b. Excavation, calculated quantity = 448.5 cubic yards
c. Structural fill, calculated quantity = 250,024 cubic yards
d. Riprap, calculated quantity = 24.7 cubic yards
e. Reinforced concrete, calculated quantity = 156.7 cubic yards
f. Drainpipes, calculated quantity = 226.5 ft
g. 72-in.-diameter welded steel pipe, calculated quantity = 575.5 ft
h. Guardrails, calculated quantity = 459 ft
i. Clearing and grubbing trees, calculated quantity = 18.57 acres
j. Dental concrete for rock foundation preparation, estimated quantity = 1,368 cubic ft (estimated to be 10% of the total foundation area).

CHAPTER 23

Estimating Prices

23.1 Estimating Prices by an Engineer

An engineer's cost estimate consists of two steps. Step one, discussed in Chapter 22, is to estimate the quantities as depicted in the design. The second step of the process is to estimate the prices for the work items identified in the design. Estimating prices can be performed by a senior engineer or by a professional cost estimator. The roles and responsibilities of cost estimating by different personnel are discussed in Section 21.3. The estimation of construction costs by an engineer is challenging for a variety of reasons:

- Most civil engineers are trained in the technical and design side of civil engineering, but not the construction side. An engineer can prepare confidently an estimated cost for professional services for an engineering study or design, based on past experiences for the direct labor costs (work hours), indirect costs (overhead and administration), or outside services (e.g., drilling, testing, and consultants). Similarly, a contractor can prepare confidently an estimated cost of a construction project because he or she understands—based on past experiences—what direct labor, equipment and material costs, subcontractors, and other overhead and administration costs are necessary. When an engineer prepares an estimate of a construction project, is he or she crossing the line and discipline into an area where he or she has little direct experience and training?
- Unlike building costs in architectural design, the costs of heavy civil construction are greatly dependent on the types of work (e.g., highways, dams, tunnels, or pipelines), locations of project sites, meteorological factors, and subsurface conditions. Accounting for the effect of these factors on productivity determines the accuracy of the cost estimate.
- The construction cost of a given project changes with the local construction market, bidding climate, availability of qualified contractors, wage requirements, and—for multiyear contracts—time. Anticipating and accounting for these factors sometimes determines whether a project can go into construction.

- The size of the project has significant influence on the prices. Historical price data, when applied indiscriminately and without adjusting for project size and duration, may result in significant errors on the actual cost of construction.

In spite of these challenges, this chapter presents the practice of estimating heavy civil construction costs by an engineer, and to a limited extent, by a professional cost estimator. Some of the general considerations listed here that affect the construction costs are discussed in more detail in Section 23.6.

23.2 Cost Components in Construction

In order to estimate the construction cost, we need to understand the cost to the contractor so that all cost components are accounted for in the cost estimate. Regardless of how a contractor is being compensated, the costs to him or her to construct that project can be broken down into the following categories:

- Direct labor cost: Direct labor includes all wages and salaries that are paid to the construction crew directly involved with the construction. The crew may include the project manager, superintendents, foremen, crew chiefs, equipment operators, and laborers. Overtime costs to workers are also included in this category.
- Equipment cost: Equipment cost includes the cost of owning, leasing, and operating the equipment that is used to construct the project, such as bulldozers, trucks, and backhoes. This cost is not to be confused with the project equipment cost, which is part of the project to be constructed and installed.
- Products and materials costs: These costs include the cost to purchase the contractor-furnished products and materials required in the construction, including delivery charges and all handling and storage costs. Some products (such as special mechanical gates and valves) require a manufacturer's representative to be on site during installation. That cost should also be included in the product cost.
- Subcontractor cost: The subcontractor cost to a general contractor includes the cost of paying the subcontractors plus a markup for overhead and profit.
- Mobilization and demobilization: Includes movement of personnel, equipment, and supplies to the project site; establishment of offices, buildings, plants, and other facilities at the project site; temporary utilities and temporary access roads; temporary site protection; permits and licenses; periodic and final cleanup; equipment not chargeable to a specific task; and demobilization of personnel and equipment.
- Bonds, insurance, and taxes: Bonds include bid bonds, performance bonds, and payment bonds. Insurance includes workers' compensation, liability, and builder's risk. Taxes include payroll tax, sales tax, and other local, state, and federal taxes.

- Overhead and profit: Overhead costs include home office expenses and support, communication, business insurance and taxes, management and accounting costs, and finance costs. The profit is the financial return of the contractor's investment, and it provides the contractor with an incentive to perform the work as efficiently as possible.

All of the costs incurred by the contractor will be charged to the owner in one way or another. There are many ways these individual costs are paid to the contractor, depending on the preference of different owners and design engineers. The following is a description of one way that the contractor can be compensated for these costs:

- The cost of mobilization and demobilization is paid for as a separate lump sum item or is incorporated into other paid items. A schedule of payment (see Section 19.5) can be set up in the measurement and payment clauses to allow the contractor to recuperate these initial costs as quickly as possible to minimize the practice of unbalanced bidding and front-loading (see Section 25.3).
- The contractor is rarely paid separately for direct labor, equipment, and materials unless it is under a *force account* contract arrangement (see Section 19.1). Rather, payment items are set up to compensate the contractor for the units of work completed (such as cubic yards of fill placed or cubic yards of concrete placed), which include all labor, equipment, and materials, including subcontractor cost. When the contractor's work is difficult to quantify for payment, lump sum items (such as dewatering, erosion control, and stream diversion) are set up, and a progress payment will be made to the contractor for each pay period based on an estimate of percent completion.
- Bonding and insurance costs are a direct cost to the project, and they should be returned to the contractor as quickly as possible. A separate lump sum bid item for bonds and insurance can be set up to allow the contractor to recuperate these costs in the first progress payment, or this cost can be included as part of mobilization and demobilization.
- No separate payment items are usually allowed for taxes, overhead, and profit, so the contractor would need to spread these costs over other scheduled paid items.

The costs of mobilization and demobilization, also referred to as "Division 1 costs" because these requirements are mainly specified in CSI Division 1, vary from site to site and from project to project. In addition to the physical mobilization and demobilization of crew and equipment, the Division 1 costs also include temporary facilities, temporary controls, utilities, and access. In general, the larger the contract, the higher the mobilization and demobilization cost. For preliminary cost-estimating purposes, one can assume the mobilization and demobilization as a percentage of the total construction cost. Fig. 23-1 shows the cost of mobilization and demobilization of more than 55 bids on small to medium–sized dam projects, expressed as a percentage of the total construction bids. The wide scatter of data is understandable, considering items

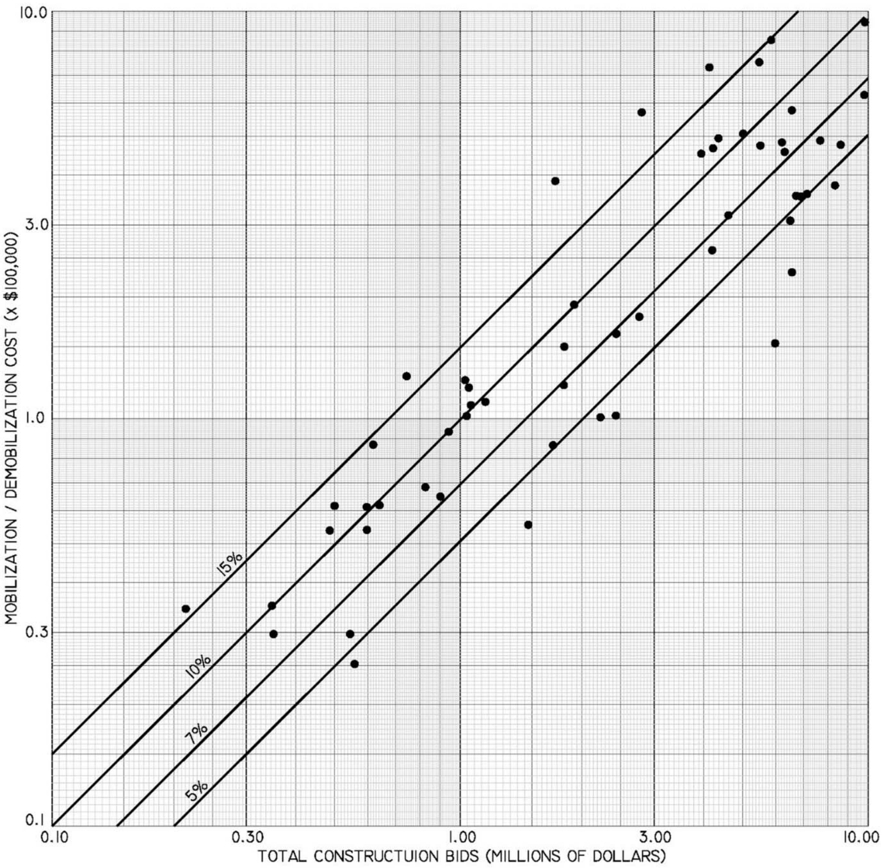


Fig. 23-1. Mobilization and Demobilization Costs for Dam Projects

including the wide difference in site conditions, the differences in equipment and crew, and locations of the projects involved. These data show that the mobilization and demobilization costs are in the range of 5% to 15% of the total cost. Even though these data are based on dam projects only, they can be applied to some of the similar types of heavy civil construction, such as dikes, levees, stream bank protection, road work, and revetment work. It should be noted that some construction contracts impose a cap on Division 1 cost bid items, e.g., 5% or 10%; in those cases, the bidders would allocate the remaining Division 1 costs into other bid items. There are no obvious advantages to imposing a cap on Division 1 costs, and the allocation of these costs to other work items only distorts the actual prices of the bid items.

The premium cost for performance and payment bonds is dependent on the types of construction work and contract amount. Fig. 23-2 shows the average bonding cost as a percentage of the contract amount, based on 2001 RS Means *Heavy Construction Cost* (R.S. Means Co. 2001). Two cost curves are shown: one for Class A contracts and another for Class B contracts. Class A contracts include construction of highways, roads,

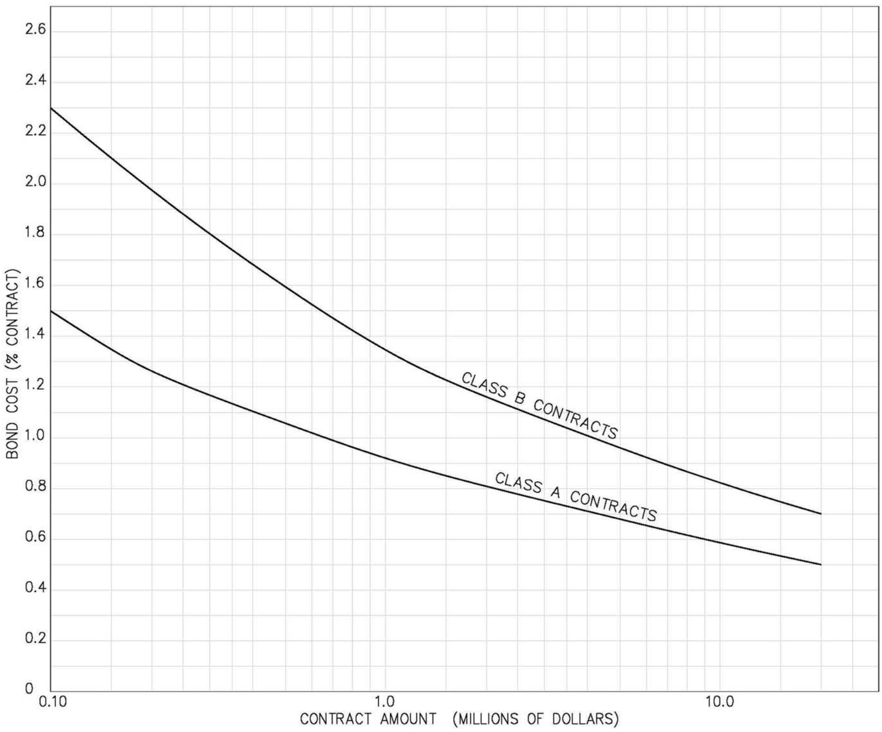


Fig. 23-2. Cost of Bonding for Heavy Civil Construction Projects

Source: Data from 2001 Means *Heavy Construction Data*

and bridges, as well as street paving, airport runways, and river bank protection. Class B contracts include construction of all types of buildings, repair work on buildings, dams, dikes, levees, wharves, sewers, pipelines, pilings, subways, tunnels, and revetments. In general, the larger the contract, the lower the percentage of bonding cost. The bonding cost, as a percentage of the contract amount, was in the range of 0.5% to 2.3%. Fig. 23-2 can be used to estimate the approximate bonding cost for cost-estimating purposes. Even though the figure was based on 2001 data, the bonding costs in 2015 are still in the range of 0.3% to 2.0% of the amount of the contract being bonded; therefore, Fig. 23-2 is still applicable. There are also other variables that affect the bonding cost. The actual cost of the bonding to a particular contractor depends on the bond rating of that contractor, which varies from contractor to contractor. Also, different bonding companies offer somewhat different rates.

23.3 Engineer's Pricing Estimate Approach

With few exceptions, the traditional method an engineer uses to estimate unit prices and lump sum prices is based on data from past projects; published construction cost data; quotations from manufacturers, suppliers, and specialty contractors; and judgment and experience. Perhaps the main weakness of this approach is that cost components to the contractor, as outlined in Section 23.2, are not identified separately. Rather, each of the estimated prices already includes direct costs (labor, equipment, and materials), indirect costs, overhead, and profit. In fact, in this approach, there is no attempt to break down these separate costs. When all of the cost items are added together for a particular project, it is assumed that all of the costs outlined in Section 23.2 will be accounted for.

Contrary to quantity takeoffs that are done by staff-level engineering personnel, pricing estimates should be performed by experienced personnel (e.g., a senior project engineer or a cost-estimate professional). This person, who is referred to as the *cost estimator,* needs to have a thorough understanding of the design and construction requirements, including the following:

Site conditions: The characteristics of the site affect the contractor's staging and stockpile areas, temporary access requirements and constraints, availability of water and power, selection of types of equipment and construction processes, environmental limitations, weather conditions, availability of local labor, labor housing and transport, and restrictions by local, state, and federal agencies.

Work requirements: Work requirements are based on construction drawings and technical specifications. However, understanding the work requirements and pricing the work requires an understanding of construction practices, means and methods, constructability, and construction schedules. For example, to estimate the cost of foundation dewatering, the cost estimator needs to know the following:

- Duration of dewatering;
- Method of dewatering (e.g., sump-pumping, well points, or deep wells), which is dependent on the foundation conditions, groundwater flow behavior, and sources of groundwater;
- Layout of dewatering facilities; and
- Operating and maintenance costs.

None of this information typically is contained in the construction documents because this type of work is generally designed by the contractor and would need to be evaluated as part of the cost-estimating process. If the cost estimator is unable to determine the appropriate construction means and method, then the estimator cannot reliably determine the construction cost. This statement is valid for all construction work, and not just for foundation dewatering. In the example of dewatering, there is significant difference in cost between dewatering with sumps versus dewatering with well points or deep wells.

Another example is to estimate the cost to borrow and process sand and gravel materials to manufacture a clean filter material using on-site, bank-run materials. Costs for this unit price item may include the following:

- Excavating and hauling bank-run materials to the processing plant;
- Screening the bank-run materials to remove oversized materials;
- Crushing the oversized material, if necessary;
- Washing the screened materials to remove excessive fines; and
- Stockpiling the processed materials.

There is a cost associated with every step listed above, and the cost estimator needs to assign the proper crew and equipment, production rates, efficiency, and how much waste (from screening, washing, and crushing) will be generated.

Understanding construction equipment and processes: Selecting the proper equipment and construction processes to meet specified requirements is a decision that the cost estimator must make to form a basis for the cost. Because there is usually more than one way to build something, the assumed method merely represents a reasonable scenario that should be practical, constructable, and price-competitive. The following are some examples showing how the site conditions control the type of equipment needed:

- If a borrow site terrain is so steep and small that only backhoes and loaders can be used, then it is not reasonable to assume scraper production of the borrow material, even though scrapers would result in a lower unit price.
- If cast-in-place concrete is being placed in a steep terrain that is not accessible to transit-mix trucks, then additional support equipment (e.g., cranes, conveyors, or pumping equipment) will be required, which will increase the unit price of the concrete.

After the cost estimator identifies the work requirements, site limitations and constraints, equipment, and construction method for a particular work item, the next step is to assign dollar values to represent each work component. To obtain these costs, the cost estimator needs the following information:

- Purchased material cost—Materials or products that are purchased should be based on quotations from the material suppliers or on recent cost data for similar materials. Material costs are usually quoted in free on board (FOB) price, which corresponds to the point at which the supplier will deliver goods without a delivery charge to the buyer. For manufactured goods, FOB usually means at the factory. For processed earthwork materials and aggregates, FOB usually means at the pit or quarry. Therefore, delivery costs would need to be added to the "FOB factory" cost to obtain the delivered price. On the other hand, delivery cost is included if the quote is "FOB site." When requesting a quote for materials and products, it is important to document in the quote the location of FOB—whether the price is FOB factory or FOB site.
- Borrow material cost—Costs for materials that are available on site should include labor and equipment to excavate, process (such as drying, wetting, and

screening), and haul the materials to the temporary stockpiles or directly to the placement locations. Some borrow areas are heavily wooded, and a significant clearing and grubbing effort is required to develop the site before any borrow excavation. At the end of construction, a borrow area may need to be regraded and reclaimed.

- Installation cost—The installation cost includes labor and equipment to install or place the required work. Labor and equipment costs are published annually by several sources, such as R.S. Means Company (see Section 23.4), Richardson (Cost Data On Line 2009), *Engineering News Record* (ENR n.d.), and *Building News* (BNI 2016). Because published data do not normally provide adequate depths and scopes for specialized construction items—e.g., slurry walls, posttensioned anchors, underwater work by divers, foundation improvements, and tunnels—it is advisable to consult specialty contractors. When it is assumed that a certain portion of the work will be performed by subcontractors, such as specialty contractors, a subcontractor markup should be added to the quotes given by these sources. For the engineer's cost-estimating purpose, a 5% to 10% markup can be assumed.
- Productivity of labor and equipment—The estimate of production rates of labor forces and equipment requires significant construction experience and familiarity with equipment performance. In heavy civil construction, the work is accomplished primarily with mechanized equipment, with the exception of concrete work, which involves significant labor effort in placing forms and reinforcements. Production rates of equipment depend on many factors, including ease or difficulty of access, size of the project, types of materials being handled, and working conditions, such as weather and time of year. Considerable experience and judgment are required to estimate production rates.

23.4 Means Cost Data

Construction cost data are published monthly and annually by many sources (see Section 23.3), including state transportation departments. Some of these sources serve primarily the building industry, but the most comprehensive and most commonly used source for heavy civil construction projects, discussed in detail in this section, is published by RS Means Company, Inc. (2014). RS Means Company, Inc., provides a comprehensive list of construction information, products, and services in North America and worldwide. Among the services are a variety of cost data books. All of these data are also available in electronic media. For heavy civil construction projects, the relevant reference is *Heavy Construction Cost Data* (R.S. Means Co. 2014), which is updated annually. The Means cost data are organized in accordance with the Construction Specifications Institute (CSI) system (see Chapter 18). The use of CSI format in Means data provides a direct reference and correlation between technical specifications and costs. To match the 2014 CSI *MasterFormat*, Means cost data are divided into 46 CSI divisions, and then are further broken down into reference numbers that follow the section numbers assigned by CSI. For example, the CSI section number for site grading is 312200. That same number can be found in Means cost references for the same construction work.

For good documentation practice, it is important to properly cite the reference number for a particular cost item when taken from the Means database. Means uses the term *Line Number* as a reference. The line number is a 12-digit code based on the 6-digit CSI *MasterFormat* classification, such as:

312316.13-0500

The first 6 digits are for the CSI section number. The remaining digits are the Means designation. The line number used above refers to trench excavation with a 3/4-cubic yard excavator, 6 to 10 ft deep. The section number 312316 is used in CSI for excavation, and Means assigned the number 13 after the section number for trench excavation; the last 4 digits are for different trench excavation depths and equipment sizes.

For each line item, a great amount of information can be found in the Means cost data:

- Type of equipment and construction method;
- Type of construction crew;
- Assumed production rate of crew and equipment;
- Unit of work production; and
- Material, equipment, and labor costs, with and without overhead and profit.

In selecting the appropriate cost item, it is important that the cost estimator understands what equipment type, crew type, and construction method are practical. That is why construction experience is important in cost estimating. Even though most engineers are not trained in the application, operation, and productivity of construction equipment, cost engineers should at least become familiar with the uses and limitations of commonly used construction equipment. Equally important is the use of a proper construction crew. In Means data, the type and size of the construction crew are defined for each cost item. Details of the crew include total number of labor categories (such as foreman, laborer, and equipment operator), type and number of equipment (such as truck, loader, bulldozer, or backhoe), hourly and daily production output, and total daily cost for each crew. This information is important in evaluating whether the crew assumed in the line item is reasonable for the work. In some situations, such as structure demolition and groundwater dewatering, it is difficult to estimate the cost of work in production units (such as cubic yards), and it is necessary to estimate the cost based on the estimated production rates of an appropriate crew and equipment. The following are two examples of construction crews used in R.S. Means Co. (2014):

Crew B-11M: 1 Equipment operator
1 Laborer
1 Backhoe loader (80 H.P.)
Crew C-12: 1 carpenter foreman
3 carpenters
1 laborer
1 equipment operator (crane)
1 hydraulic crane, 12 ton

The Means cost data represent the national average based on 30 major U.S. cities. For a given type of construction work, the cost is different from city to city and from region to region. The estimated costs for a particular project need to be adjusted for this geographic factor. Means uses the term *city cost index* (CCI) to make this adjustment for 731 cities in the United States and Canada. The CCI is different for Division 1 through 46 work, and it is also separated for materials and labor. The adjustment is made as follows:

$$\text{Specific city cost} = \text{CCI} \times \text{National average cost}$$

As an example, the 2014 CCIs for a project located in San Antonio, Texas, are the following:

Division 3: Cast-in-Place Concrete	CCI = 0.766
Division 5: Metals	CCI = 0.876
Division 31–34: Site and Infrastructure	CCI = 0.945

Table 23-1 illustrates how the Means cost data are used to estimate construction cost components for a project located in San Antonio, Texas. The cost data used are based on *Heavy Construction Cost Data* (R.S. Means Co. 2014).

23.5 Alternative Price Estimating Approach

Instead of using published unit prices as illustrated in Section 23.4, an alternative approach can be used to price the cost of construction. This approach is commonly used by contractors and professional cost estimators and is based on a separate breakdown of materials, labor, and equipment, as well as production rates. The process of estimating prices using this approach is much more involved and is beyond the scope of this book, but it is more precise and requires the estimator to assume a crew size and to identify all the required equipment, the production rates, and the durations of the installation.

To illustrate the approach, Table 23-2 is an example of estimating the unit price for furnishing and placing a filter sand. The work consists of importing 450 cubic

Table 23-1. Examples Using Means Cost Data to Estimate Construction Cost Components

1. Open-cut earth excavation			
2014 Means, 312316.42-1300			
Front-end loader, 3 C.Y. capacity			$2.05/C.Y.
2014 Means, 312323.20-0016			
Dump truck, 8 C.Y. capacity, 1 mi round trip			$3.38/C.Y.
	Subtotal:		$5.43/C.Y.
	Adjust for CCI, Division 31 work	× 0.945	
	Adjusted unit price:		$5.13/C.Y.
	Round off:		$5.25/C.Y.
2. Placing embankment earthfill, using on-site borrow			
2014 Means, 312316.42-1300			
Front-end loader, 3 C.Y. capacity			$2.05/C.Y.
2014 Means, 312323.20-0016			
Dump truck, 8 C.Y. capacity, 1 mi round trip			$3.38/C.Y.
2014 Means, 312316.46-5020			
Bulldozer, 300 H.P., spread fill			$1.71/C.Y.
2014 Means, 312323.23-5720			
Sheepsfoot roller, 12-in. lift, 4 passes			$0.27/C.Y.
	Subtotal:		$7.41/C.Y.
	Adjust for CCI, Division 31 work	× 0.945	
	Adjusted unit price:		$7.00/C.Y.
	Round off:		$7.00/C.Y.
3. Furnishing and placing concrete grade walls			
2014 Means, 033053.40-4200			
Concrete wall in place, 8 ft high, including forms, rebars, finish			$490.00/C.Y.
	Adjust for CCI, Division 3 work	× 0.766	
	Adjusted unit price:		$375.34/C.Y.
	Round off:		$375.00/C.Y.
4. Furnishing and installing PVC slotted drainpipes			
2014 Means, 333113.25-2040			
6-in. PVC pipe in place, SDR 35, unslotted			$7.95/L.F.
Cut slots to meet specifications (per quote from shop)			$2.50/L.F.
	Subtotal:		$10.45/L.F.
	Adjust for CCI, Division 33 work	× 0.945	
	Adjusted unit price:		$9.87/L.F.
	Round off:		$10.00/L.F.

Note: C.Y. is cubic yards, and L.F. is linear feet.

yards of clean filter sand from a commercial source, stockpiling the material on site, and placing it in a dam by compacting it with a vibratory roller.

This example illustrates how a contractor or a professional cost estimator typically performs a pricing estimate using direct information on labor, equipment,

Table 23-2. Example of Estimating the Unit Price of Placing Filter Sand

C33 concrete sand, delivered, 945 tons @ $16.50/ton	$15,292
Supervisor, 20 h @ $50.28/h	$1,006
Pickup truck for supervisor and crew, 40 h @ $7.00/h	$280
Grader, 20 h @ $47.35/h	$947
Cat 966 Loader, 20 h @ $85.00/h	$1,700
Cat D6 Bulldozer, 20 h @ $90.00/h	$1,800
Cat CS563 Single Drum Smooth Roller, 20 h @ $60.00/h	$1,200
Equipment operator (excavator), 20 h @ $47.35/h	$947
Equipment operator (bulldozer, roller), 40 h @ $46.91/h	$1,876
Skilled laborer, 20 h @ $37.76/h	$755
Total:	$25,803
Summary:	
	Material = $15,292
	Labor = $4,584
	Equipment = $5,927
Unit price: $25,803/450 cubic yards = $57.34/cubic yard, or round off to $57.50/cubic yard.	

and materials. Much of this process is now performed efficiently in a spreadsheet on the computer where labor and equipment rates are already programmed into the spreadsheet, and the program can be learned in a typical construction management and cost-estimating course.

23.6 Other Pricing Considerations

The previous sections discuss how to estimate the construction costs based on average published data. In reality, there are many factors unique to a specific project that will affect the average costs and that need to be taken into account in finalizing the cost estimate. This section contains a discussion of these project-specific factors and how they will increase or decrease the construction cost. This discussion is qualitative only, as it is impossible to quantify all these factors without understanding the circumstances in each project. The price adjustments necessary to compensate for these factors are left to the experience and judgment of the individual cost estimator.

Wage Requirements

The labor costs contained in most published cost data, such as the Means cost data, are typically based on average prevailing wages for construction trades. If a project mandates that *Davis-Bacon wages* be used, such as in federal construction, adjustment would need to be made for this wage difference. Davis-Bacon wages are wages mandated through the Davis–Bacon Act of 1931, which is a federal labor law requiring that mechanics and laborers receive not less than prevailing wages as determined by the U.S. Secretary of Labor. In some cities or regions, labor wages are higher because of the dominance of trade unions. Also, published labor information does not include overtime costs. If the schedule of a project is such that significant overtime is anticipated, then the overtime costs should be factored into the labor costs.

Availability of General Contractors

Before a project goes into bid, it is advantageous for the owner to research the qualified local, regional, and national contractors' level of general interest in his or her project. In general, the more interest the project receives from contractors, the more favorable will be the bids. The reverse is also true. There are two separate issues regarding the availability of qualified contractors:

- The number of qualified contractors available if the project requires special construction skills and experience, and
- The availability of the contractors during the bidding period. This bidding climate is a supply-and-demand issue. When contractors are busy, there is less tendency for them to submit competitive bids, and the bids generally come in higher. The reverse is also true.

Based on the results of the owner's research, the engineer's cost estimate may need to be adjusted up or down to account for these factors.

Site Factors That Increase Costs

In heavy civil construction, each site is unique and poses a set of factors that will affect the cost of the construction. Some of these factors will be accounted for in the mobilization and demobilization costs, and others will affect individual work items, such as stream diversion or dewatering. In general, the following site factors tend to increase the cost of construction:

- Adverse weather conditions, such as frequent precipitation, and short construction season.
- Short contract duration, which limits the contractor's flexibility on human resources and equipment and can result in higher labor cost from overtime and higher equipment cost for support during night shifts.
- Remote site, which limits the availability of laborers. A short local labor supply will increase labor costs because the contractor will need to bring in workers from other areas. A remote site also increases the haul costs of materials and supplies.
- Difficult access, which requires significant improvement to temporary access roads or new roads.

- Traffic problems and extensive traffic control in an urban setting.
- Off-site disposal requirements, which increase haul and disposal costs in landfills.
- Quarry or borrow-pit permit requirements—These contractor permits are generally costly, and approval for these permits is time-consuming because of necessary compliance with numerous environmental laws.
- Excavation adjacent to high groundwater, such as adjacent to a stream, river, or lake.
- Restriction on how a site can be developed—The limits on an area that the contractor can develop at any given time may affect the types of equipment that can be used and decrease the production rates.
- Restriction on working hours—Contractors prefer to work from sunrise to sunset, and on weekends when necessary. Restricting working hours (e.g., in a residential neighborhood) may increase the number of workdays if the contractor cannot take advantage of all of the daylight for construction.
- Restriction on noise level while working—This restriction may limit the contractor on the type of equipment that can be used. For example, if diesel pumps cannot be used for dewatering in a residential neighborhood, then more expensive electric pumps would be needed.

Other Nonsite Factors That Increase Costs

Other factors or circumstances besides the project site conditions could increase construction cost and result in bids that are significantly higher than the engineer's cost estimate. These factors include the following:

Busy construction market—In a busy construction market, fewer contractors are available to bid on a project. Those bidders that are interested are probably very busy with other ongoing or new projects, and there is little incentive to be competitive on the bid price. It is a simple problem of supply and demand. To avoid the higher bid prices in a busy construction market, an owner can put the bid documents "on the shelf" and wait for a more favorable bidding climate. Otherwise, the engineer should advise the owner to increase the construction budget to account for this cost inflation due to market conditions.

Inadequate competition and interest—Sometimes the lack of interest and bidders is not because of a busy construction market, but rather a result of inadequate advertising on the part of the owner. Not enough general contractors are aware of the project. A lack of bidders and competition also results in higher bids. To avoid this situation, the designer should assist the owner to identify and contact as many interested general contractors and subcontractors as possible in addition to the owner's usual channel of construction advertisement.

Short material supply—From time to time, the global demand of construction materials, such as steel, cement, and timber, from other countries creates a local supply problem, a corresponding increase in material cost, and an increase in delivery time. Many materials suppliers and distributors might have advised the engineers on this problem during the request for price quotation. It is the responsibility of the engineer or cost estimator to make appropriate adjustments in the cost estimate and construction schedule to take into account the consequences of short material supply.

Federal construction—All things being equal, construction for the federal government is generally more costly than the same construction for private-sector owners because of higher labor rates, significantly more paperwork and bureaucracy, restricted work schedules, permit compliance, and other restrictions that reduce contractor production. If the cost estimate is based on average prices obtained from published sources or other nonfederal projects, then some adjustment factor should be added to the cost to account for this "government factor."

Size of the Project

The unit rates and production rates obtained from published cost data, such as Means cost data, represent average productivity and may even represent somewhat idealized working conditions. These conditions may be achievable for medium to large projects, but they may not be possible for small projects. For small projects, the unit rates from published data or other historical data should be adjusted up, sometimes by a significant amount, to account for small quantities and low production rates. For example, an estimated unit rate of $3.00 per cubic yard for open-cut excavation may be reasonable when the quantity is 10,000 to 20,000 cubic yards, but—because the same equipment is mobilized to perform significantly less work—may be too low for 300 cubic yards. When quantities are low, the published costs can be misleading and should be used with caution. In some cases, the unit rate for a small quantity may be several hundred percent higher than that estimated for a large quantity in published databases.

23.7 Checking Pricing Estimates

Pricing estimates should be checked and reviewed by another senior professional who is experienced in design and construction. The main focus of the checking is not merely on the mathematics, but rather the following:

- Are the material and product costs consistent with the specifications? For example, if the specifications call for a slotted PVC drainpipe, the pricing estimate should not be based on a perforated pipe.
- Are the quotes for the material costs properly documented, including the sources and the delivery schedule? It is important that the cost estimator contacted one or more sources for the materials, such as a processed C33 fine aggregate as a filter sand. It is a good practice to request test data from the material source to make sure that the material complies with the requirements.

- Is proper equipment being used to perform the installation, given the site conditions and site constraints? For example, if the site is tight and has little working room, it is inappropriate to assume an excavation with a large scraper; rather, a hydraulic backhoe with a higher cost should be assumed. As another example, if access to concrete placement is difficult, then a concrete pump truck should be added to the concrete placement cost.
- Do the unit prices reflect the production quantity? For example, an excavation unit price of $2.00 per cubic yard is reasonable for a larger quantity, such as 10,000 cubic yards, but not reasonable if the work is only for 100 cubic yards; in that case, perhaps a unit price of $10.00 per cubic yard is more appropriate.
- Do the unit prices reflect the technical requirements in the drawings and specifications? For example, placing structural concrete in a new outlet works gate tower with heavy reinforcements requires crane support, segmented construction, and higher forming and material costs. As a result, the unit price should be on the order of $800 to $1,000 per cubic yard instead of $200 to $300 per cubic yard.

It is quite clear based on the discussion above that checking pricing estimates requires a seasoned designer or a professional cost estimator experienced in construction methods, but not an inexperienced staff engineer. In addition, the checker should be familiar with typical bid ranges of similar work, based on past experience or other published sources. If such a person is not available within the design organization, an outside consultant should be engaged to perform such a task. The consequences of an unchecked pricing estimate far outweigh the cost to properly perform this important quality control. In the worst case, all the bids far exceed the owner's estimate, and the project cannot go into construction.

CHAPTER 24

Allowances and Contingencies

24.1 Cost Allowances for Uncertainties

This chapter discusses how cost allowances are used to account for contingencies associated with various unknown and variable factors during design and construction of heavy civil projects. *Contingencies* represent degrees of uncertainty that result from a variety of causes. Some are inherent and unavoidable, and some can be minimized. There are two types of contingencies: *design contingency* and *construction contingency*, and they are quite different. Cost allowances for contingencies are carried throughout a project, from the inception through conceptual and final design and into construction. As a project progresses from the planning level through final design, the allocation of allowances for contingencies also changes. In general, the higher the degree of uncertainty in a project, the higher will be the contingency cost allowance. Also discussed in this chapter is the allowance for future cost escalation, which should be included in budgets for projects for which construction will not begin immediately after the effective date of the construction cost estimate.

24.2 Design Contingency

Design contingency is a cost allowance in a construction cost estimate to account for the uncertainties and unknowns during the design phase. Design contingency is associated with the following uncertainties:

- Uncertainty in the definition of the project, especially at the early stages of project design. Design contingency can cover small changes in the scope of the project (e.g., from one type of canal liner to another type), but is not intended for major changes. When a project scope or definition changes significantly (e.g., from a pipeline to a canal for water conveyance), the engineer is responsible for advising the owner that the project cost should be updated for the new scope.
- Uncertainty from a lack of design details and site information, which is typical at early levels of design. The absence of detailed design information may be a result

of incomplete site characterization—such as an inadequate topographic base map or inadequate subsurface exploration—or it may be a conscious effort to explore several alternatives that are feasible, and in-depth details may not be developed when multiple alternatives are screened for technical feasibility, constructability, and cost.

- Construction cost items that are not yet identified (so-called *unlisted items*). In feasibility design or conceptual design, only the major cost items (so-called *listed items*) are identified, and minor cost items are accounted for in the design contingency as unlisted items. It should be noted that upon completion of final design, there should be no unlisted items on the construction cost estimate.
- Quantities of identified cost items are only approximate because complete details are not available for a more accurate quantity takeoff, or because a detailed topographic base map is still not available. When several alternatives are screened in a feasibility design, it is not unusual to have the quantities based on only a typical section for each design alternative, and on a coarse base map such as the published USGS 1:24,000 quadrangle map.

The example of the canal liner design in Section 4.2 can be used to illustrate the concept of unlisted items in cost estimating. The design cross sections for the canal liner for the planning level, conceptual level, and final design are illustrated in Figs. 4-1, 4-2, and 4-3, respectively. Note that as the design progresses from planning to final design, there are more design details shown on the cross sections. At the same time, there are also more cost items that are identified from the cross sections. Table 24-1 shows the listed cost items and the unlisted cost items in the cost estimate for the three levels of design. In the planning-level cost estimate, there are only two major cost items (excavation and HDPE liner), and the remaining cost items are unlisted. In the conceptual-level cost estimate, there are more major cost items (excavation, HDPE liner, gravel cover, and earth cover), and the remaining cost

Table 24-1. Listed and Unlisted Cost Items in Canal Liner Example

Cost Items	Planning-Level Design (Fig. 4-1)	Conceptual-Level Design (Fig. 4-2)	Final Design (Fig. 4-3)
Excavation	Listed	Listed	Listed
HDPE liner	Listed	Listed	Listed
Gravel cover	Unlisted	Listed	Listed
Earth cover	Unlisted	Listed	Listed
Dike fill	Unlisted	Unlisted	Listed
Road fill	Unlisted	Unlisted	Listed
Dewatering	Unlisted	Unlisted	Listed
Sediment control	Unlisted	Unlisted	Listed

items are unlisted. In final design, all anticipated cost items are listed, and there are no unlisted cost items.

In general, allowances for design contingency should decrease as design information becomes better defined and there are fewer unknowns. Design contingency should be largest during a planning level or reconnaissance level design and should be zero at the completion of final design. Different engineers or owners have different guidelines on allowances for design contingency. The recommended guidelines for design cost contingencies are shown in Table 24-2. The contingency factors recommended in Table 24-2 can be changed somewhat on a case-by-case basis, depending on the uncertainties that are unique to each project. It is quite acceptable to carry a design contingency cost allowance during final design before it is completed, for the following reasons:

- During early final design, e.g., at 30% completion, not all of the design details are shown, and therefore the quantities are still approximate and there may even be some unlisted cost items.
- Sometimes design layouts and details are changed during final design, as a result of internal review, owner's review, or review by regulatory agencies, and the design contingency can be used to accommodate those changes.

It is important, however, that no design contingency is left at the end of final design, because that would imply that the design is incomplete. When a particular design feature is expected to change during construction because of differing site conditions, the cost increase should be accounted for in the construction contingency discussed in Section 24.3.

24.3 Construction Contingency

The construction contingency is a cost allowance in the construction cost estimate to account for the following uncertainties during bidding and construction:

Table 24-2. Recommended Design Cost Contingencies

Level of Design	Cost Allowance Contingency (%)
Planning level, reconnaissance level	20–30
Conceptual-level design	15–25
Final design, 30% completion	5–10
Final design, 75% completion	0–5
Final design, 100% completion	0

- Uncertainty related to the local construction market, bidding climate, and availability of interested contractors during bidding and construction period—This uncertainty almost always exists each time a project is being bid. In some cases, an unfavorable bidding climate may result in either very few bids and/or very high bids, to a point where the owner cannot afford to build the project. That is why it is important for the cost estimator to investigate and anticipate this uncertainty during design (see Section 23.6) and to adjust for these market factors in the engineer's cost estimate. The construction contingency can only absorb small adjustments in market factors. When a major portion of the construction contingency is spent to account for the market factors, it leaves little allowance during the construction. This situation is not advisable.
- Uncertainty related to differing site conditions—Differing site conditions, such as softer foundation or deeper or shallower bedrock surface, may directly affect the plan quantities, and they also may result in design changes with cost implications. The design engineer can minimize this uncertainty to some extent during design by a thorough site characterization investigation, but the uncertainty remains if the geology and subsurface conditions are complicated. In general, the cost and effort spent for an adequate site characterization during design more than offsets the cost increase during construction caused by differing site conditions.
- Changes associated with inaccuracies in quantities or errors in plan quantities—The design engineer can minimize this uncertainty by a proper cost-estimating effort during design (see Chapters 22 and 23).
- Errors in design—Design errors may result in design changes and corresponding change orders with associated cost increases. The design engineer can minimize this uncertainty with a thorough quality control and review of the construction documents before bid (see Sections 9.10 and 15.4).
- Owner-issued change orders—These change orders are issued unilaterally by the owner to increase the contract scope at no fault to the engineer.

Unpredictable conditions, such as unusually wet or cold construction weather, major storms or flooding, war, or "acts of God," should not be included in the construction contingency. Risk associated with unpredictable conditions should be borne by the owner and not by the contractor. Experience has shown that insistence of an owner to transfer all the risk cost to the contractor only results in claims, litigation, and ruined working relationships. In a high-risk project, conscientious and responsible bidders usually submit very high bids if they have to take all the risks.

Regardless of the quality of the construction documents, a heavy civil project should never go into construction without some allowance for construction contingency. Despite competent design effort and careful review, construction drawings and specifications are never perfect. Plan quantities are estimated with accuracies of up to a few percent, but most importantly, subsurface conditions and other site conditions for heavy civil construction projects always contain some level of uncertainty, regardless of how conscientiously the designer tries to characterize the project site.

For heavy civil projects, it is recommended that a 5–15% construction contingency factor be included in the construction cost estimate. The actual contingency depends on the uncertainties and risk to be assessed by the engineer for each particular project. An average of 10% is used for most projects.

24.4 Escalation Cost Adjustment

Escalation is the cost allowance in project cost to account for future inflation. There are three situations in which the project cost should be adjusted for escalation:

1. A project that was designed a few years ago is ready for construction. In this case, the project cost estimated in the past would need to be escalated to the current construction year.
2. A project has been designed now and is expected to go into construction some years in the future. In such a case, the project cost estimated now would need to be escalated to a future construction year.
3. An ongoing project will be constructed over many years.

There are many published sources from which inflation factors can be obtained. For heavy civil construction purposes, the commonly used source in the profession is the cost indices published by the *Engineering News Record* (ENR n.d.). The ENR publishes a construction cost index (CCI) and a building cost index (BCI) every month. These indices are based on average costs of labor and materials for 20 cities in the United States and two cities in Canada (Montreal and Toronto). Only the CCI is discussed here. The CCI has been compiled by ENR since 1908, with a base index of 100 in the year 1913.

The following is used to compute the escalation factor from Year A to Year B:

$$\text{Escalation factor} = (\text{CCI for Year } B)/(\text{CCI for Year } A)$$

Two examples are given below to illustrate the estimation of escalation factors for the two situations cited above.

Example 1—Estimate current project cost for a design completed in 1990 that will be under construction in 2000.

CCI for 1990 = 4,732
CCI for 2000 = 6,222
Escalation factor = 6,222/4,732 = 1.31

Therefore, the project cost estimated in 1990 should be increased by 31%.

Example 2—Estimate future project cost for a design completed now (say 2015), that will be under construction in 2020.

The ENR only provides 12-month projections. The escalation factor will therefore need to be estimated if the year of construction is in the future. Based on records since 1980, the average U.S. annual inflation is approximately 3% to 4%. Assume 3% annual inflation:

$$\text{Escalation factor} = 1.03^5 = 1.16$$

Therefore, the project cost currently estimated should be increased by 16% for future construction.

CHAPTER 25

Evaluation of Bids

25.1 Bidding before Design Completion

The design phase of a project ends with the completion of construction drawings, technical specifications, and the engineer's cost estimate. Bid solicitation is traditionally viewed as part of the procurement phase of project development, and it occurs after the plans and specifications are completed. As discussed below, the design phase sometimes does not end during bid solicitation. When a project schedule is tight, some owners start the bid solicitation process—advertisement, prebid conference and site visit, bid amendments, questions and answers—before the design is finalized. The design is finalized during bid solicitation, and changes to the original construction documents are made in bid amendments. For a variety of reasons, this practice should be discouraged, but it is commonly used by owners to "buy additional time" to complete design.

Significant revisions to the plans and specifications during bidding should be avoided for the following reasons:

- Major changes to the design confuse the bidders and can result in misunderstandings of work requirements and erroneous bids.
- Major changes to the design may complicate issues during construction, as both the contractor and construction manager would need to go back to bid amendments instead of the original documents. The use of conformed drawings (see Section 13.1) eliminates this problem.
- Major changes during bidding always result in a prolonged bidding process, and the early bidding may not even result in any time-saving advantages.

After bids are received and opened, they are usually summarized and evaluated by the owner, frequently with the assistance of the design engineer. The evaluation and analysis of bids may reveal errors in the bids, unbalanced bidding, or items that require bid verification to obtain additional information from the biddings. When the owner is satisfied with the bids, a contractor is selected based on price, qualifications, or both.

This chapter discusses the process of summarizing, evaluating, and verifying bids. The topic of unbalanced bidding is introduced, as this practice is sometimes used by contractors for a variety of strategic reasons.

25.2 Bid Summary

Bids can be summarized in a *bid tab*, which is a tabulation of all bid prices identified in the bid schedule and submitted by each of the bidders. In general, bid tabs contain the following information:

- Name of the project and bid opening date;
- All the information in the bid schedule, including bid item number, item description, units, and plan quantities;
- The engineer's cost estimate, representing the owner's estimate of the project cost; and
- The names of the bidders and their respective bid prices and total costs.

For publicly funded projects, bid tabs are considered public information and may be available from the public agencies upon request. For privately funded projects, bid tabs may be considered confidential information and may not be available to the public. In any case, data from bid tabs are generally evaluated and analyzed by the owner and his or her engineer before a contractor is selected. Bid data are valuable to a design engineer or cost estimator for future projects and represent a valuable resource.

Table 25-1 is an example of a bid tab for a fictitious project for illustration purposes. The project is for rehabilitation of an existing stream channel. The work consists of 14 bid items, including dewatering and stream diversion, excavation, backfill, reinforced concrete hydraulic control structures, channel lining, and reclamation. Three bids are received, and their bids, along with the owner's estimate, are summarized in the table. The engineer's cost estimate is \$244,175, which is within the bid range of \$231,953 to \$308,693. The apparent low bidder is Bidder No. 2, with a bid of \$231,953.

25.3 Unbalanced Bidding

To maximize profit during construction, contractors sometimes use *unbalanced bidding* to establish a contractual advantage on prices during bidding. A bid with unbalanced bidding still maintains the competitiveness as far as the total bid amount is concerned, because the bidder still needs to win the project to execute his or her strategy. Unbalanced bidding is not illegal, and a bid with unbalanced bidding

Table 25-1. Little Clear Creek Rehabilitation Bid Tabulation

				Engineer's Estimate		Bidder No. 1		Bidder No. 2		Bidder No. 3	
Item	Item Description	Quantity	Unit	Unit Price	Amount	Unit Price	Amount	Unit Price	Amount	Unit Price	Amount
1	Mobilization and Demobilization	1	Lump sum	$10,000	$10,000	$18,000	$18,000	$12,000	$12,000	$13,000	$13,000
2	Dewatering and Stream Diversion	1	Lump sum	$20,000	$20,000	$5,000	$5,000	$25,000	$25,000	$18,500	$18,500
3	Clearing and Grubbing	1	Lump sum	$10,000	$10,000	$8,800	$8,800	$7,500	$7,500	$6,800	$6,800
4	Sediment and Erosion Control	1	Lump sum	$3,000	$3,000	$2,500	$2,500	$1,500	$1,500	$4,400	$4,400
5	Unclassified Excavation	1,500	Cubic yard	$4.50	$6,750	$9.00	$13,500	$5.00	$7,500	$4.25	$6,375
6	Rock Excavation	100	Cubic yard	$25.00	$2,500	$75.00	$7,500	$22.00	$2,200	$30.00	$3,000
7	General Fill	1,850	Cubic yard	$5.50	$10,175	$6.75	$12,488	$5.15	$9,528	$3.55	$6,568
8	Structural Fill	500	Cubic yard	$7.50	$3,750	$10.25	$5,125	$8.85	$4,425	$6.25	$3,125
9	Reinforced Concrete	300	Cubic yard	$300.00	$90,000	$350.00	$105,000	$275.00	$82,500	$375.00	$112,500
10	Riprap	1,500	Cubic yard	$40.00	$60,000	$65.00	$97,500	$35.00	$52,500	$45.00	$67,500
11	Riprap Bedding	500	Cubic yard	$25.00	$12,500	$45.00	$22,500	$22.50	$11,250	$27.75	$13,875
12	New Asphalt Walkway	1,000	Square foot	$3.00	$3,000	$3.25	$3,250	$2.75	$2,750	$4.00	$4,000
13	Placing Topsoil	400	Cubic yard	$25.00	$10,000	$10.70	$4,280	$24.50	$9,800	$28.50	$11,400
14	Seeding and Mulching	1	Acre	$2,500	$2,500	$3,250	$3,250	$3,500	$3,500	$1,875	$1,875
		Total, Items 1–14			$244,175		$308,693		$231,953		$272,918

Note: Bid opening date is October 17, 1987.

cannot be thrown out for that reason only. The practice, however, borders on unethical and is generally viewed negatively by owners and engineers.

In unbalanced bidding, the prices of certain bid items are distorted so that they do not reflect the actual costs to the contractor. It is used to gain the following advantages during construction:

- Cash-flow issue—The prices of work items that will be performed first are artificially inflated so that the contractor can be paid for these work items early, and thus improve cash-flow management and finance of the construction. This bidding practice is called *front-loading*, and it is used to decrease the interest cost to the contractor.
- Quantity difference—When a bidder recognizes that the bid quantity is significantly underestimated on a particular work item, that bidder may deliberately overinflate the bid price to obtain a large profit on that item. In other words, the bidder is taking advantage of an engineer's estimating error.

The bid tabulation in Table 25-1 is used to illustrate the concept of unbalanced bidding. For this example, Bidder No. 1 is using the tactic of unbalanced bidding in his or her bid. Specifically, the following bid items are unbalanced:

Item 1—Mobilization and Demobilization	$18,000 (lump sum)
Item 2—Dewatering and Stream Diversion	$5,000 (lump sum)
Item 5—Unclassified Excavation	$9.00/cubic yard
Item 6—Rock Excavation	$75.00/cubic yard
Item 13—Placing Topsoil	$10.70/cubic yard

The strategy for Bidder No. 1 is as follows:

- Unbalance the costs of Items 1 and 2 to improve cash flow, so that the combined cost of these two items is equal to the actual costs. For this contract, 90% of the cost for mobilization and demobilization will be paid early, whereas the cost for dewatering and diversion will be distributed throughout the project.
- Unbalance the costs of Items 5 and 13 to improve cash flow, so that the combined cost of these two items is equal to the actual costs. Earth excavation will need to be performed early, and placing topsoil for reclamation will be performed at the end of the project.
- Unbalance the unit price of Item 6 because the bidder recognizes that the plan quantity for rock excavation will be exceeded by at least 50%.

Table 25-2 shows how the costs are being shifted between Items 1 and 2, and between Items 5 and 13.

As illustrated in Table 25-2, the exercise of shifting costs from one item to another does not change the actual costs to the contractor for performing the work

Table 25-2. Example of Unbalanced Bidding

Item	Actual Cost	Unbalanced Cost	Difference
1. Mobilization and Demobilization	1 LS @ $8,000	1 LS @ $18,000	+$10,000
2. Dewatering and Stream Diversion	1 LS @ $15,000	1 LS @ $5,000	–$10,000
5. Unclassified Excavation	1,500 CY @ $3.85/ CY = $5,575	1,500 CY @ $9.00/ CY = $13,500	+$7,725
13. Placing Topsoil	400 CY $30.00/ CY = $12,000	400 CY @ $10.70/ CY = $4,280	–$7,720
		Net difference:	+$5.00

Notes: LS means lump sum, and CY means cubic yards.

and thus maintains his or her competitive edge. However, his or her strategy to overinflate the unit price of rock excavation is an added risk to Bidder No. 1, because the amount for that item is now overinflated and becomes less competitive than the other bidders. Nevertheless, because the quantity is low, the bidder decides that this risk, typical for contractors, is worth taking.

When the bids are compared among one another and with the engineer's cost estimate, the unbalanced bidding of Bidder No. 1 becomes obvious. His or her prices are either significantly higher or significantly lower than the other prices. In this particular example, Bidder No. 1 is not the low bidder, and the owner does not have to deal with the consequences of the unbalanced bidding. If the bid for Bidder No. 1 were the apparent low bid, Bidder No. 1 might be selected as the contractor, and the owner would need to readjust his or her construction cash flow to deal with this payment schedule. As for the inflated unit price for rock excavation, the engineer should check and reestimate the quantity for rock excavation after discovery of the unbalanced bid strategy, and a design change may be required to minimize the increase in construction cost caused by a much higher quantity estimate for rock excavation.

25.4 Bid Verification

Bid verification is the process of evaluating a bid by requesting additional information on bid items that are significantly different from the engineer's cost estimate. When a bid price is significantly different from the engineer's estimate, one of the following scenarios is likely to occur:

- The bidder misunderstands the scope of work.
- The engineer has made an error in his or her quantity or pricing estimate.
- Unbalanced bidding has occurred.

- The bidder understands the scope of work, but his or her method of construction is different, his or her material supplier provides a different quote, or the production rate is different.
- The bidder deliberately underpriced or overpriced that item because of market conditions and his or her busy schedule.

The main purpose of bid verification is to make sure that the bid reflects the contract scope of work and that no error has been made unintentionally. All of the other reasons listed above, including unbalanced bidding, are not grounds to disqualify a bid, unless the contract explicitly forbids such a practice. Of course, if the engineer discovers that he or she has made a mistake in estimating the price or quantity of a particular item, that matter is between the owner and the engineer.

Assuming that the contractor is being selected based on price only, the owner is interested in verifying the apparent low bid first. In some cases, a so-called bid hearing meeting will take place between the owner and the apparent low bidder to discuss the basis of the low bid. Typically, one or more of the following pieces of information will be requested from the apparent low bidder on bid items to be verified:

- Schedule of values (breakdown of materials, equipment, and labor cost, especially for lump sum bid items);
- Work to be produced by those bid items (e.g., types of materials, locations, limits, and criteria);
- Sources and quotations of materials and products;
- Schedule of work for those bid items; and
- Quantities that are estimated independently by the bidder.

Only when the owner is satisfied with the information provided by the apparent low bidder, and no errors are discovered, will the apparent low bid become the low bid, and the contract will be awarded to the low bidder. The construction phase begins when the contract is awarded or when notice to proceed is given to the contractor. The end of the design phase is an appropriate end to this book.

GLOSSARY

Azimuth: Angles measured clockwise from any meridian, ranging from 0 degrees to 360 degrees.

Bank run: An informal term used in heavy civil construction and aggregate industry to denote natural state or composition of materials obtained directly from the ground without any processing. Also referred to as a *Pit run*.

Base bid: A list of bid items in the bid schedule that the owner is obligated to award in a construction contract.

Benchmark: A permanent reference point with known elevation and datum, which may also include horizontal coordinates.

Bid additive: An optional paid item in a bid schedule in addition to the base bid.

Bid alternative: An alternative work item in a bid schedule to replace one or more items in the base bid. Also referred to as a *bid option*.

Bid amendment: A modification to bidding documents, issued during bidding.

Bid schedule: Breakdown of construction work items accompanied, where appropriate, by estimated quantities that are used to solicit prices from contractors and later used as a basis for contractor compensation during construction.

Bid tab: A compilation or summary of bid prices from all bidders, usually including the engineer's cost estimate.

Bond: A sum of money paid in advance to guarantee a certain obligation, such as performance of a construction contract or payment of bills for labor and materials.

Borrow: Earth or rock materials that are excavated from the ground and hauled to a project site for construction.

Catch line: Intersection of an excavated surface or fill slope with the ground surface.

Catch point: Intersection of an excavated line or fill line with the ground surface.

Change order: Documentation of a change of scope of work during construction; may or may not accompany a change in contract price or contract schedule.

Claim: A request from a contractor for compensation on work not scheduled for payment in the contract.

Clay shale: Sedimentary rock composed mainly of silt- and clay-sized particles, typically weakly cemented and with medium to high plasticity.

Clearing: Removal of trees, brush, grass, debris, rocks, and other surface materials; typically done before excavation in the ground.

Conformed drawings: Construction drawings incorporating all design changes made during bidding; issued for construction after award of bid.

Constructability: Ability of a construction project to be built safely using conventional materials and equipment.

Contour: Line of equal elevation.

Cost-plus contract: Cost reimbursement contract where a contractor is paid for all of its allowed expenses to a set limit plus additional payment for a profit.

Davis–Bacon wages: Wages mandated through the Davis–Bacon Act of 1931, which is a federal labor law requiring that mechanics and laborers receive not less than prevailing wages as determined by the Secretary of Labor.

Day-labor method: See *Force account.*

Declination: Horizontal angle between the magnetic meridian and the true or geographic meridian.

Deliverables: The products of an engineering study or design, to be submitted to the client, such as engineering reports, memoranda, design drawings, and technical specifications.

Descriptive geometry: Science of graphic representation and the solution of spatial relationships of points, lines, and planes by means of projections.

Dewatering: Removal of groundwater through pumping, sumps, ditches, well points, deep wells, or other methods.

Easting: North–south grid lines in a horizontal coordinate system, with coordinates increasing in the easterly direction.

Engineer of record: The principal designer with the overall technical responsibility in the production of construction documents.

Engineering geology: Discipline of applying knowledge of geology to engineering problems.

Force account: A method of construction procurement (also known as *Day-labor method*) in which the contractor is compensated for actual labor and equipment through hourly rates.

Force majeure: A common clause used in construction contracts that frees the owner and the contractor from liability or obligation when an extraordinary event or circumstance occurs beyond the control of both parties, such as war or an "act of God."

Free on board (FOB): A point of delivery of materials and supplies without delivery charge to the buyer.

Freeboard: A vertical distance between the waterline and the top of a structure, such as a canal bank or a dam crest.

Front-loading: An unethical bidding strategy in competitive bidding that uses artificial overinflation of the bid prices for work items that will be performed first, with the objective of improving the cash-flow management and decreasing interest cost to the contractor. It is considered unbalanced bidding.

Geomembrane: Any of the many manufactured synthetic fabrics, typically with low permeability, used in geoenvironmental and geotechnical applications.

Glacial till: Sediments deposited by a glacier, typically unsorted and unstratified.

Grade: A term used in heavy civil construction to denote a ground surface.

Ground penetration radar: A technique used in geophysical field investigations to locate underground pipes, voids, structural defects, concrete structures, and other subsurface features.

Grubbing: Removal of the bottom portion of vegetation, such as tree stumps and roots.

Invert: A control point or surface in a structure, generally at the bottom, such as the inside bottom of a pipe or culvert.

Lacustrine deposits: Sediments deposited in a lake environment, typically fine-grained silts and clays.

Layer: A term used in computer-aided drafting (CAD) to denote a group of pieces of information in a drawing, such as controls, vegetation, and utilities.

Legend: An explanatory caption in a construction drawing, usually for symbols, lines, or hatched patterns.

Mensuration: The measurement of geometric quantities.

Micrometer: A dimension equal to one millionth of a meter.

Monument: A surface reference point used for survey control. A monument can be a *Benchmark*.

Neat line: A term used in heavy civil construction and design to denote the design limit of a feature, such as limit of excavation, fill, and concrete.

Northing: East–west grid lines in a horizontal coordinate system, with coordinates increasing in the northerly direction.

Offset: A distance measured perpendicular to a baseline or centerline.

Outlet works: An appurtenant structure in a dam with the function of controlling water releases through the dam.

Photogrammetry: The science of obtaining measurements and other qualitative information from photographs.

Pit run: See *Bank run.*

Plan holder: A person, firm, or other entity on a recorded list that has an interest during bidding of a construction project and is issued a set of bid documents and all amendments.

Plan quantity: Estimated quantity of a construction paid item based on the design shown in the construction drawings; used as the basis during bidding.

Planimeter: An instrument used for estimating areas on a drawing by manually tracing the perimeter of the area.

Polyline: A term used in computer-aided drafting (CAD) to denote a continuous, three-dimensional line consisting of straight-line segments with known coordinates.

Pro bono: Voluntary work performed by a professional without a service fee.

Record drawings: Construction drawings issued after construction that incorporate all design changes made during construction.

Redline: A document with marked-up review comments or changes.

Resident engineer: Lead field personnel in a construction representing the designer and owner with the primary responsibility of observing construction work for compliance with the drawings and specifications. The person does not necessarily need to be an engineer.

Riparian vegetation: Vegetation that grows adjacent to a stream or lake.

Riprap: Natural rocks or stones that are used to provide erosion resistance from moving water or waves.

Risk analysis: The application of a probabilistic approach to identify project deficiencies and prioritize mitigation of those deficiencies for public protection and public safety.

Rock quality designation (RQD): The RQD is used in rock mechanics to quantify the in situ rock quality; it is defined as the sum of the rock cores 4 in. or longer, expressed as a percentage of the total core run.

Roller-compacted concrete (RCC): A lean, zero-slump concrete placed using earth-moving equipment in lifts. The aggregate for the concrete typically contains a significant amount of gravel and relatively low fines contents.

Running average: An average of two or more consecutive numbers, starting with the most current number.

Schedule: A tabulation of information on a construction drawing or specification.

Screening: A technique of creating lighter line weights or light objects as background in a design drawing.

Seismotectonic assessment: Engineering geology study intended to evaluate faults and sources and magnitudes of seismic loads.

Shop drawings: Construction drawings prepared by a contractor during construction, showing installation details and other construction details and descriptions not shown in the design that are within the responsibility and expertise of the contractor.

Slaking: A physicochemical process in a plastic bedrock such as a clay shale whereby the rock rapidly deteriorates into a soil-like material upon exposure to cycles of wetting and drying.

Soil cement: A lean, zero-slump mixture of soil and cement placed using earth-moving equipment in lifts. The aggregate for the soil cement typically contains a relatively low gravel content and high fines content.

Spillway: An appurtenant structure in a dam used to pass flood flows through the dam.

Standard dimension ratio (SDR): Ratio of the outside diameter of a pipe to its wall thickness.

Standard penetration test blow counts: A field test procedure in foundation engineering for the number of blows of a standard-size hammer to drive a standard-size split-spoon soil sampler into the ground; generally used to evaluate in situ density or consistency of the materials.

Subgrade: A surface in the ground, generally obtained through excavation, used for structural support.

Tempering: The time required for adequate hydration of a clay soil at the particle level upon addition of free water.

Triangular irregular network (TIN): A vector-based representation of a physical land surface, made up of irregularly distributed nodes and lines with three-dimensional coordinates (x, y, and z) that are arranged in a network of nonoverlapping triangles.

Unbalanced bidding: Bidding strategy in which the bid prices of some work items are deliberately distorted to create a contractual advantage.

Unconfined compressive strength: Axial strength of a soil or rock specimen by axial loading without lateral confinement.

Unwatering: Removal of surface water by means of sumps, ditches, pumping, drainpipes, or other methods.

Value engineering: A study or evaluation of alternatives that satisfies the original function and need at the lowest lifecycle cost.

Solutions to Exercise Problems

Chapter 3—Characterization of Project Site

3.1a The glacial till will introduce primarily groundwater problems because of the high permeability and the proximity of the source of water from the adjacent stream. During design of the excavations below the groundwater level, it is important to consider the effects of groundwater infiltration into the excavation, such as erosion and slope stability. The excavation slopes shown in the design drawings should be flatter than the slope normally required by OSHA. During construction, the contractor will be responsible for dewatering the excavation and maintaining it in a dry condition so that all excavations and other construction work are performed "in the dry." Dewatering of the glacial till foundation will likely require several "deep wells" in the perimeter of the excavation.

3.1b The cobbles and boulders in the glacial till will introduce significant obstructions to the sheet piles during driving. It is anticipated that the progress of driving will be slow because of the frequent obstructions. And it is likely that the sheet piles may not reach the design depths because of "refusals"; the hard driving may even cause significant damage to the steel sheets. This problem will persist even if the designer specifies heavy steel sheet piles such as PZ35. From a design standpoint, the selection of steel sheet piles as a seepage cutoff wall is a poor choice because of the difficult driving conditions in the glacial till. It may even be considered a design error. A different solution should be considered, such as a slurry wall.

3.1c Because there will be a permanent storage pool impounded by this high embankment, the key design issues are the seepage reduction and seepage control of the permeable foundation. Foundation seepage can be reduced by pressure-grouting the foundation glacial till at least to the depth equal to the "hydraulic height" of the dam. Foundation seepage can be controlled and filtered safely by the use of downstream filters, drain blankets, and toe drains. Generally, the method used to drill the grout holes is determined by the contractor. Because of the presence of cobbles and boulders in the foundation, the contractor is likely to select a percussion drilling method to cut through the obstructions.

3.2a One of the key engineering characteristics of loess is its potential to collapse upon wetting, which causes the breakdown of the weak cementation bonds among the soil particles. In its natural dry state, the compressibility of loess is relatively low, and there may not be any significant settlements to the apartment building in the first few years after construction. However, over the years after construction, there may be gradual groundwater infiltration under the building, either from surface runoff or from broken utility pipes. The wetted loess foundation will undergo large differential or general settlements, resulting in cracking of the floor and walls. To remedy the problem, the voids in the foundation should be grouted using "mud jacking" or other similar methods. Even after remediation, there is no guarantee that similar collapse episodes will not recur. From a design standpoint, construction of the building on the loess foundation without treatment is considered a design error, given our understanding of the behavior of this material. The loess foundation can be effectively treated before construction of the building by flooding the foundation to remove most or all of the collapse potential of this material.

3.2b The unlined canal in the loess will experience various problems during operation, including significant erosion and scour from the moving water, slumping of the canal side slopes, and perhaps seepage and piping. In addition to the collapse potential of the material upon wetting, this material has relatively high permeability, resulting in high seepage rates in the canal foundation. The seepage problems may result in related slumping and slope stability problems and internal erosion known as "piping," which may cause a breach failure of the canal. As a minimum, a canal in such a material should be lined with concrete, with seepage control provisions such as filters and drains under the lining.

3.3a These young marine clays typically have high compressibility and low strength. A highway embankment constructed on this type of weak foundation will experience large settlement, along with slope stability and bearing capacity issues. For clays, which have low permeability, the settlement is time-dependent and may last for years. The slope stability and bearing capacity problem are more short term, i.e., they will happen sooner. If the foundation is untreated, the highway embankment may experience short-term slope stability problems and long-term slumping and pavement cracking problems, and thus the highway would become a frequent maintenance headache. Treatment of the soft foundation may include preloading of the foundation to remove the majority of the settlement potential to increase the short-term "undrained shear strength" through consolidation.

3.3b Grain silos are heavily loaded when full, and thus the design of the silo foundation slab is controlled by the bearing capacity of the foundation to prevent the silo from failure. Even if the silo slab is safe against a bearing capacity failure, long-term settlements will still be a problem, and differential settlements over the long term may make this structure look like the Leaning Tower of Pisa. It is prudent that grain silos not be constructed on this type of foundation.

3.4a Glacial till contains numerous cobbles and boulders that will obstruct the drilling progress. Drilling with augers will not be feasible in this case. Instead, percussion drilling should be used in this material in order to be able to chisel through these rocks. Percussion drilling progress is low, however, and it is possible that quality samples will not be able to be obtained in this material.

3.4b The alluvial deposit will likely contain clean sand and gravel, which can be drilled with a hollow-stem auger. However, sampling of saturated sand and gravel inside a hollow-stem auger will be problematic because of the hydrostatic uplift and seepage inside the auger when the end plug is removed. Without counteracting this uplift and seepage potential, the natural material outside the auger will tend to move inside, and thus sampling with a split spoon becomes impossible. Instead of using an auger, a steel casing and a tricone roller bit should be used. The inside of the casing should be filled with a “drill mud” at any time to balance the hydrostatic pressure outside, so that there will not be any seepage potential inside the casing during sampling.

3.4c Drilling through bedrock is typically done with a core barrel with circulating water. If circulating water is used to core through the plastic clay shale, the core sample will swell against the core barrel wall, and it is impossible to push the sample out of the barrel from one end to the other. Instead, it is advisable to use the “dry core” method for clay shales (e.g., Bearpaw Shale, Fort Union Shale, Pierre Shale, or Mancos Shale) with a split barrel similar to the split-spoon sampler used in the standard penetration test for soil samples. No water is used for drilling so that there is no water available for swelling. The core barrel is split lengthwise, so that it is easy to log and retrieve the core without damaging it.

3.5a A clean filter sand (similar to the ASTM C33 Fine Aggregate) can be processed from a natural sand deposit by screening to remove the gravels and washing in water to remove most of the fines (percent passing the No. 200 sieve). However, the washing process is ineffective if there are too many fines and if the fines are clayey. Alluvial deposits are typically water-sorted sand and gravel without significant fines, though there are exceptions. Colluvial deposits are deposited by gravity along slopes and hillsides, and the materials can be very heterogeneous, ranging from boulders to silts and clays. Contrary to an alluvial deposit that was sorted through water and thus is relatively clean, there can be significant amount of fines and little sand fraction in a colluvial deposit. There is a much higher likelihood that the alluvial deposit is more suitable as a source of borrow for the filter sand than the colluvial deposit. Of course, drilling and testing are still required to confirm the suitability of the alluvial material.

3.5b Riprap is a natural stone used for erosion protection from waves or moving water. The characteristics of riprap include hard and sound rock quality (as quantified by the Los Angeles abrasion soundness, sulfate soundness, and specific gravity), as well as the blocky shape of the stones. In other words, weak rocks with slab-shaped stones are not desirable. Shale is generally a weak rock and is easily broken into thin slabs because of the thin bedding planes. On the other hand, granite is generally massive, strong, and broken into blocks controlled by joints. Therefore, a shale outcrop should not be considered as a borrow source for riprap regardless of the formations.

3.5c It is possible that some alluvial deposits contain a significant amount of clay, but generally alluvial deposits contain mostly sand, gravel, and silt; they will not be classified as plastic, fine-grained soils needed as a low-permeability clay fill. On the other hand, soils deposited in a low-velocity coastal floodplain geologic environment are likely to contain a significant amount of fine-grained soils, especially clays. The answer to this question is not as clear-cut, and subsurface explorations will be needed to explore both borrow areas.

3.6a Single-drum or dual-drum vibratory rollers are effective to compact clean granular materials, such as an aggregate base course.

3.6b The aggregate for roller-compacted concrete (RCC) is primarily a clean sand and gravel, similar to aggregate base course. Typically, 10-ton single-drum or dual-drum vibratory rollers are used to compact this material as soon as it is batched.

3.6c Compaction of a clay fill requires a static roller with kneading action during rolling. Suitable rollers include a sheepsfoot roller or a tamping roller without vibration.

3.6d Compacting a clean filter sand requires a steel-drum vibratory roller. It is very important that the sand not be overcompacted to avoid breakdown of the sand particles to create additional fines. Sand with more than 5% fines will not function as a clean filter.

3.7a Stripping a thin layer (e.g., 6–12 in. thick) of topsoil can be done with a bulldozer.

3.7b Grading the large area can be effectively done with scrapers, which require a wide-open area for operation. The materials that are scraped off are collected in the storage bed of the scraper and hauled to areas that require filling. In this way, the scraper is functioning as an excavator, a haul truck, and sometimes a compactor. The weight of the scraper is large enough to act as compaction equipment, but it is important that the contractor route the construction traffic to obtain adequate compaction effort.

3.7c A trench excavated in a residential street for a sewer pipe will not have adequate room for an open cut with flat slopes and will therefore require a "trench box" for protection. A hydraulic excavator will be required to excavate this narrow trench inside the trench box.

3.7d Clam shells suspended from a crane are used to dredge river sediments.

3.7e Sprinkler lines are very shallow (a few inches deep) and require hand shovels to excavate.

3.8a Some sort of haul truck (e.g., end dump, side dump, or belly dump) is needed because of the haul distance.

3.8b Because the haul distance is so short, the contractor will probably use a loader to excavate and haul the material in the loader bucket from the stockpile to the placement location. Using the haul truck for such a short haul will not be cost effective.

3.8c Because the work area is wide open, a scraper will be cost effective to both excavate and haul the material for a site-grading operation. The scraper is functioning both as an excavator and a haul truck.

3.8d Transporting freshly mixed roller-compacted concrete (RCC) can be done by end-dump haul trucks or by a conveyor system, depending on the haul distance and the vehicle access considerations. Both methods have been used effectively. Because RCC is zero-slump when fresh, it is not suitable to transport the material in a transit mixer because it is impossible to discharge such a stiff material out of the transit mixer.

3.9a A stiff sandy clay is classified as a Type A Soil by OSHA for two reasons: (1) the soil is cohesive because it is a clay; and (2) the soil consistency is stiff, implying that the unconfined compressive strength is higher than 1.5 tons per square foot. The maximum allowable slope is 0.75H:1V (horizontal:vertical).

3.9b A soft to very soft silty clay is classified as a Type C Soil by OSHA for two reasons: (1) the soil is cohesive because it is a clay; and (2) the soil consistency is soft to very soft, implying that the unconfined compressive strength is less than 0.5 tons per square foot. The maximum allowable slope is 1.5H:1V (horizontal:vertical).

3.9c A dense, dry, gravelly sand is classified as a Type B Soil by OSHA because the soil is granular, cohesionless, and above the water table. It is important to note that OSHA ignores the relative density of the granular soil and whether the soil is dense or loose; the same maximum allowable slope of 1H:1V (horizontal: vertical) is imposed.

3.9d A loose, saturated, silty sand is classified as a Type C Soil by OSHA because the soil is granular, cohesionless, and below the water table. It should be noted that even if the saturated silty sand is dense, it will have the same classification as long as it is submerged. The maximum allowable slope is 1.5H:1V (horizontal:vertical).

3.10 To be conservative, the area used for the quantity calculation is taken as 420 ft by 320 ft to stay within the limits of the bottom of the future farm pond. The average thickness of the topsoil, clay fill, and structural fill is assumed to be 1, 3, and 2.5 ft, respectively. All three granular soil types encountered at the site (SP, SW, and SW-SM) can be used as structural fill. The following is a summary of the available quantities and the factors of safety (available quantity divided by the required quantity):

Material	Available Quantity (cy)	Factor of Safety
Topsoil	5,000	2.5
Clay fill	15,000	1.25
Structural fill	12,500	1.92

Ideally, the factor of safety should be at least two, in order to account for field variations in the ground. The results of the quantity calculation are evaluated as follows:

- The available topsoil is adequate.
- The factor of safety for the clay fill is not adequate, and it is possible that during construction, the borrow area will run out of the clay fill when the maximum depth of 10 ft is reached. That does not mean that this borrow area should not be used to obtain the clay fill, because it is still the most economical way to obtain this material. The strategy for the owner is to require the contractor to exhaust all clay fill from this borrow area, and then obtain the remaining quantity from an off-site source to be determined by the contractor. This is an example where a bid additive (see Section 19.2) can be used to obtain a bid price for an off-site clay fill based on some arbitrary quantity (say 2,000 to 3,000 cubic yards). If there is indeed a shortfall, then there is already a bid item to pay for the import fill instead of negotiating with the contractor during construction. If there is no material shortage from the borrow area, there is no need to award this bid additive.
- The factor of safety for the structural fill is slightly less than the required 2.0. Considering that there will be some structural fill from the side slope areas around the perimeter of the future farm pond that are not accounted for in the calculations, the available quantity is judged to be adequate.

Chapter 7—Graphical Representation of Civil Design

7.1 Section A–A′ and Section B–B′ are shown in Fig. 7S-1.
7.2 The plan of excavation using only topographic contours is shown in Fig. 7S-2.
7.3 The plan of the road detour embankment using slope lines and slope inclinations is shown in Fig. 7S-3.
7.4 Table 7S-1 is a summary of the relevant elevations for the two cross sections. Section A–A′ and Section B–B′ are shown in Fig. 7S-4.

Chapter 8—Legend, Abbreviations, and Notes

8.1a 26" DIA. ALUMINUM MANHOLE COVER, NEEDHAM TYPE R-1594, OR APPROVED EQUAL.
8.1b 1/4" DIA. NYLON BOLTS AND STAINLESS STEEL DROP-IN ANCHORS.
8.1c END UPSTREAM REINFORCED EARTH WALL, STA. 5 + 10.
8.1d TOP OF RCC, UPSTREAM EDGE OF DAM CREST.
8.1e 18" x 18" FABRICATED UNION, CARBON STEEL, EXTRA-STRONG PIPE WITH 150 LB FLANGE EACH END.
8.2a LIMIT OF EXCAVATION (SEE NOTE 2).
NOTE 2: EXCAVATE 6 INCHES UNDER TRI-LOCK BLOCKS. SOME LOCAL GRADING MAY BE REQUIRED TO FILL IN LOW SPOTS AND TRIM OFF HIGH SPOTS.
8.2b SECURE CONDUITS UNDER WALKWAY TO ACTUATORS (SEE NOTE 4).
NOTE 4: SECURE THE FOLLOWING CONDUITS UNDER WALKWAY TO

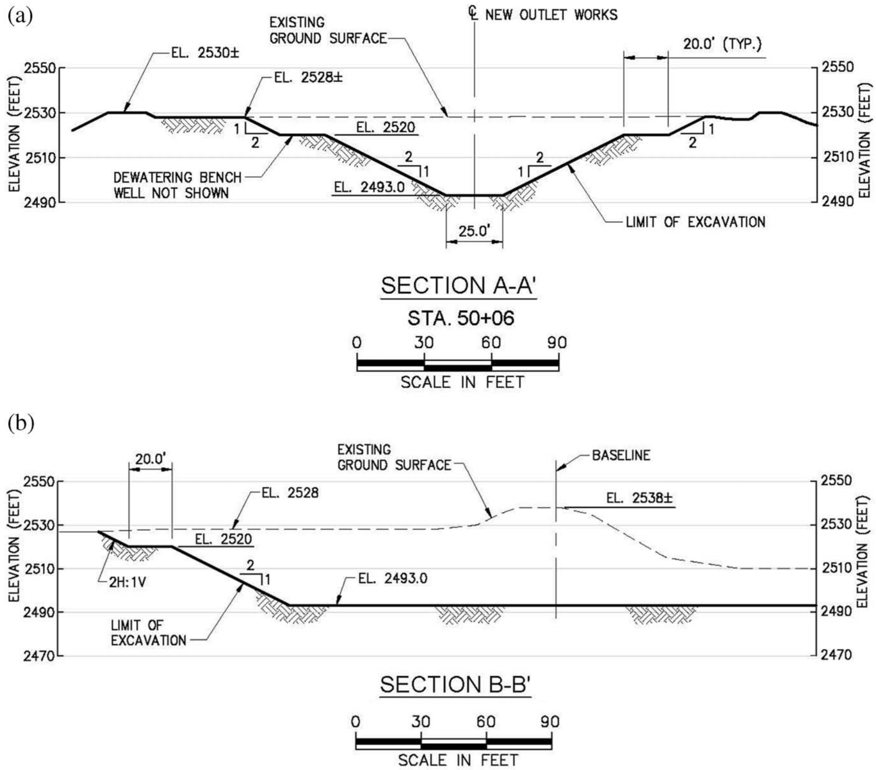


Fig. 7S-1. Outlet Works Excavation for (a) Section A–A′ and (b) Section B–B′

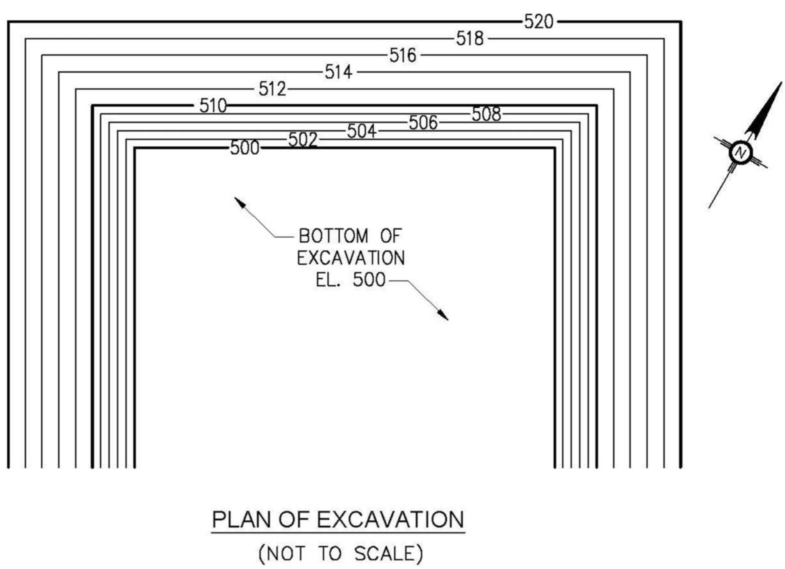


Fig. 7S-2. Plan of Excavation Showing Topographic Contours

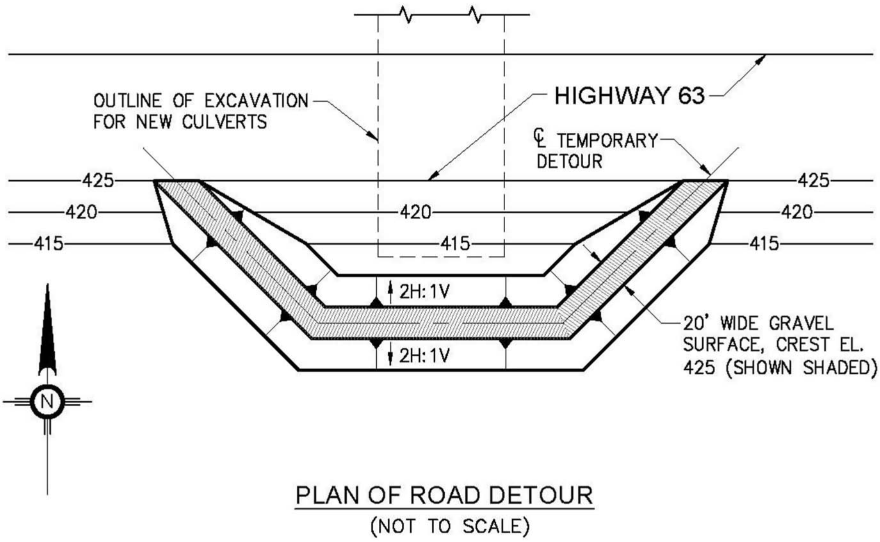


Fig. 7S-3. Plan of Road Detour Showing Slope Lines and Inclinations

Table 7S-1. Summary of the Relevant Elevations for the Two Cross Sections in Exercise Problem 7.4

	Section A–A′ Sta. 12 + 20	Section B–B′ Sta. 12 + 50
Ground surface elevation	236.0	230.0
Culvert invert elevation	214.0	211.0
Subgrade elevation	213.5	210.5

ACTUATORS: 3-1.5" CONDUITS FOR 480VAC; 1-1.5" CONDUIT FOR CONTROL WIRING; 2-1.5" CONDUITS FOR ANALOG WIRING.

8.2c LIMIT OF SITE DISTURBANCE (SEE NOTE 1).
NOTE 1: LIMIT OF SITE DISTURBANCE SHALL BE LIMITED TO 15 FEET BEYOND TOE OF NEW RIPRAP, EXCEPT AT NEW RETAINING WALL WORK AREA. SEE SHEET 2.

8.2d BLOCKOUT FOR ELECTRICAL CONDUITS (SEE NOTE 5).
NOTE 5: PROVIDE A BLOCKOUT FOR ELECTRICAL CONDUITS IN THE TRANSFORMER PAD IF THE PAD IS PLACED PRIOR TO THE INSTALLATION OF THE CONDUITS. THE BLOCKOUT LOCATION AND DIMENSION SHALL BE FIELD DETERMINED.

8.2e 42" × 36" PIPE REDUCER (SEE NOTE 4).
NOTE 4: PIPE REDUCER SHALL BE CARBON STEEL WITH 150-LB SLIP-ON FLANGES EACH END (2" RUBBER LINING TYPICAL).

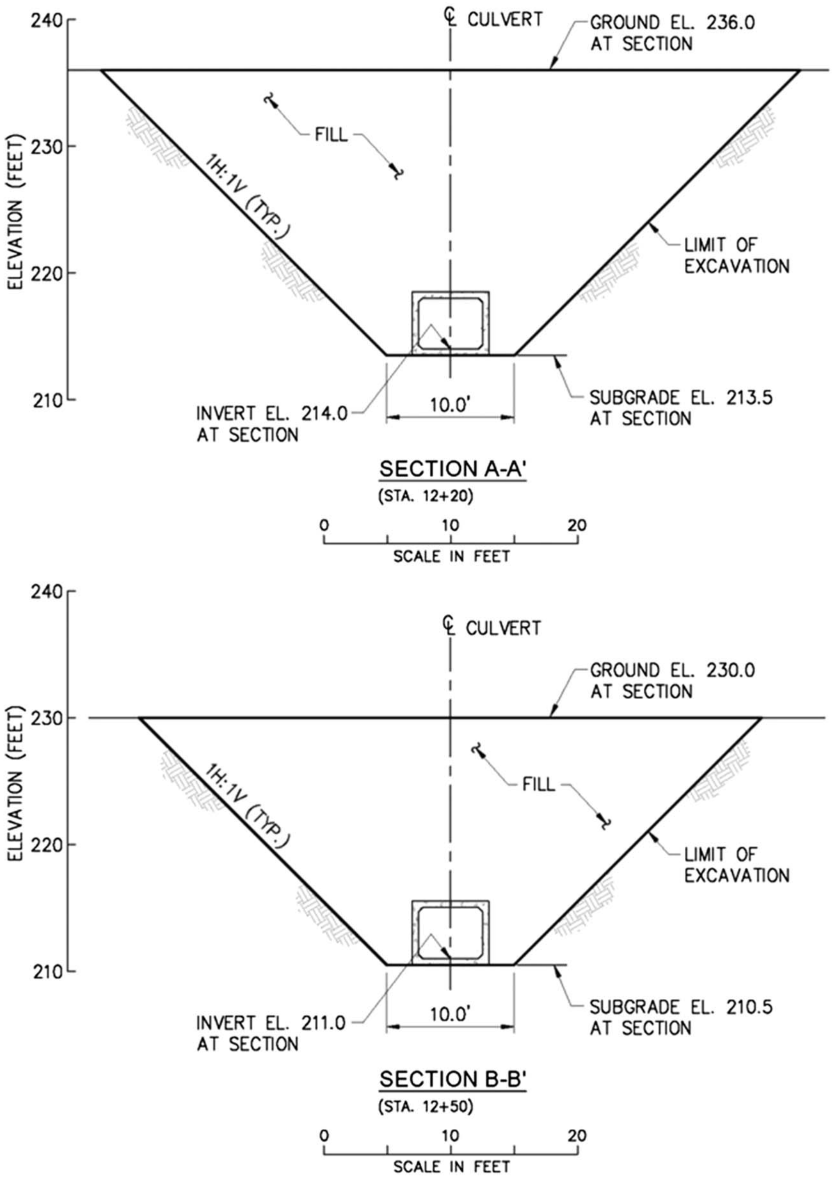


Fig. 7S-4. Section A–A′ and B–B′ of Box Culverts

Chapter 9—Drawing Production Techniques

9.1a The catch lines for the fill limits of the level jetty are shown in Fig. 9S-1. In order to complete this plan, it is necessary to add fill slope symbols and slope labels along the three fill slopes.

9.1b The typical cross section A–A′ of the jetty is shown in Fig. 9S-2. Only one of the slopes is labeled using "typical" because both slopes are the same. Note the 1-ft

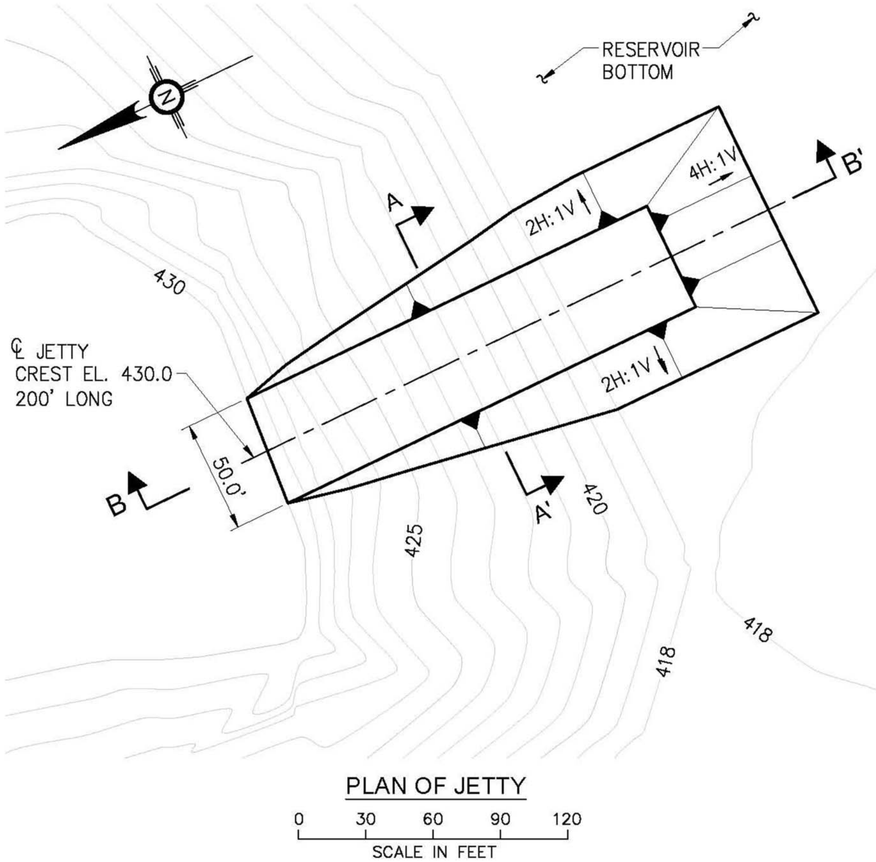


Fig. 9S-1. Fill Catch Lines of Fishing Jetty in a Reservoir

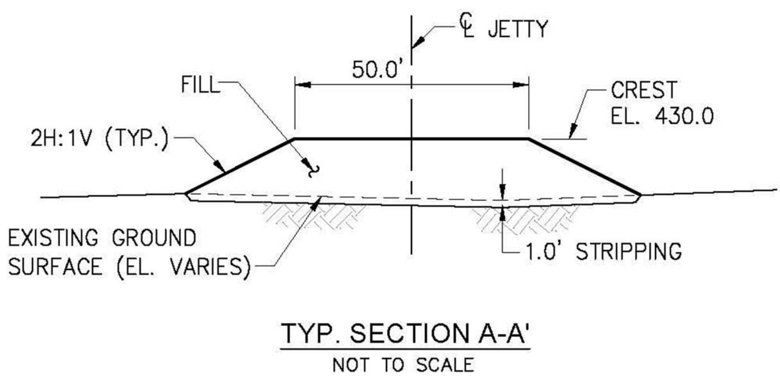


Fig. 9S-2. Typical Cross Section A–A′ of Fishing Jetty

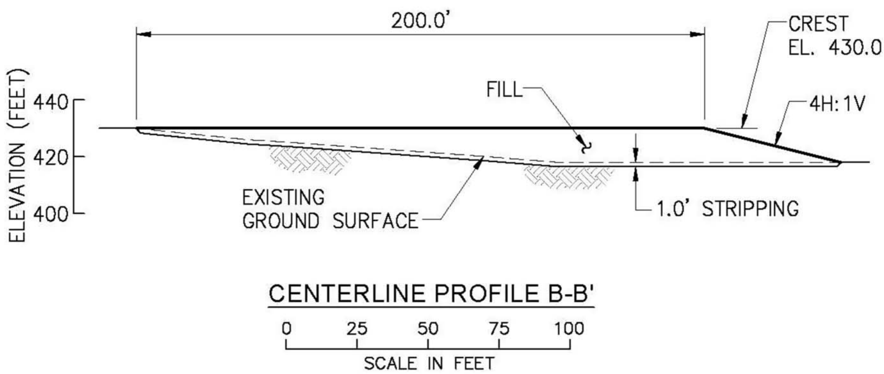


Fig. 9S-3. Centerline Profile B–B′ of Fishing Jetty

stripping below the existing ground surface, whose elevation varies because it is on a slope.

9.1c The centerline profile B–B′ of the jetty is shown in Fig. 9S-3. The profile along the length of the jetty is also called the "longitudinal section."

9.2a The catch lines for the excavation limits of the outlet works are shown in Fig. 9S-4. In order to complete this plan, it is necessary to add excavation slope symbols and slope labels along the side slopes and the end slopes. Note that the excavation slope symbol is different from the fill slope symbol. The triangle in the excavation slope symbol is hollow, while the triangle in the fill slope symbol is solid (compare to Fig. 9S-1). Construction of catch points and catch lines for a sloping excavation bottom requires some additional explanation. Fig. 9S-5 illustrates how to construct a typical catch point for the excavation. Before we draw the excavation catch lines, the contours along the bottom of the excavation should be identified. The bottom slopes uniformly from El. 5,635 to 5,630 along the 160-ft length, or a 1-ft drop for every 32 ft of length. For example, the elevation of Point a' is 5,634; that point is close to an existing contour of El. 5,658. Therefore, Point a' is about 24 ft lower than the 5,658 contour. An offset distance of 48 ft is required in order for the excavation contour to intersect the 5,658 existing contour. That point of intersection is Point a, as shown in the figure. The other catch points are established similarly, using other excavation contours 5,633, 5,632, and 5,631 on both the north and south sides of the excavation.

9.2b The typical cross section of the excavation is shown in Fig. 9S-6.

9.2c The excavation profile is shown in Fig. 9S-7. The profile should include the existing ground surface, the sloping bottom of the excavation, and the length of the upstream end and downstream end of excavation, as referenced to the centerline of the dam crest.

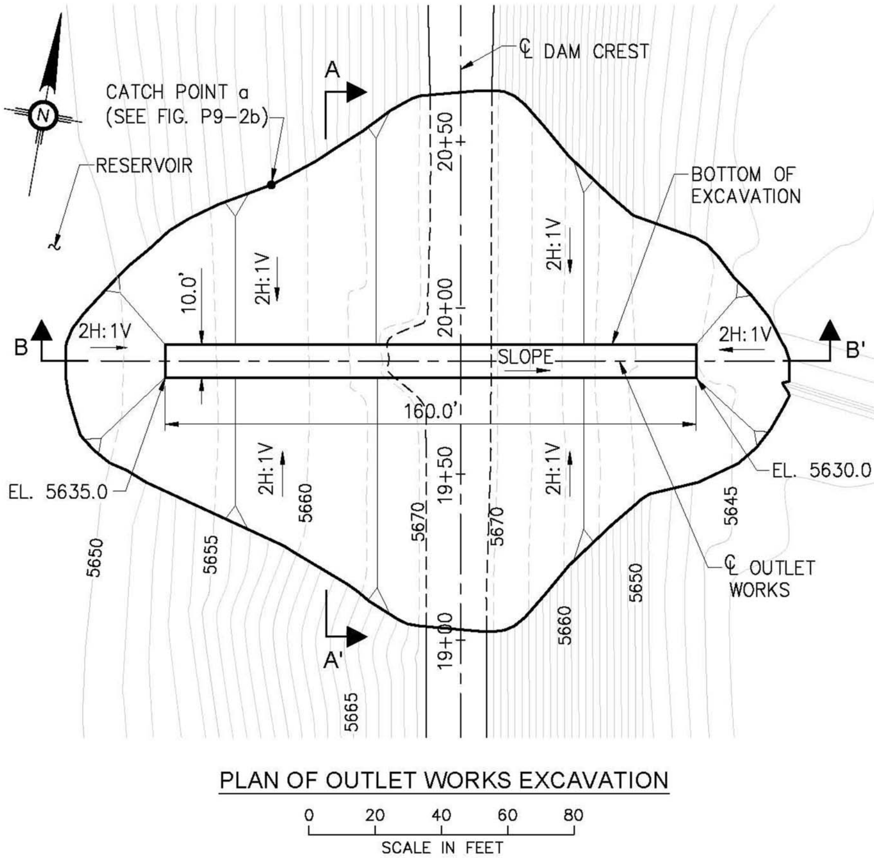


Fig. 9S-4. Excavation Catch Lines of Outlet Works

9.3a The catch lines for the fill limits of the sloping berm are shown in Fig. 9S-8. When compared to the level jetty in Fig. 9S-1, this berm is smaller because of the sloping fill. The technique to construct the catch points and catch lines for the sloping fill is similar to that used for the sloping excavation in Fig. 9S-5. The first step is to identify the contours of the top of the berm, which slopes from El. 430 to 425 over a distance of 200 ft, or a 1-ft drop for every 40-ft length of the berm. Fig. 9S-8 shows the contours 429, 428, 427, and 426 along the top of the berm. Using these contours, catch points are established on both east and west sides.

9.3b The typical cross section A–A′ of the berm is shown in Fig. 9S-9. Note that the top of the berm is sloping and thus should be labeled "ELEVATION VARIES."

9.3c The centerline profile B–B′ of the berm is shown in Fig. 9S-10. The variable top of berm elevations should be identified at each end.

9.4a The catch lines for the excavation limits of the outlet works with the intermediate benches are shown in Fig. 9S-11. The method to draw the catch points and catch lines from the bottom of the excavation up to each of the two

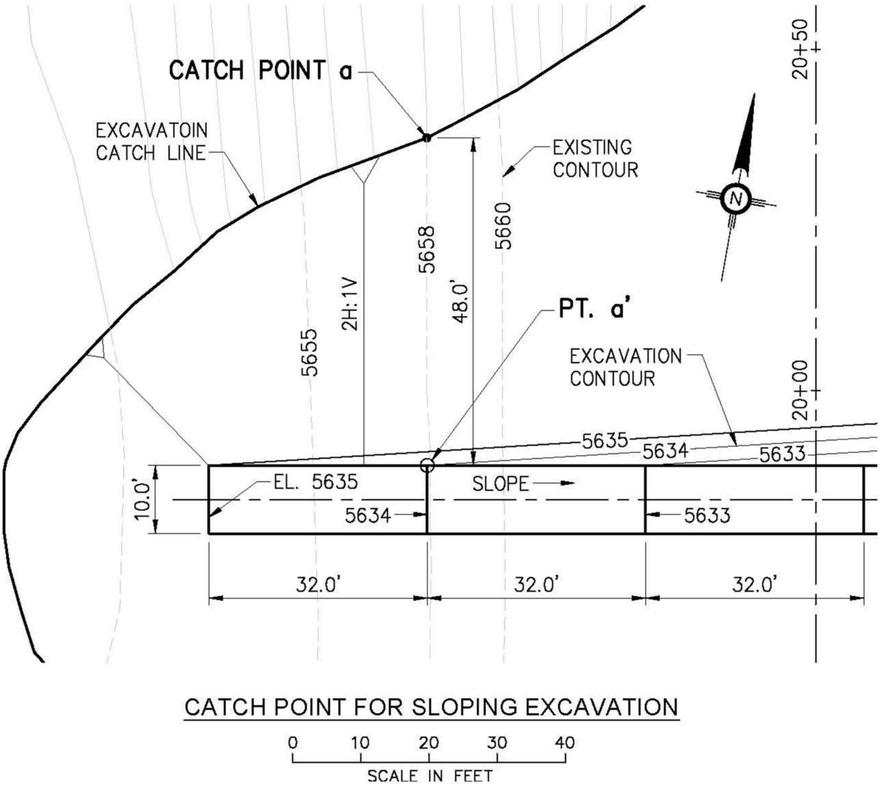


Fig. 9S-5. Constructing a Typical Catch Point for a Sloping Excavation

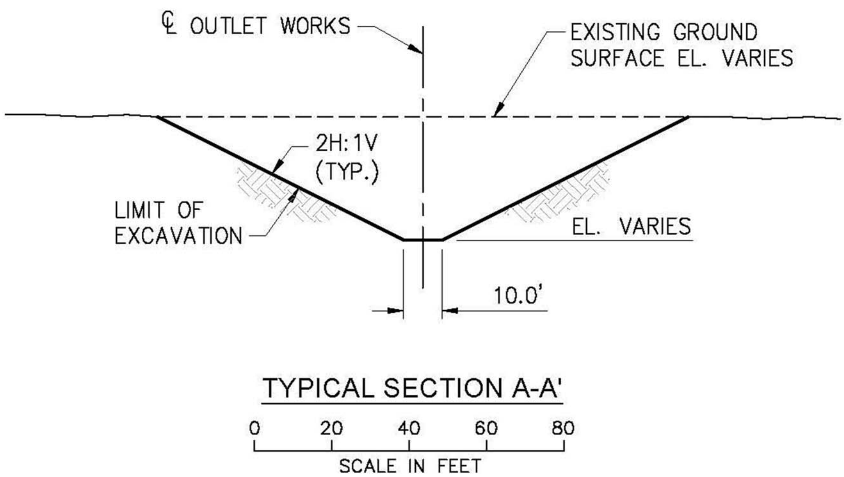


Fig. 9S-6. Typical Section A–A′ for a Sloping Excavation

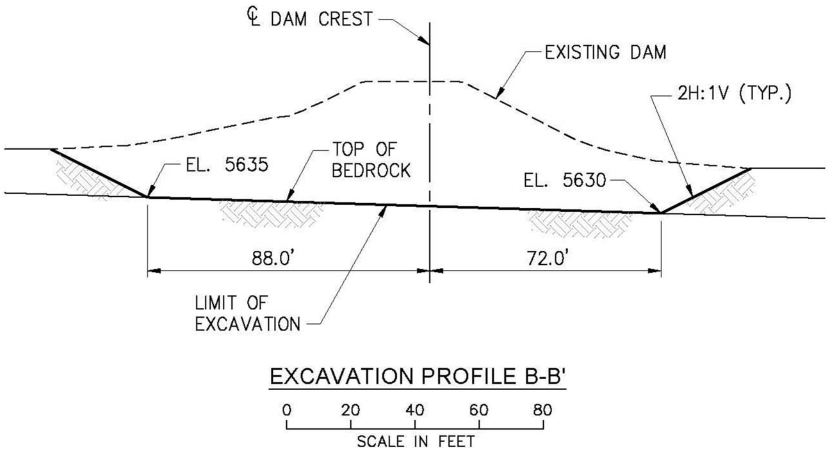


Fig. 9S-7. Centerline Profile B–B′ for a Sloping Excavation

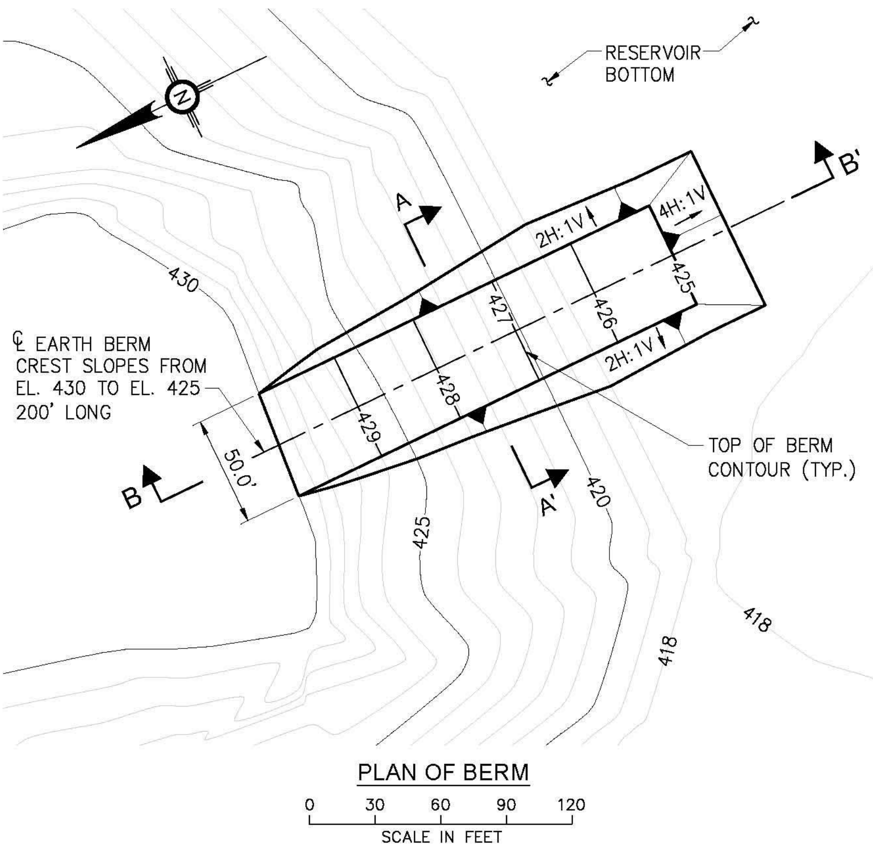


Fig. 9S-8. Fill Catch Lines of a Sloping Berm

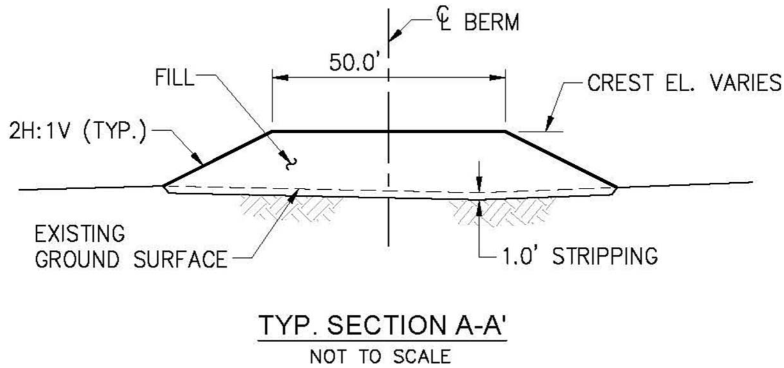


Fig. 9S-9. Typical Section A–A′ of a Sloping Berm

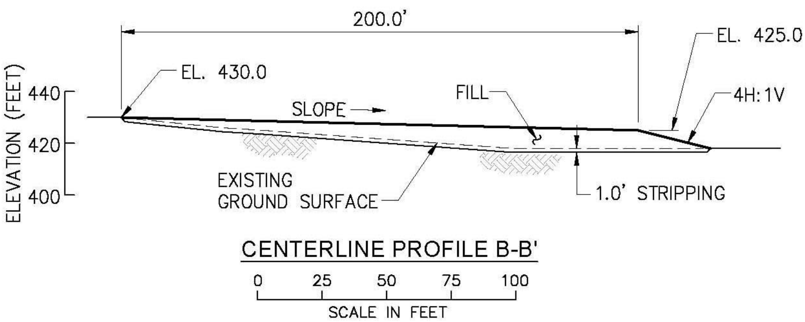


Fig. 9S-10. Centerline Profile B–B′ of a Sloping Berm

benches is the same as that for Problem 9.2. The two flat benches are drawn in next, with a width of 10 ft. For the bench on the north side, the east and west ends of the bench are at the existing 5,655-contour lines. For the bench on the south side, the east and west ends of the bench are at the existing 5,660-contour line. It becomes a simple matter to complete the catch points and catch line above each of the level benches.

9.4b The cross section A–A' taken along the top of the dam (El. 5,671.0) is shown in Fig. 9S-12. The section shows the two intermediate benches at El. 5,655 on the left side and 5,660 on the right side. The bottom of the excavation varies from El. 5,635 at the upstream end to El. 5,630 at the downstream end; at the cross section, the bottom elevation is computed to be 5,632.25.

9.5 A variety of different views of different features and objects typically encountered in heavy civil design are used in this problem to practice the skill of dimensioning. In general, dimensions are called out by the use of extension lines and dimension lines. All of the views used in this problem are intended to be for construction, in other words, there must be sufficient information in the drawings to allow the contractor to build it. Remember, the contractor is not

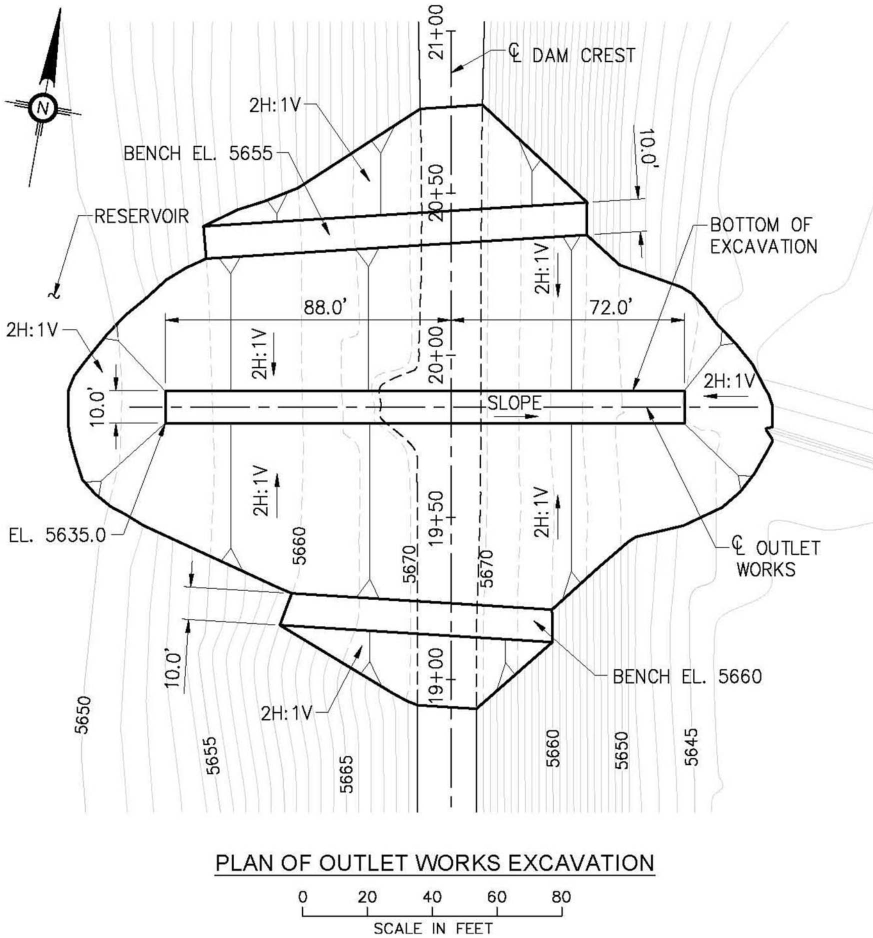


Fig. 9S-11. Excavation Catch Lines with Intermediate Benches

supposed to do his or her own measurement, and all relevant dimensions should be called out. For each view shown, add the extension lines and dimension lines to define the geometry of all of the features (e.g., concrete, riprap, holes, and drains). The dimensions themselves are not important in this problem, and there is no need to label the dimensions or do any measurements.

a. Fig. 9S-13 shows where and how the dimensions are taken for the riprap, riprap bedding, and the concrete slab of the ford crossing.
b. Fig. 9S-14 shows where and how the dimensions are taken for the concrete gate tower.
c. Fig. 9S-15 shows where and how the dimensions are taken for the limit of excavation, riprap, and riprap bedding of the rock drop structure.

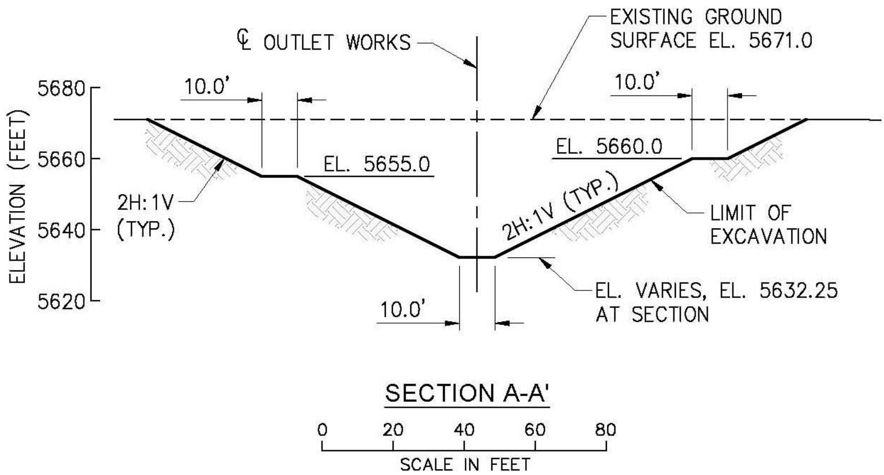


Fig. 9S-12. Cross Section A–A′ of Excavation Showing the Intermediate Benches

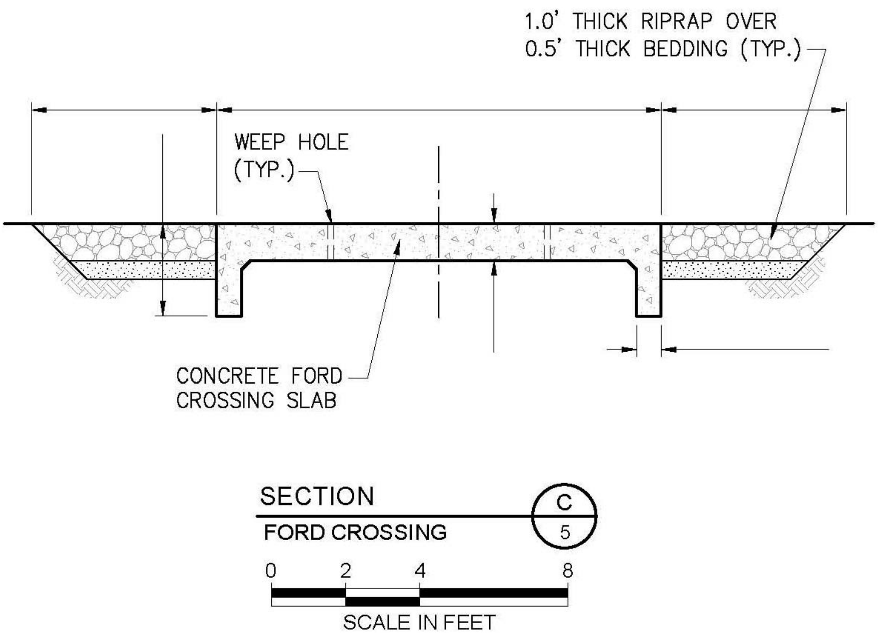


Fig. 9S-13. Dimensioning of Ford Crossing

d. Fig. 9S-16 shows where and how the dimensions are taken for the concrete slab and anchor bar of the footing anchor.
e. Fig. 9S-17 shows where and how the dimensions are taken for the geometry of the sediment pond.

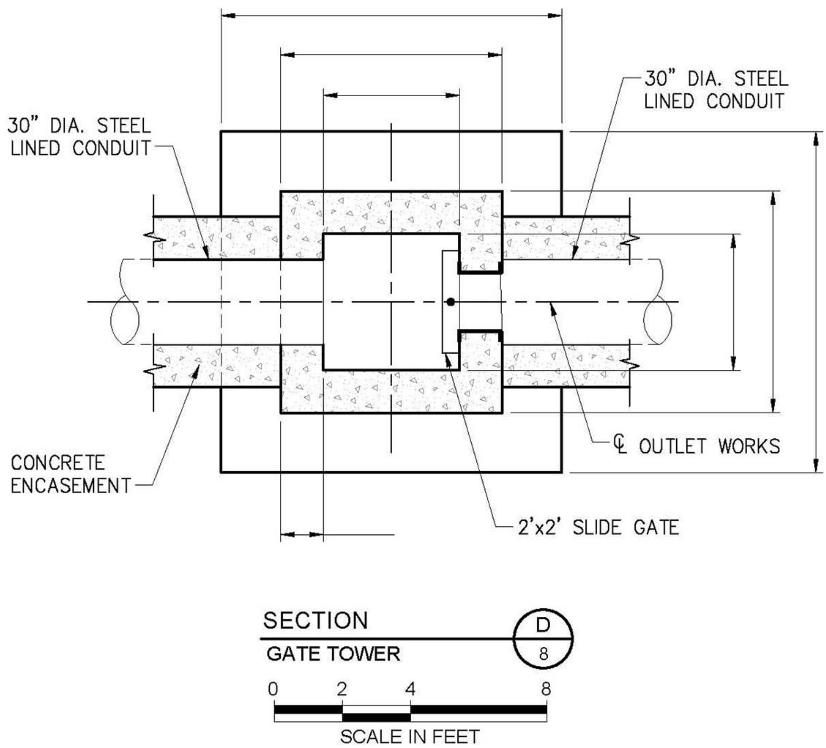


Fig. 9S-14. Dimensioning of Concrete Gate Tower

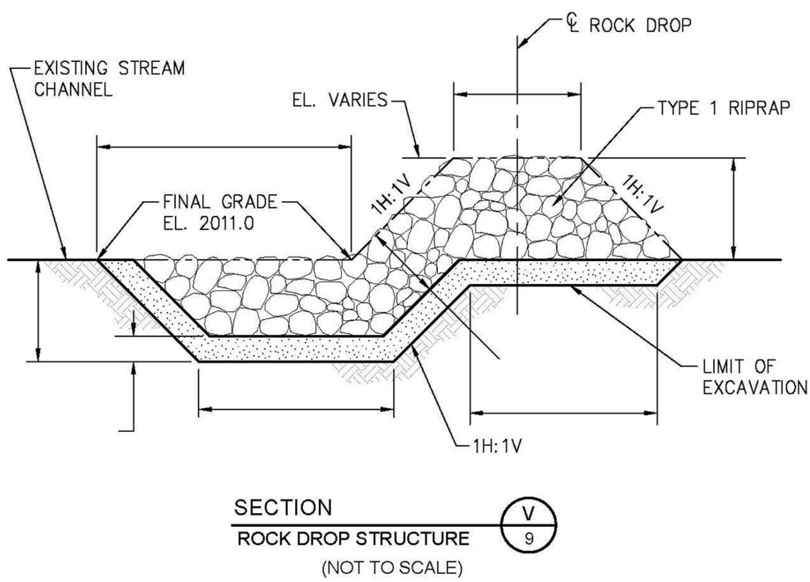


Fig. 9S-15. Dimensioning of Rock Drop Structure

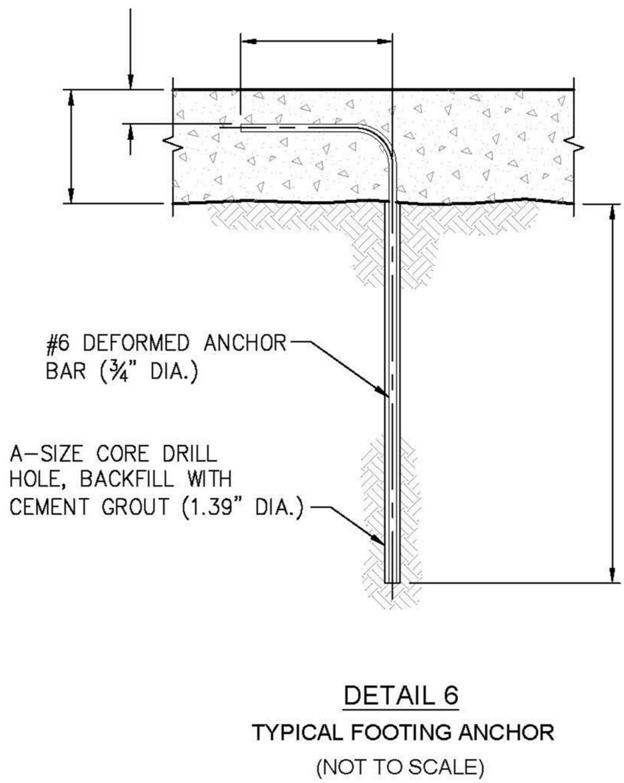


Fig. 9S-16. Dimensioning of Typical Footing Anchor

f. Fig. 9S-18 shows where and how the dimensions are taken for the chimney drain and gravel drain.
g. Fig. 9S-19 shows where and how the dimensions are taken for the excavation, concrete structure, riprap, riprap bedding, embankment fill and steel fence of the upper spillway chute.
h. Fig. 9S-20 shows where and how the dimensions are taken for the steel angle, expansion anchors, and bolt holes of the V-notch connection to the weir plate.
i. Fig. 9S-21 shows where and how the dimensions are taken for the steel plate, post, and anchor holes of the handrail post plate.

Chapter 15—Technical and Design Issues

15.1a The word “large” is ambiguous: are 4-in. rocks considered large, or 6-in. rocks? Instead, the size of the rocks to be removed should be defined, e.g., rocks over 6 in.

15.1b Both the words “cold” and “hot” are ambiguous. The American Concrete Institute (ACI) has guidelines for what is considered cold weather and hot weather for placing concrete, and they should be referenced:

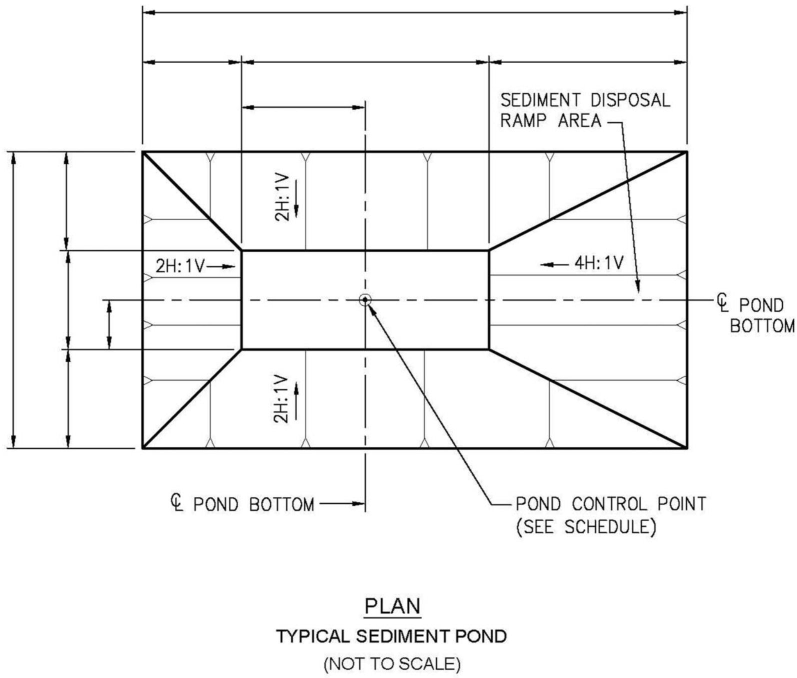


Fig. 9S-17. Dimensioning of Typical Sediment Pond

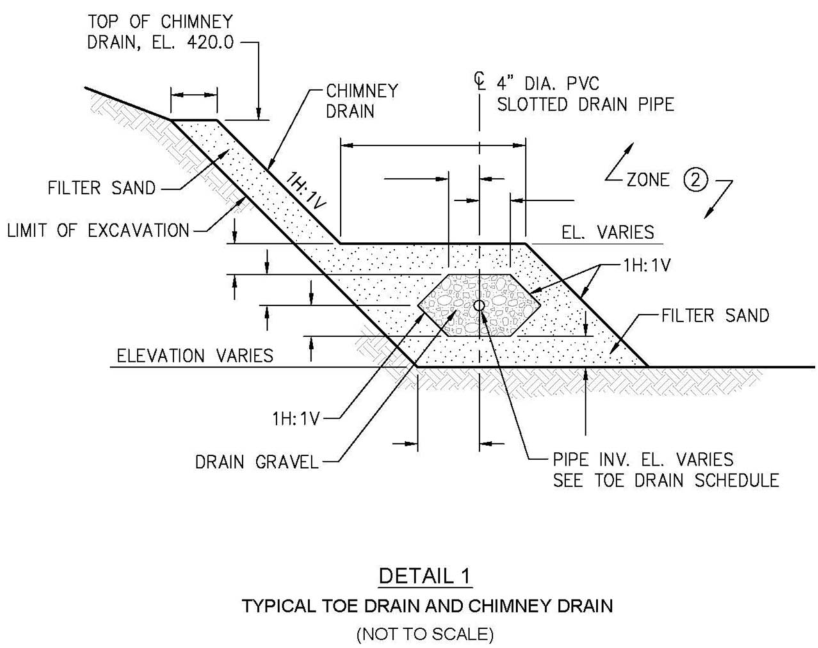


Fig. 9S-18. Dimensioning of Typical Toe Drain and Chimney Drain

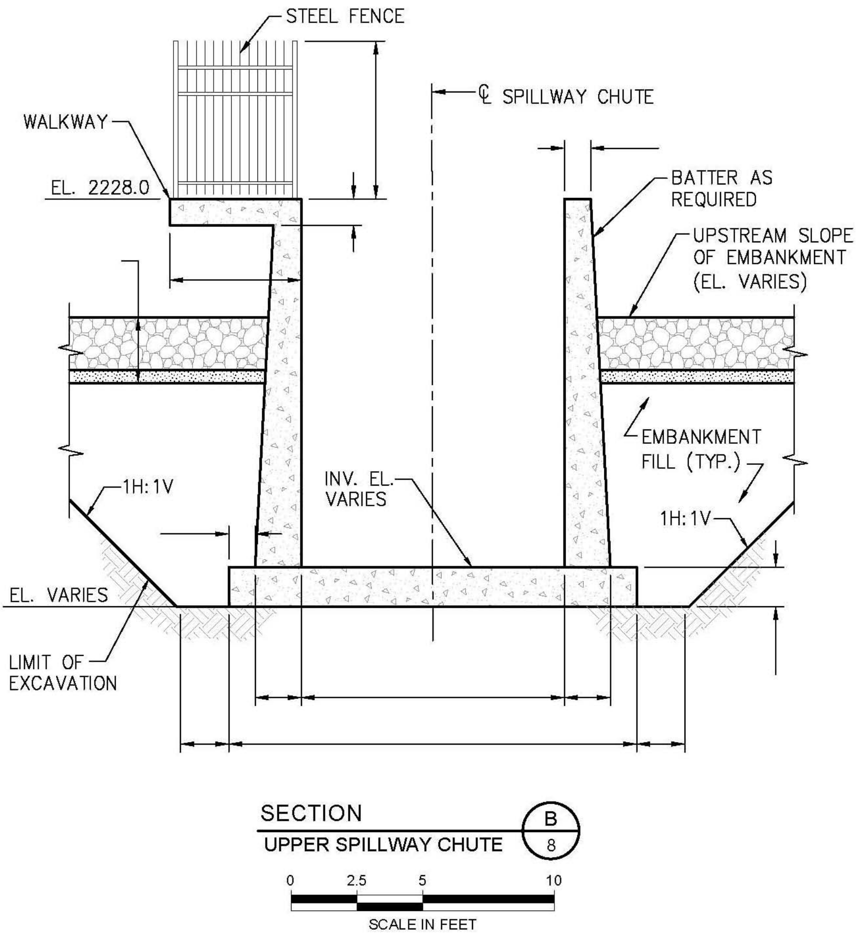


Fig. 9S-19. Dimensioning of Upper Spillway Chute

ACI 306.1: Standard Specifications for Cold Weather Concreting and ACI 305: Hot Weather Concreting.

15.1c This specification requirement is common in concrete placement, but is not practical to enforce. Other than coring through the concrete and testing for strength, there is no practical way to determine whether the concrete has gained at least 75% of the design strength. A more straightforward and less ambiguous way is to require the form to stay on for at least 7 days. Research has shown that properly hydrated and cured concrete will achieve at least 60% to 70% of the design strength in the first week.

15.1d The ambiguity is in “as soon as possible.” When exposed to air for more than 24 hours, clay shale that exhibits slaking behavior deteriorates rapidly. Therefore, exposed clay shale should be protected within 24 hours after excavation.

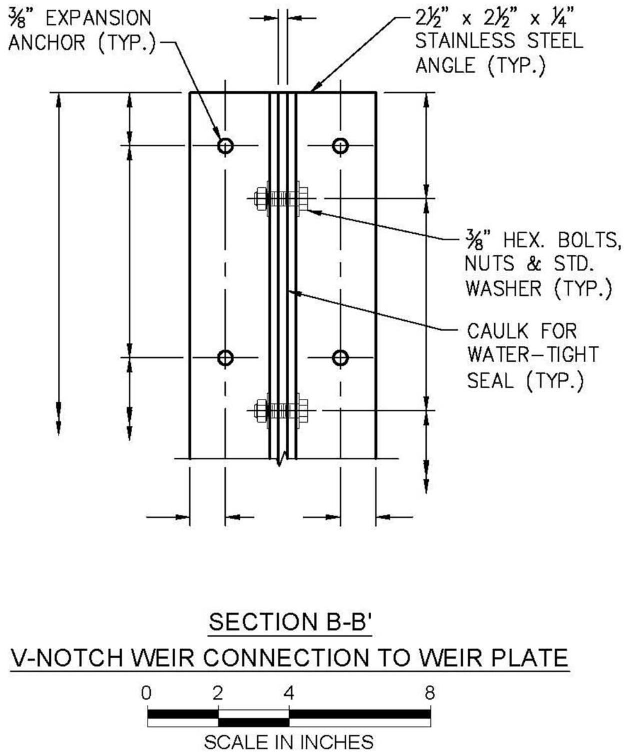


Fig. 9S-20. Dimensioning of V-Notch Connection to Weir Plate

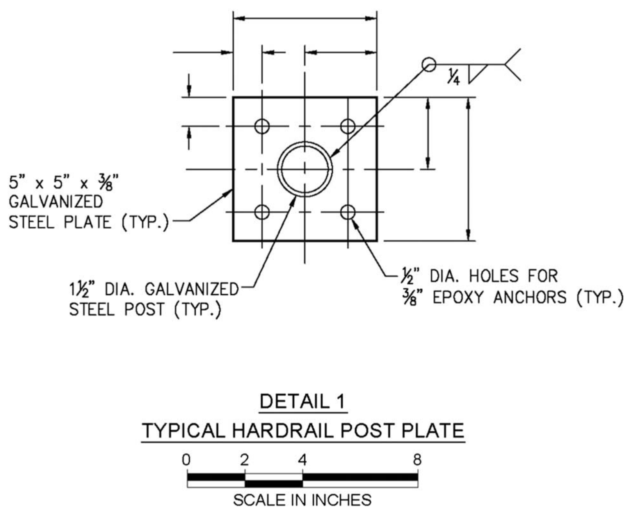


Fig. 9S-21. Dimensioning of Typical Handrail Post Plate

15.2a There are two conflicts: (a) stainless steel in the specifications versus PVC in the drawings; (b) Johnson screens are slotted, whereas drawings call for perforated openings. Assuming that stainless steel Johnson screens are the correct products in the specifications, the drawings should call out Johnson screens and should refer to the specifications for details.

15.2b The conflict is in the timing of cofferdam installation in the two documents. In general, construction sequence is a narrative, which should be handled in the specifications. One of the sequences is wrong and should be corrected. There should be a note or callout in the drawings that refer to the construction sequence in the specifications.

15.2c The conflict is that the specified method does not yield the expected performance. When it is uncertain whether the descriptive specifications will yield the expected performance, there should be a test fill to check the various compaction parameters, preferably during the design. If the test fill is done during construction, then any changes to the compaction parameters will be considered "design changes" and will require a change order.

15.2d The conflict is in the two different sets of quality requirements between the project specifications and the standard highway specifications. If the more stringent requirements for the riprap are needed for this project, then exceptions to the specific gravity and L.A. abrasion soundness should be called out when the highway specifications are referenced.

15.3a Without a firm subgrade, it is impossible to compact the first one or two lifts of fill to meet the 98% compaction requirement. There are two ways to avoid this problem: (a) overexcavate the soft subgrade and backfill it with a compacted fill; or (b) relax the compaction requirement for the first two lifts until the subsequent lifts have a firmer base on which to compact.

15.3b The excessive clay fines in the soil aggregate lower the strength of the soil–cement mix, and the specified 56-day strength of 2,000 psi is likely to be unachievable. Testing during design would have disclosed this problem. Because it is difficult and expensive to process and remove the clay fines, the soil aggregate should have been imported instead of borrowed. The designer should have specified an imported soil aggregate with nonplastic fines.

15.3c For such deep drilled holes, a zero-deviation tolerance is impossible to achieve, even with a diamond-bit drilling method. The two drain holes should be moved away from the existing pipes, and a more achievable drill tolerance should be specified.

15.4a This testing requirement is a so-called "open target," and it is impossible for the contractor to budget the testing cost. If the contractor is responsible for testing, then the frequency of testing should be specified so that the number of tests is defined.

15.4b When the contractor is not responsible for testing, then the frequency and location of the tests are not an issue. Typically, the contractor and the engineer work out an arrangement for a convenient time for testing so that the contractor's work progress is not impeded.

15.4c During construction, the contractor and the engineer may not agree on what finish is considered "nonskid." A more standard concrete finish should be specified that will result in the design intent, such as a broom finish.

15.4d When the contractor is in the wrong, it is customary to require the contractor to pay for the repair to satisfy the owner. There is no problem with this specification.

15.4e This is another one of those "open target" requirements because the contractor does not know how many test pits and how deep to excavate. If the locations of the test pits are not known in advance, then as a minimum, the total number of test pits and maximum anticipated depths should be defined in the specifications.

15.4f There are no problems with this specification. The total number of test pits and maximum depths are defined ahead of time, so that the contractor can budget the excavation effort, while the engineer will choose the locations during construction.

15.5a All of the risk of flooding for work adjacent to the stream has been shifted to the contractor. By asking the contractor to decide on the level of protection, the owner assumes no responsibility for any flooding damages. Bids for this work item will be highly variable, depending on how much risk each bidder is willing to take.

15.5b The absence of contract provisions to handle environmental issues exposes the contractor to the relatively high risk of delays or work stoppage in the likely event that buried artifacts are encountered in this environmentally sensitive area. Without the benefit of contract provisions to handle contract schedule and compensation from the delays or work stoppage, the contractor has no recourse but to file claims to recover his or her losses.

15.5c The designer recognizes the risk and serious consequences (namely, uncontrolled seepage and loss of fines) associated with inadequate dewatering for this project and assumes the responsibility of designing the deep-well dewatering system. This is an actual case history, and the owner in this case is a federal agency. For this project, the risk to the contractor is lowered, and as a result, the bids were uniform and favorable. During design, the designer performed a series of pumping tests in test wells to obtain design parameters for the design of the dewatering system.

15.5d The designer recognizes the risk and serious consequences associated with inadequate bracing support, which will affect the stability of the highway and public safety. Similar to Problem 15.5c, this is also an actual case history, and the owner in this case is also a federal agency. The designer is a competent geotechnical engineer, and the design of a multilevel tieback bracing system is within his or her expertise and experience. This is a good example of the engineer not shifting design responsibility to the contractor, and the risk to the contractor is lowered.

15.6a For this application, the key characteristics of the geogrid include the polypropylene material, the geometry of the grid, the load transfer capability, the stiffness, and resistance to ultraviolet degradation. The specifications are worded as follows:

2.2 GEOGRID REINFORCEMENT

A. The geogrid for reinforcing the subgrade shall have the following key characteristics:
   1. The grid material shall be manufactured from a punched polypropylene sheet, with the ribs oriented in three equilateral directions.
   2. The nominal dimensions shall be 1.4–1.8 inches longitudinal, and 1.4–1.8 inches diagonal.
   3. Load transfer capability (ASTM D6637-10): minimum 90% of ultimate tensile strength.
   4. Radial stiffness @ 0.5% strain (ASTM D6637-10): minimum 200 kN/m.
   5. Resistance to ultraviolet light and weathering (ASTM D4355-05): 65%.

B. The geogrid shall be Tensar TriAx Geogrid, or approved equal.

It should be noted that some of the key characteristics (e.g., dimensions, load transfer capability, radial stiffness, and ultraviolet resistance) have been changed in the specifications from values provided by the manufacturer to different values and ranges. The designer has judged that these different values still provide the required performance, while allowing competition from other brands.

15.6b For this application, the key characteristics of the sealant include swelling upon exposure to water and gun-grade packaging. The specifications are worded as follows:

2.6 WATER-EXPANDABLE SEALANT

A. Water-expandable sealant shall have the following key characteristics:
   1. A single component elastic sealant packaged for gun-grade application.
   2. Capable of expanding upon contact with water up to 100% by volume.

B. Water-expandable sealant shall be Adeka Ultraseal P-201, or approved equal.

Note that not all the listed characteristics of the manufacturer are necessary in the specifications, such as color and other applications for this product.

15.6c For this application, the key characteristics for this MSA wall system are the precast concrete panels, galvanized steel strips, control of a panel alignment during installation, and the granular backfill. The specifications are listed as follows:

2.2 MECHANICAL STABILIZED WALL SYSTEM

A. Mechanical stabilized wall system shall consist of the following components:

1. Precast concrete wall panels produced in a concrete mixing plant.
2. Concrete 28-day compressive strength: 4,000 pounds per square inch.
3. The exterior face of the panels shall be uniform and shall not show significant variations from one panel to the other.
4. Tie strips shall be plain flats of Grade 250 supplied prebent and hot-dip galvanized.
5. Tie strips shall be bolted to the concrete panels.
6. Dowels and tubes shall be cast into the concrete panels for alignment.
7. Backfill shall be sand and gravel meeting the Unified Soil Classification System for SP-SM, SW-SM, and SM.

B. The mechanical stabilized wall system shall be manufactured by Reinforced Earth Wall Company, or approved equal.

Note that not all of the details listed in the manufacturer's brochure are needed in the specifications, in order not to exclude other similar systems by other manufacturers. During construction, the manufacturer will be required to submit the remaining design details of the system, such as panel wall thickness, tie strip width and thickness, connection details between the tie strip and the wall panels, dimensions of dowels and tubes, and soil data on the proposed backfill.

Chapter 16—Good Specification-Writing Practices

16.1a Remove rocks more than 3 inches in diameter and strip the top 12 inches of topsoil at the borrow area.

16.1b Compact the aggregate base course with 3 passes of a 10-ton vibratory roller.

16.1c Do not disturb the two existing masonry monuments adjacent to the entrance gate.

16.1d Install the geotextile fabric under the revetment, as shown in the Drawings.

16.2a Compressive strength at 28 days: 4,000 pounds per square inch (psi).

16.2b Do not use large roller for compaction adjacent to the existing conduit.

16.2c Payment to the Contractor for all structural concrete shall be based on the unit price per cubic yard bid in the schedule for Furnishing and Placing Cast-in-Place Concrete.

16.2d Compact the embankment fill to a minimum of 95 percent maximum dry density in accordance with ASTM D698. The in-place water content shall be within plus or minus 2 percent of the optimum water content.

16.2e Maximum allowable in-place temperature: 70 degrees Fahrenheit.

16.2f Piezometer pipe: 3 inch diameter (inside diameter).

16.3a Slotted PVC drainpipes, fittings, and couplings:

1. 6-inch nominal diameter, unplasticized polyvinyl chloride (PVC) plastic gravity sewer pipe with integral wall bell and spigot joints, Standard Dimension Ratio (SDR) 26, and meeting ASTM D3034.
2. The pipe joints shall have provisions for contraction and expansion with a rubber ring.

3. The slot width shall be 0.06 inch.
4. The minimum inlet open area shall be 20 square inches per linear foot of pipe.
5. All fittings and accessories shall be as manufactured and furnished by the same pipe supplier.

16.3b Inspection and testing of the in-place drainpipes:

1. Conduct inspection and testing by pulling a torpedo-shaped rigid plug through the drain segment, or by a method approved by the Engineer.
2. The torpedo-shaped rigid plug shall be tapered on both ends.
3. The diameter of the plug shall be 1 inch less than the inside diameter of the drain to be tested.
4. The length shall be sufficient to eliminate the possibility of wedging the plug in the drain by tipping.
5. The maximum pull allowed shall be 150 pounds of steady pull with no jerking.
6. The line used to pull the plug shall be free of any protrusions that could snag the tubing or joints.

16.3c Embankment fill shall comply with the requirements:

1. A mixture of clay, silt, sand, and gravel with a maximum particle size of two (2) inches, a minimum of 35 percent passing the No. 200 sieve, a minimum plasticity index of 10, a maximum plasticity index of 45, and a maximum liquid limit of 60.
2. Classified as either clayey sand (SC), or clay (CL, CH), in accordance with the Unified Soil Classification System.
3. Free of peat and other organic materials, debris, and trash.

16.3d Metal fabrication requirements:

1. Fabricate structural steel and miscellaneous metal items to straight lines and true curves.
2. Drilling and punching shall not leave burrs or deformations.
3. Continuously weld permanent connections along the entire area of contact.
4. Exposed work shall have a smooth finish with welds ground smooth.
5. Joints shall have a close fit with corner joints coped or mitered and shall be in true alignment.
6. Unless specifically indicated in the Drawings, there shall not be bends, twists, or open joints in any finished member nor any projecting edges or corners at intersections.

Chapter 18—Construction Specifications Institute Format

18.1a Division and section numbers in 2014 CSI *MasterFormat* for work items in Bid Schedule A are shown in Table 18S-1. There are several important observations from this exercise problem:

Table 18S-1. Division and Section Numbers in 2014 CSI *MasterFormat* for Work Items in Bid Schedule A

Item No.	Division No.	Section No. and Title
1	2	024100: Demolition
2	31	311400: Earth Stripping and Stockpiling
3	31	312319: Dewatering
4	31	312313: Subgrade Preparation
5	31	312316: Excavation
6, 7, 8	31	312323: Fill
9	3	034000: Precast Concrete
10	3	031000: Concrete Forming and Accessories
		032000: Concrete Reinforcing
		033000: Cast-in-Place Concrete
		033500: Concrete Finishing
		033900: Concrete Curing
11	5	055200: Metal Railings
12	32	329200: Turf and Grasses

- Many of the heavy civil work items are contained in Division 31.
- A specific section can cover several work items, such as Section 312323: Fill, which covers all three earthfill work items.
- A specific work item may require more than one section, such as Work Item 10 (Cast-in-Place Concrete Structures), which requires different sections for forming, reinforcing, placing, finishing, and curing.

18.1b Division and section numbers in 2014 CSI *MasterFormat* for work items in Bid Schedule B are shown in Table 18S-2.

Table 18S-2. Division and Section Numbers in 2014 CSI *MasterFormat* for Work Items in Bid Schedule B

Item No.	Division No.	Section No. and Title
1	31	312500: Erosion and Sedimentation Controls
2	31	315200: Cofferdams
3, 4	31	312316: Excavation
5	31	312313: Subgrade Preparation
6	3	036000: Grouting
7	3	033723: Roller-Compacted Concrete
8	35	352016: Hydraulic Gates
9	33	334616: Subdrainage Piping
10	32	321100: Base Courses
11	32	323100: Fences and Gates

SECTION 011113

SCOPE OF WORK

PART 1—GENERAL:

1.1 CONTRACT DESCRIPTION

A. This Contract includes the construction of two embankments and appurtenant structures as part of the South Yampa Court Dam. Major items of work include:
   1. Site preparation including clearing, sediment and erosion control, and surface and groundwater controls.
   2. Foundation excavation for embankments and appurtenant structures.
   3. Constructing East and West Embankments.
   4. Constructing a combined low-level outlet works and service spillway structure under the East Embankment, with all associated gates, pipes, and metalwork.
   5. Constructing an emergency spillway structure in the left abutment of the West Embankment, with all associated metalwork.
   6. Installing dam instrumentation.

1.2 CONTRACTOR USE OF SITE

A. Access to site: Contractor shall limit operations to the area designated on the design drawings. Other areas shall not be used by the Contractor unless authorized by the Owner in writing.

B. Health and Safety Requirements: The Contractor shall assume full responsibility for the health and safety of all of his or her on-site personnel and the protection of all equipment and materials.

C. No construction activity will be permitted until required submittals, if applicable, for that activity have been accepted by the Owner and Notice-to-Proceed has been issued for the applicable phase of the project.

1.3 GEOTECHNICAL DATA

A. A Geotechnical Data Report for South Yampa Court Dam was prepared. The report contains results of the field investigations and subsurface conditions of the dam foundations, and limited data on the fill borrow area in the pond area.

B. The geotechnical data are available from the Engineer upon request

PART 2—PRODUCTS:

NOT USED

PART 3—EXECUTION:

NOT USED

END OF SECTION 011113

Fig. 18S-1. Technical Specifications for Scope of Work in Example Problem 18.2a Converted to 2014 CSI Format

18.2a Converted to 2014 CSI format, the division number and section number for the summary of work are Division 1 and Section 011113, respectively, as shown in Fig. 18S-1.

18.2b Converted to 2014 CSI format, the division number and section number for the sluice gate procurement are Division 35 and Section 352016, respectively, as shown in Fig. 18S-2.

18.2c Converted to 2014 CSI format, the division number and section number for the excavation is Division 31 and Section 312316, respectively, is shown in Fig. 18S-3.

Chapter 19—Measurement and Payment Provisions

19.1a Furnishing and Placing Aggregate Base Course.

19.1b Borrowing and Placing Clay Liner.

SECTION 352016

SLUICE GATE

PART 1—GENERAL:

1.1 DESCRIPTION

A. Provide all labor, materials, equipment, tools, and services necessary to furnish a cast iron sluice gate.

B. This section includes requirements for materials, installation, and testing of cast iron sluice gates conforming to AWWA C560 and as supplemented herein.

1.2 SUBMITTALS

A. Provide the following submittals:

1. Shop drawings.
2. Certificate of compliance to comply with AWWA C560.
3. Dimensional drawings.
4. Manufacturer's catalog data and descriptive literature.
5. Calculations showing lift and stem sizing.
6. Manufacturer's installation instructions.
7. Manufacturer's operation and maintenance manual.

PART 2—PRODUCTS:

2.1 DESIGN CRITERIA

A. Sluice gate and appurtenances shall comply with AWWA C560.

B. The sluice gate shall be designed for a minimum seating head of 37 feet and a minimum unseating head of 10 feet.

C. Provide nonrising stem and manual lift.

2.2 MATERIALS OF CONSTRUCTION FOR SLUICE GATE

A. Materials of construction shall be as listed in AWWA C560.

2.3 SLIDES

A. The sluice gate slide shall be of one-piece construction.

2.4 STEM AND STEM GUIDES

A. Stem threads shall be machine cut or rolled and of the square or Acme type. The stems shall be supported with adjustable stem guides such that the l/r ratio (as defined in AWWA C560) does not exceed 200. Gate stem diameter shall be a minimum of 2 inches.

2.5 FLOOR BOX MOUNTING

A. Provide a cast iron floor box mounting for gate lift. The floor box shall have a lockable latching cover designed to be tamper resistant.

B. Floor box shall be supplied with a counter indicator for gate position. The lift nut in the floor box shall be 2 inches square.

2.6 GATE LIFT

A. Provide a manual gate lift conforming to AWWA C560. A maximum effort of 40 pounds shall be required to operate the gate at the specified operating head.

B. Provide a T-wrench for operation of the lift nut mounted in the floor box. Cross bar of the T-wrench shall be a maximum of 30 inches long. Bottom end of T-wrench shall be furnished with a 2-inch square socket to fit over the lift nut inside the floor box.

2.7 WALL THIMBLE

A. A cast iron wall thimble shall be provided by the sluice gate manufacturer for the sluice gate. The downstream flange of the wall thimble shall be drilled and tapped to match the mating pipe flange.

B. The wall thimbles shall be E-type, circular, conforming to AWWA C560.

2.8 BOLTS

A. Bolts shall be stainless steel conforming to ASTM F593 or ASTM F594, alloy group 1 or group 2.

PART 3—EXECUTION:

NOT USED

END OF SECTION 352016

Fig. 18S-2. Technical Specifications for Sluice Gate Procurement in Example Problem 18.2b Converted to 2014 CSI Format

SECTION 312316

EXCAVATION

PART 1—GENERAL:

1.1 WORK INCLUDES:

A. Excavation in the foundation for constructing the low-level outlet works structures and seep collar cutoff.

B. Excavation in the left abutment for constructing the emergency spillway structure.

C. Excavation for constructing PVC toe drain pipe and other drainage facilities.

D. Excavation in borrow area.

E. Other excavation incidental to the work as specified herein and shown on the drawings.

F. Disposal of all excavated materials that are not suitable for construction.

1.2 CLASSIFICATION

A. All excavations for this work shall be unclassified. This shall include excavation in soil, trench excavation, and excavation in bedrock.

1.3 PROTECTION

A. Comply with all safety requirements of OSHA.

B. Protect existing structures, facilities, and instrumentation designated to be protected and any such facilities under construction during excavation. Damage to structures, facilities, and instrumentation designated as protected resulting from the Contractor's excavation activities shall be repaired by the Contractor at no cost to the Owner and to the satisfaction of the Engineer.

C. Protect existing trees, shrubs, and other vegetation as shown on the drawings.

D. Blasting shall not be allowed for this Work.

E. When excavating, dust shall be controlled within safe hygienic limits (less than 10 milligrams per cubic meter) as specified in the "Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment" published by the American Conference of Governmental Industrial Hygienists.

PART 2—PRODUCTS:

NOT USED

PART 3—EXECUTION:

3.1 PREPARATION

A. Identify required excavation lines, levels, contours, and datum, as shown on the drawings.

3.2 EXCAVATION

A. All excavation shall be performed in the dry.

B. Excavate to the lines and grades as shown on the drawings.

C. The Contractor shall assume all responsibility for deductions and conclusions as to the nature of the materials to be excavated and the difficulties of making and maintaining the required excavations.

D. The Owner reserves the right, during the progress of the work, to vary the slopes, grades, or the dimensions of the excavations from those specified herein. Where the Engineer determines that foundation material is unsuitable through no fault of the Contractor, additional excavation and backfill will be ordered in writing.

E. Take all necessary precautions to preserve the material below and beyond the established lines of all excavation. Any damage to the work or the foundations due to the Contractor's operations shall be repaired as directed by the Engineer at the expense of and by the Contractor.

F. Do not excavate in frozen materials, except with written approval of the Engineer.

G. Side slopes of all earth excavations shall be no steeper than shown on the drawings. In all cases, excavations shall conform with all safety requirements of OSHA.

3.3 EXCAVATION IN BORROW AREAS

A. All excavations in the borrow area shall be in the dry, unless authorized in writing by the Engineer. Provide drainage in the borrow area for surface water runoff.

3.4 EXCAVATED MATERIAL SUITABLE FOR CONSTRUCTION FILL

A. Stockpile excavated material suitable to be re-used as embankment fill. Stockpile materials within limits of site disturbance, in staging and stockpile areas, or other areas approved by the Engineer.

3.5 DISPOSAL

A. Excavated materials which are not suitable for embankment fill shall be disposed.

END OF SECTION 312316

Fig. 18S-3. Technical Specifications for Excavation in Example Problem 18.2c Converted to 2014 CSI Format

19.1c Clearing and Grubbing.
19.1d Furnishing and Installing 6-inch PVC Drainpipes.
19.1e Reclaiming Disturbed Area.
19.1f Placing Cast-in-Place Concrete Culverts.
19.1g Furnishing and Installing Miscellaneous Metalwork.
19.2a Unit price. Excavation quantities are never precise, and they should be treated as approximate.
19.2b Lump sum or unit price. An exact concrete quantity can be estimated based on the design dimensions, and thus lump sum can be used for payment. Contractors usually prefer a unit price for concrete so that they are paid for the exact quantity that is placed during a particular pay period. Either method is acceptable.
19.2c Lump sum. It is difficult to quantify this work.
19.2d Unit price. The bottom of the sheet pile is expected to be variable, based on the variable top of bedrock. Thus, the quantity cannot be precisely estimated.
19.2e Unit price. The area needing rock preparation can only be determined during construction. The bid quantity is only approximate.
19.2f Lump sum. All of the quantities in the structure components can be determined exactly.
19.2g Unit price. It is always difficult to predict or estimate the "grout take" in the rock for foundation grouting, because that is controlled by the geology in the ground.
19.2h Lump sum. The total length of the guardrails can be determined exactly.
19.3a Unclassified excavation will be measured for payment in cubic yards to the nearest cubic yard, measured from the existing ground surface to the limit of excavation shown in the Drawings.
Payment to the Contractor for earthwork excavation will be at the unit price per cubic yard bid in the Schedule for Unclassified Excavation, which price shall include all labor and equipment to excavate in foundation soil, rockfill, or highly weathered shale bedrock; to stockpile suitable excavated materials as backfill; and to dispose of excess materials in on-site disposal area.
19.3b Structural concrete will be measured for payment in cubic yards to the nearest 0.1 cubic yard, measured in place to the neat lines shown in the Drawings. Payment to the Contractor for structural concrete will be at the unit price per cubic yard bid in the Schedule for Furnishing and Placing Structural Concrete, which price shall include furnishing ready-mix concrete, forming, reinforcing, placing, finishing, and curing.
19.3c Cofferdams and stream diversion will not be measured for payment.
Payment to the Contractor for cofferdams and stream diversion will be at the lump price bid in the Schedule for Cofferdams and Stream Diversion, which price shall include furnishing, installing, and removing upstream temporary sheet pile cofferdam, downstream earthfill cofferdam, 24-inch diversion pipe, and shutoff valves.

19.3d Road fill will be measured for payment in cubic yards to the nearest cubic yard, measured in place after compaction.
Payment to the Contractor for road fill shall be at the unit price per cubic yard bid in the Schedule for Borrowing and Placing Road Fill, which price shall include excavating fill materials from borrow area; moisture-conditioning and stockpiling if necessary; hauling to the road embankment; spreading; and compacting.

19.3e Riprap will be measured for payment in tons to the nearest 0.1 ton. The weight of the riprap shall be based on weight tickets of the delivery trucks.
Payment to the Contractor for riprap shall be at the unit price per ton bid in the Schedule for Furnishing and Placing Riprap, which price shall include purchasing riprap stones from off site, hauling to the designated stockpile area, and placing the riprap stones along the stream bank.

19.3f Precast concrete manholes will be measured for payment per each manhole completed and accepted by the Engineer.
Payment to the Contractor for precast concrete manholes shall be at the unit price per each manhole bid in the Schedule for Furnishing and Installing Precast Concrete Manholes, which price shall include furnishing precast concrete manholes and manhole covers, access ladders, cast-in-place concrete bases, and gaskets.

19.3g Sediment and erosion control will not be measured for payment.
Payment to the Contractor for sediment and erosion control shall be at the lump sum price bid in the Schedule for Sediment and Erosion Control, which price shall include furnishing, installing, and removing temporary hay bales, silt fences, and sediment collection ponds.

Chapter 22—Estimating Quantities

22.1a Clearing and grubbing is usually paid per acre.

22.1b Drilling work, such as foundation drain holes, is paid per linear foot.

22.1c Shotcrete is typically applied pneumatically to a surface with relatively uniform thickness. Use an area unit such as square foot. The area unit of square yard is typically used for fabric such as geomembrane or geotextile.

22.1d Clay liner is designed with uniform thickness. Use an area unit that can be applied to a large area, such as acres or thousand square feet (MSF).

22.1e Stripping work can be paid by area if the thickness is uniform. However, topsoil thickness is usually variable, so it is best to pay for stripped topsoil per cubic yard in the stockpile after stripping.

22.1f Assuming that the box culverts have the same cross section, the culverts can be paid per linear foot. If the box culverts change in size, then separate bid items should be used for each size.

22.1g Asphalt thickness in a particular road section usually is uniform. Use an area unit such as square foot if the width is not uniform. If the width of the road is uniform, then the pavement can be paid per linear foot.

22.1h Proof-rolling with a piece of heavy equipment is used to evaluate whether there are any soft areas of subgrade in the foundation. Use an area unit such as square foot.

22.1i Grass seeds, mulch, and fertilizer are applied to the surface of the topsoil. Use an area unit such as acre, thousand square feet (MSF), or square foot.

22.1j On-call testing service can be paid per hour for a particular crew size.

22.2a Strip topsoil, 1 ft deep at bottom of embankment.
Length = 200 ft
Width = 64 ft (assume uniform for entire embankment)
Volume = 200 ft long × 64 ft wide × 1 ft deep = 474 cubic yards—say 475 cy.

22.2b Aggregate base course, 1 ft thick along road surface.
200 ft long × 20 ft wide × 1 ft thick = 148 cubic yards—say 150 cy.

22.2c Road fill, maximum cross section area = 462 sf (square feet).
Total embankment volume:
From Point a to Point b
1/2 (462 sf + 0) × 40 ft long = 342 cubic yards (average end-area method)
From Point b to Point e
462 sf × 120 ft long = 2,053 cy
From Point e to Point f
1/2 (462 sf + 0) × 40 ft long = 342 cy
Total volume: = 2,737 cy
Minus aggregate base course volume:
2,737 − 148 = 2,589 cy—say 2,600 cy.

22.2d Guardrails
200 ft each side × 2 sides = 400 lf (linear feet).

22.3a Draw Section C–C′ and Section D–D′ (see Fig. 22S-1). Then, use average end-area method:
Excavation area at Sta. 12 + 00 (Section C–C′) = 845 sf (square feet)
Excavation area at Sta. 12 + 70 (Section D–D′) = 481 sf
Excavation volume = 1/2 (845 + 481) sf × 70 ft long = 1,719 cy—say 1,720 cy.

22.3b Culvert volume:
[(5 ft × 6 ft) − (4 ft × 5 ft)] sf × 70 ft long = 25.9 cy—say 26 cy.

22.3c Fill volume = 1,719 − 25.9 cy = 1,693.1 cy—say 1,700 cy.

22.4a Slab volume = 68.3 cy
Footing volume = 7.2 cy
Slab + footing volume = 75.5 cy.

22.4b Sidewall volume = 78.3 cy
Wing wall volume = 18.8 cy
Sidewall + wing wall = 97.1 cy.

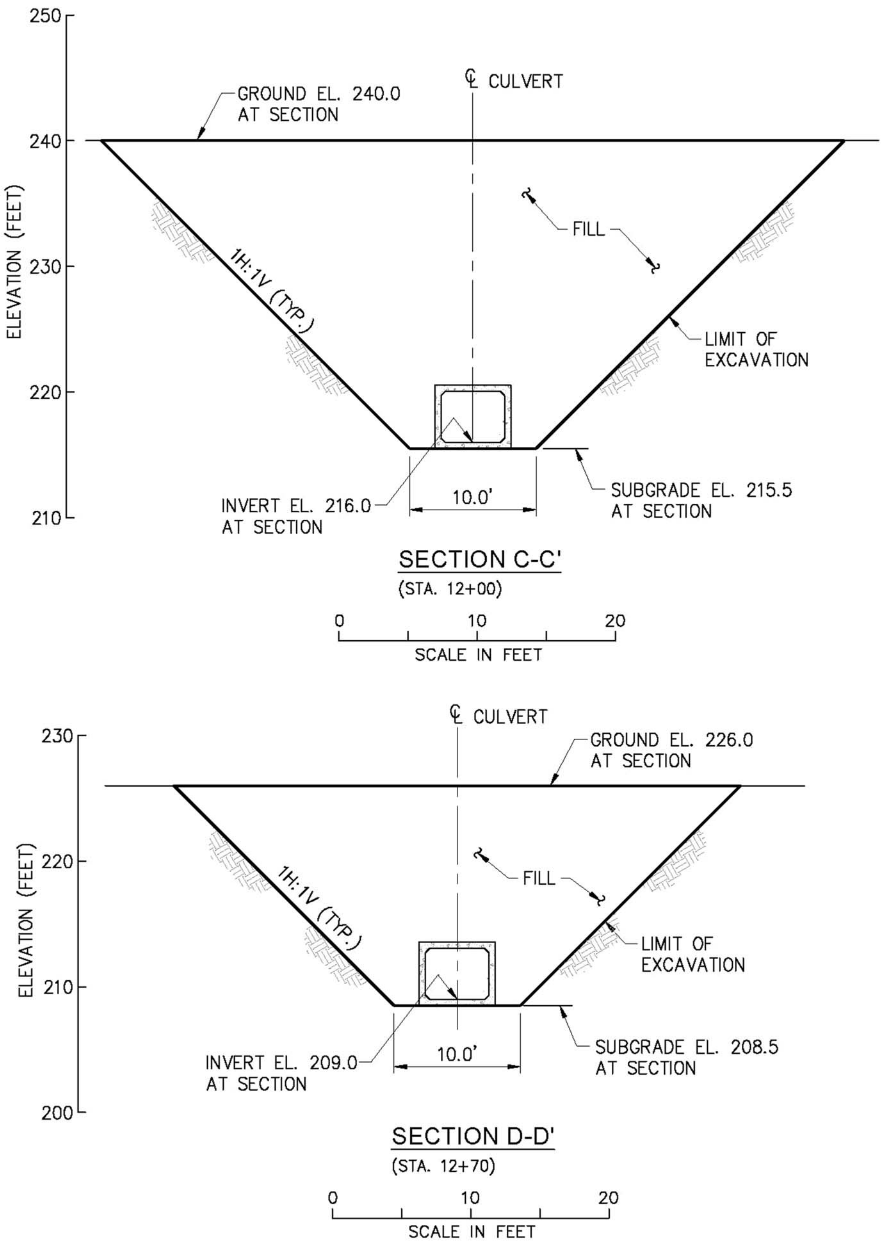


Fig. 22S-1. Culvert Sections at Sta. 12 + 00 and 12 + 70

22.4c Total structure concrete volume = 75.5 + 97.1 cy = 172.6—say 173 cy
Note: If this structure is bid as a unit-price work item, the plan quantity used in the bid schedule will be 173 cubic yards. During price estimating, the estimator breaks down the structure into slab/footing and walls and then prorates the unit price:

Slab/footing, 75.5 cy @ $400/cy	= $30,200
Walls, 97.1 cy @ $600/cy	= $58,260
Total structure cost, $30,200 + $58,260	= $88,460
Prorated unit cost, $88,460/173 cy	= $511/cy. Use $515/cy in bid.

22.5a Round off excavation from 23,987 to 24,000 cubic yards. The estimated quantity is only approximate, which is typical for earthwork. For a quantity of this magnitude, rounding off to the nearest 100 cubic yards (third significant figure) is appropriate.

22.5b Round off excavation from 448.5 cubic yards to 450 cubic yards. In general, earthwork should not be reported in fractions of a cubic yard because measurement and payment are to the nearest cubic yard.

22.5c Round off structural fill from 250,024 cubic yards to 250,000 cubic yards.

22.5d Round off riprap from 24.7 cubic yards to 25 cubic yards. Because of the small quantity, rounding off to the nearest cubic yard is appropriate.

22.5e Round off reinforced concrete from 156.7 to 157 cubic yards. Reinforced concrete is expensive, and the calculations are based on exact dimensions of regular geometric shapes. Rounding off should be done to a minimum.

22.5f No rounding off is needed. The calculated length of 226.5 ft is based on design layout that has no uncertainty or approximation. The contractor will procure some additional lengths because these pipes are sold at certain standard lengths (e.g., in 8-ft or 10-ft stocks), but he or she will only be paid for the 226.5 ft installed at the design locations.

22.5g No rounding off is needed. The calculated length of 575.5 ft is based on design layout that has no uncertainty or approximation. During construction, that exact length will be procured and fabricated in the shop and then delivered to the site.

22.5h No rounding off is needed. The calculated length of 459 ft is based on design layout that has no uncertainty or approximation. The contractor will procure some additional lengths to include wastes, but he or she will only be paid for the 459 ft installed at the design locations.

22.5i Round off clearing and grubbing from 18.57 acres to 20 acres. Calculating clearing and grubbing area based on topographic information (tree limits on map) is approximate at best, even for an accurate survey map. That uncertainty and approximation require fairly generous rounding.

22.5j Round off dental concrete from 1,368 to 1,500 cubic ft. The assumed 10% of the foundation area requiring dental concrete is an educated guess, based on the borehole data and understanding of the site geology. Depending on the confidence of the designer, it may be necessary to round off the quantity to 2,000 cubic ft for bidding purposes.

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About the Author

Ying-Kit Choi, Ph.D., P.E., is a licensed civil engineer specializing in geotechnical engineering, design and construction of heavy civil projects, and dam engineering. He earned a B.A. in pre-engineering from St. Anselm's College, a B.S. in civil engineering from the University of Notre Dame, and his master's and doctorate degrees in civil engineering from the University of Illinois at Urbana-Champaign. He has two years of university teaching experience at the University of Illinois at Urbana-Champaign and more than 33 years of experience in consulting engineering practice. Currently, he is an independent geotechnical and design consultant based in Centennial, Colorado.

Dr. Choi has worked on more than 150 dams in 30 states and three foreign countries. The scope of work for these projects included the entire spectrum in dam engineering: safety evaluation and analysis, inspection, field investigation and testing, conceptual design, final design, construction engineering, and design review. Dam types include earthfill and rockfill embankments, conventional concrete and RCC gravity dams, tailings dams, and masonry dams.

Dr. Choi has worked on the final design of more than 50 heavy civil projects that include new dams, dam rehabilitation, levee repairs and flood protection, stream bank protection, and tailings conveyance projects. For 35 of these design projects, he was the principal designer or project manager, responsible for the preparation of construction drawings, technical specifications, and construction cost estimates. He has designed seven new dams, ranging from 25 to 400 ft high. In the past 15 years, Dr. Choi has been engaged as a technical reviewer for dam design by federal and state agencies, municipalities, engineering companies, and private dam owners.

He has worked on a wide range of geotechnical engineering projects with the consulting industry, including foundation investigations for commercial and industrial buildings, embankment dams, concrete dams, outlet works, and spillway structures; analysis and design of braced excavation support systems; static and seismic slope stability analysis of embankment dams; seismic deformation analysis of embankment dams; two-dimensional and three-dimensional liquefaction analysis of dam foundations; seepage and design of filters and drains for embankment dams; analysis and design of posttensioned anchors; and rock slope stability analysis. He has planned and managed subsurface investigations for various dam foundations for dams up to about 500 ft high, including rock foundation for concrete and RCC dams, soil foundation for embankment and tailing dams, and dam rehabilitation projects.

In addition to *Principles of Applied Civil Engineering Design*, Dr. Choi has 25 other publications on subjects including dam safety evaluation, slope stability, roller-compacted concrete, settlement analysis, evaluation and measurement of compressibility of soft cohesive materials, permeability evaluation, theory of consolidation and swelling, numerical methods, and prediction of pore-water pressures.