Engineering of Dunes

Protection Benefits of Coastal Sand Dunes

In addition to providing habitat for a variety of species, coastal sand dunes are an integral part of a well-planned coastal defense system. Coastal sand dunes act as reservoirs of sand that help the beach maintain its equilibrium and preserve the ability of the beach to respond naturally to storm events. Beaches evolve during a storm by taking on a more dissipative state that causes waves to break farther offshore, reducing the wave energy near the shoreline. During this transition, the beach slope is reduced and one or more sand bars may form. The bars are formed as sand is transported offshore during the peak of the storm and is deposited near the region of most intense wave breaking. During smaller storms, the waves don't reach the base of the dune, and the erosion is limited to the beach face (berm) itself. The dunes only become active during moderate to large storms when the dissipation created by the bars is insufficient to prevent the waves from attacking the base of the dune. As a dune erodes, it releases a portion of its built-up reservoir of sand into the littoral system, where it contributes to bar formation and the development of a more dissipative profile, ultimately reducing damage to inland infrastructure. Larger dunes can withstand more wave activity and therefore provide more protection to areas behind them. In the simplest terms, the sand stored in a dune buys time and provides protection from severe storms.

FEMA Dune Standards

Although dunes of nearly any size are beneficial, in order to be considered as a barrier to coastal flooding for flood insurance purposes, coastal sand dunes need to meet the size criteria established by the Federal Emergency Management Agency (FEMA). Based on an analysis of hurricane-related dune erosion, FEMA identified the amount of sand stored within the cross-sectional area of the frontal half of the primary dune above the 100-year stillwater elevation (Figure 10A) as the critical parameter for protection against a 100-year storm event. It has been established that a dune that is predominantly below the 100-year stillwater elevation will be rapidly overwashed and eroded and will not provide significant protection. As the dune erodes, sand is transported both seaward into the littoral drift and landward into the backdune, resulting in a landward migration of the dune. Along developed shorelines, this process will ultimately cause the loss of the dune. A dune that is only slightly above the 100-year stillwater elevation will typically undergo significant erosion and will deflate, reducing in height and width. Studies by Hallermeier and Rhodes (1986) and by Dewberry & Davis, LLC (1989) found that 540 cubic feet of sand per linear foot of dune (equivalent to 20 cubic yards per foot) was required to resist the 100-year storm. FEMA's current V-zone mapping procedures (FEMA 1995) are based on these observations and require this quantity of material be present in the cross-sectional area of the frontal half of the primary dune, above the 100-year stillwater elevation (Figures 10A and 10B), to be considered substantial enough to withstand erosion during a base flood event. This criterion is commonly referred to as the *FEMA 540 rule*.

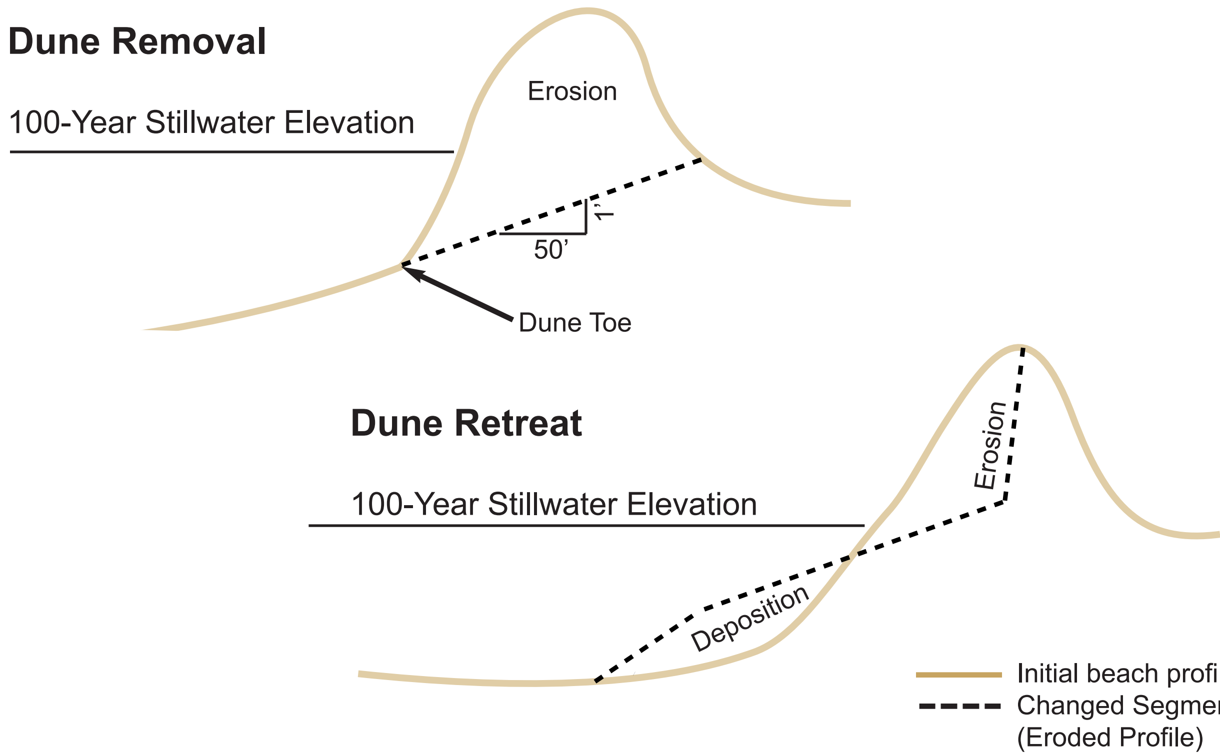

Figure 10A. FEMA's current determination of dune retreat and removal.

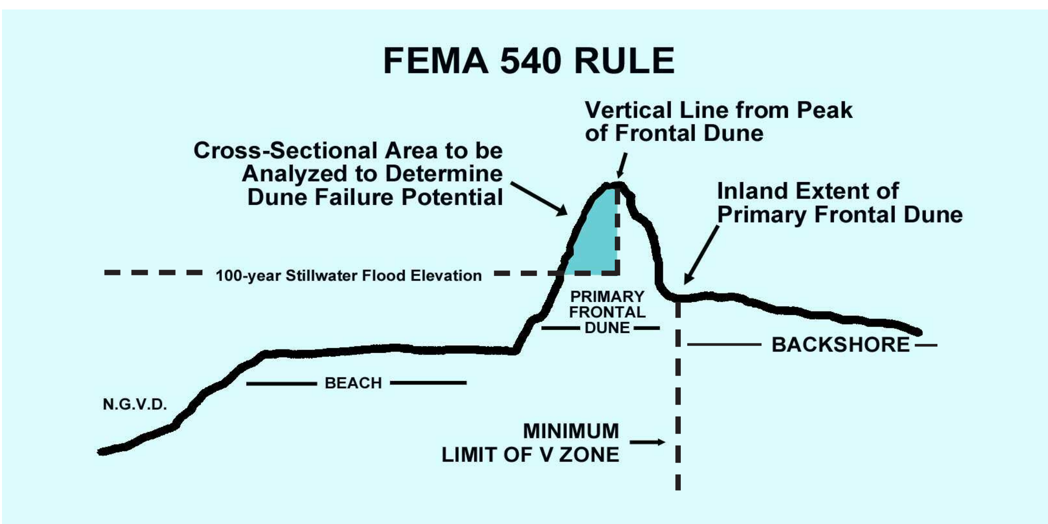

Figure 10B. Factors to be considered in determining dune failure and V-Zone mapping.

More recently, post-storm surveys have indicated that an even larger volume of sediment is necessary to withstand significant erosion events. The revised FEMA Coastal Construction Manual (FEMA 2000) recommends a minimum frontal dune volume (measured the same way as the 540 rule) of 1,100 cubic feet per linear foot (equivalent to 40.7 cubic yards per foot) above the 100-year stillwater level. Since the National Flood Insurance Program (NFIP) regularly encourages communities to establish standards above the minimum NFIP standards, New Jersey has taken the proactive step of referencing this higher standard in its Coastal Zone Management Regulations, although it is not yet required in the rules. Currently, very few communities in New Jersey even meet the lower standard. However, federal beach nourishment programs are authorized for the majority of New Jersey's Atlantic coast communities. In Ocean, Atlantic, and Cape May counties, the approved federal projects include construction and maintenance of dunes of specific dimensions, with the dune crest typically 12 to 22 feet above sea level (U.S. Fish and Wildlife Service 2005). These approved dunes, along with the associated beach berm, have been determined by the Army Corps of Engineers to provide sufficient storm protection. Projects to enlarge or modify a Corps-built dune should be reviewed by the ENSP and the U.S. Fish and Wildlife Service before starting any work. Likewise, any proposals for dune building in Monmouth County should be reviewed by the ENSP and the U.S. Fish and Wildlife Service, since the Corps-approved beach nourishment program in Monmouth County does not include any dunes.

Human-Induced Modifications of Dune Systems

The ability of a dune to withstand the extreme forces of a severe storm event can be either enhanced or diminished by human modifications to the dune system. Dunes are dynamic features that naturally erode during extreme storm events and then recover when storm conditions subside. Although robust dunes have been shown to be extremely effective in minimizing damage during even very large storm events (Barone et al. 2014), several New Jersey communities have sought to supplement the protection provided by these natural systems by incorporating a non-erodible core to their existing or planned dunes. Some of the materials that have been utilized and/or proposed include geotextile cores, rock, and steel/vinyl sheet pile. The objective is to combine the aesthetic and habitat benefits of a dynamic beach and dune system with the robust storm protection provided by a structural core.

Although constructing a dune core can have significant benefits from a storm-protection standpoint, there are several important factors that must be considered. Hard structures that are routinely exposed to wave activity have been shown to accelerate erosion in front of and along the edges of the structure; therefore, dunes with a structural core must be properly maintained. After storm events, the beach fronting a dune with a structural core should be restored as soon as possible to ensure that the exposed core does not create additional erosion. When constructed on eroding beaches, dune cores should only be considered within the context of a larger beach management strategy that addresses the long-term sustainability of the beach in front of the dune, including the potential impacts to habitat for rare and listed species (evaluated in coordination with the ENSP and the U.S. Fish and Wildlife Service).

Examples of Engineered Dune Stabilization Methods

Geocore

Geocore refers to one of several approaches in which the natural beach sand is encased in a geotextile fabric. Geotextile is a synthetic woven product that is used in many soil-stabilization projects to increase the strength of the soil and maintain proper drainage. The two most popular forms of geocores used in beach stabilization projects are geotubes (Figure 11) and geocubes (Figure 12). In both cases, the geotextile containers are manufactured offsite and are shipped to the installation location where they are filled mechanically with sand from the beach on which they are being deployed. Geocores are frequently viewed as a quasi-soft approach to shoreline stabilization and in some locations may be preferred over rock and/or sheetpile.

Geotubes come in a variety of shapes and sizes; however, the most common for dune-core applications is an oval-shaped tube with a diameter of between 4

Figure 11. Exposed geotube after Superstorm Sandy in Ocean City, New Jersey.

and 8 feet. The geotube casing is typically filled by pumping a water and sand mixture, known as a slurry, into the casing through a fill port. As the geotextile material is porous, the water percolates through the fabric, leaving behind a large-diameter, sand-filled tube. Geotubes have been used in several locations in New Jersey, including Strathmere, Atlantic City, and Ocean City on the ocean coast, and at Mordecai Island in Barnegat Bay. The installation in Ocean City was completed just prior to Sandy, and although the most severe impacts of the storm were experienced well north of the project site, the geotube core performed its intended function and successfully absorbed the wave impacts.

Geocubes are a relatively new and less commonly used approach for stabilizing coastal dunes. A single geocube consists of a series of interconnected rectangular compartments that can be filled with an

Figure 12. Trapbag geotextile (geocube) container installation in Ocean City.

excavator (Figure 12). The manufacturer of the product suggests that one of the advantages of the product compared to geotubes is that if a single unit or compartment fails, the integrity of the structure as a whole is generally preserved. Currently, the only known geocube installation in New Jersey is an experimental system deployed in Ocean City after Superstorm Sandy.

Rock

Figure 13. Exposed dune rock core after Superstorm Sandy in Bay Head, New Jersey.

Generally, rock dune cores are constructed as rock revetments backing an already existing beach. The structures are usually covered in sand, and in some cases, planted with dune grass to improve the overall aesthetic appeal of the project. Current practice is to design rock cores independently as traditional revetments in the event they become exposed during a storm. Design guidance for revetments can be found in both the Coastal Engineering Manual (U.S. Army Corps of Engineers 2002) and the Rock Manual (CIRIA; CUR; CETMF 2012). After Superstorm Sandy, many communities in New Jersey pointed to the effectiveness of Bay Head's relict rock seawall in protecting the community (Walling et. al. 2014; Irish 2014) as rationale for their own proposed dune enhancements. During the 2015-2016 winter, several sections of the Bay Head seawall were undermined, illustrating a potential shortcoming in the traditional design philosophy and highlighting the importance of maintaining a wide beach in front of proposed dune core projects.

Sheet Pile/Bulkhead

Figure 14. Sheet pile dune core (picture taken shortly after installation, before it is capped and buried by the dune), in Brick Township, New Jersey.

Most modern sheet pile dune core projects are constructed using steel or vinyl sheet pile; however, in New Jersey there are many older timber bulkheads that essentially perform the same function. Steel/vinyl sheet pile is typically used due to its durability and ease of construction. Similar to other dune core stabilization approaches, the intent of the sheet pile wall or bulkhead is to function as a last line of defense during severe storms. The sheet pile technique has been incorporated at several shoreline locations in New Jersey, including Sandy Hook and Mantoloking. The Mantoloking bulkhead was constructed in response to the breach that occurred during Sandy that compromised a major coastal evacuation route. The project successively resisted the erosive forces associated with the 2015 Joaquin nor'easter and winter storm Jonas, however, the beach in front of the wall eroded significantly. In several places, 15 to 20 feet of wall were exposed after the storms, highlighting the importance of maintaining a wide beach in front of the structure.

Beach Nourishment and Dunes

In New Jersey, beach nourishment projects have been designed and constructed both with and without dunes. Projects that include a dune generally specify a trapezoidal cross-section with regularly spaced plantings (typically American beachgrass). Such a dune provides

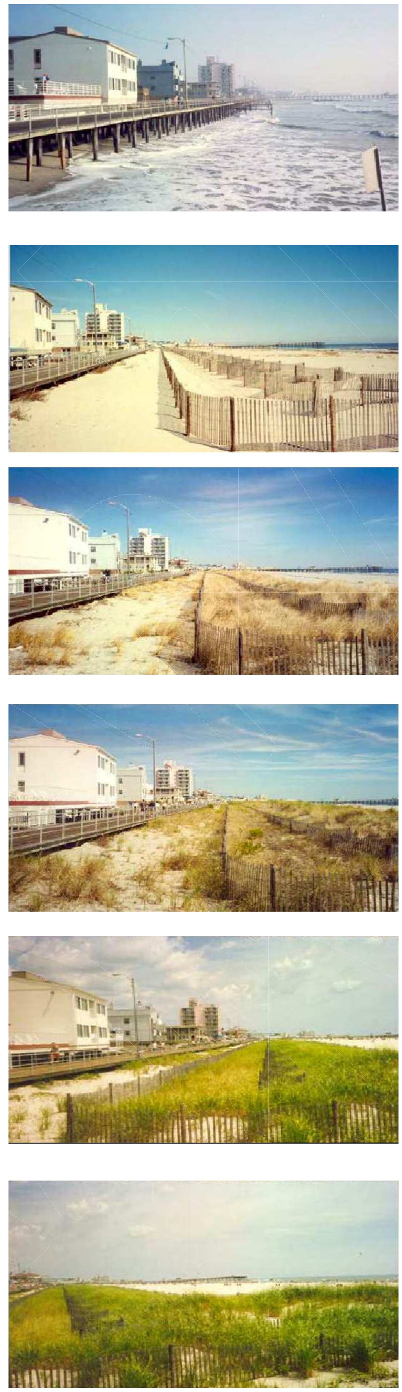

Figure 15. A photo set showing the development of a dune system after a nourishment project at a severely eroded beach.

uniform storm protection at the expense of the creation of more natural dune forms. While there has been some discussion recently about modifying project design specifications to allow for the creation of more natural features, there has been no formal adoption of these suggestions. Beach nourishment projects designed without a dune typically have higher and wider berms to compensate for the absence of the dune. These berms, which can be 150 to 300 feet wide, often provide a unique opportunity for dune development in areas where the natural sediment supply is scarce and the beaches are naturally narrow (Figure 15). The rate at which the dunes will grow on these constructed beaches depends on the rate at which the placed sand is transported onto the dune from the beach berm and on the effectiveness of the vegetation, fencing, and/or the dune itself in retaining the sand.

Both primary and secondary dune features (multiple dune lines) have been found on nourished beaches because of the enhanced sediment supply (Nordstrom and Mauriello 2001). As an example, a 6.6 million cubic yard beach-fill project that created a 100-foot-wide berm in Ocean City, New Jersey, successfully re-established the natural cycle of dune growth (Nordstrom and Mauriello 2001). By following a carefully crafted protocol that allowed the dune to develop naturally, both a primary and a secondary dune were developed within 5 years in regions where only small foredunes previously existed.

Considerations to Dune Engineering

Walkways/Crossovers

Although stabilized dunes with no gaps degrade habitats for rare, threatened, or endangered (RTE) species, the protective value of a coastal dune for human infrastructure is maximized when the dunes are continuous. Any break or gap in a dune becomes an area where the erosive power of storm surge and waves are concentrated. Typically, water seeks the path of least resistance and is funneled toward any gap or low spot in a dune. Unfortunately, since natural dunes are made of erodible material, the concentration of the flow accelerates erosion along the flow path. In order to avoid creating this hazardous condition, dune walkovers are considered the preferred means of beach access, since they allow the dune line to remain continuous.

Dune walkovers are typically timber structures consisting of stairs and/or ramps on both the front and backside of the dunes, with a flat deck-type structure across the dune crest. Ideally, the walkover structure is constructed in such a manner that it does not interfere with natural dune processes, including the movement of sand and the growth of dune vegetation. Dune walkovers are often used in areas where there is heavy foot traffic, and typical dimensions are dependent on the intended use of the structure. Guidance for constructing walkover structures in New Jersey can be found in the New Jersey Coastal Zone Management Rules, section N.J.A.C.7:7E. In general, for multiple family or public beach accesses, the walkover structure must not exceed 6 feet wide in overall dimension, and

Figure 16A. Wooden dune walkover (preferred method); B. angled walkway through dune; C. shore-perpendicular walkway through dune (least preferred method).

must meet a minimum clearance of 3 feet 10 inches above the dune crest. Walkovers for single family use are limited to 4 feet wide and require a minimum of 3 feet of clearance above the dune crest. Structures are intended to pose the least possible amount of disruption to the natural dune, and thus are required to terminate at either 10 feet seaward of the line of permanent beach dune vegetation or at the toe of the frontal dune. Support posts are not to be encased in concrete, should have a minimum soil penetration of 5 feet, and should allow for the erosion of sand during a storm event (Beach and Dune Walkover Guidelines).

Although dune walkovers are preferable from a coastal protection standpoint, there are some locations and situations where they are not possible or necessary, such as areas of minimal dune development, sparse vegetation, low foot traffic, or critical habitat value. In these cases, there are several alternatives that may be used to provide access at grade. The least preferred method is a shore-perpendicular street-end cut. Shore-perpendicular entrances provide minimal resistance to waves and surge, and they provide a conduit for funneling high-velocity flow directly inland. If beach access must be provided at grade, two preferable alternatives, which provide at least some additional storm protection, include angling the entrances to at least 45 degrees with respect to the shoreline, or incorporating a small blockading feature to deflect the surge from flowing straight through the access way. In both cases, the intent is to deflect or divert the potential storm surge. State regulations require that on-grade footpaths be limited to 6 feet in width, and be constructed of materials other than solid concrete or stone, which may become dangerous projectiles in a storm event. The use of geotextile fabrics or cabled wood planks is reviewed on a case-by-case basis. An alternative that has been utilized with some success in Avalon, as well as in several other communities, is the construction of a mixed-sediment footpath. The mixed sediments are selected to be more resistant to erosion than the native sand, provide a stable base, preserve natural aesthetics, and have a relatively minor ecological impact. The mixed-sediment approach can also be used to construct footpaths over existing dunes when walkovers are not possible. On-grade footpaths are not considered appropriate in locations where an escarpment exists between the dune structure and beach berm (Beach and Dune Walkover Guidelines).

In addition to their effects on the storm protection functions of the dune system, dune crossings are important in managing human disturbance and trampling of rare, threatened, and endangered species, because human density is strongly and inversely correlated with distance from access points on recreational beaches (Tratalos et al. 2013). The number, spacing, and locations of dune crossings should be carefully evaluated for their individual and cumulative effects to rare, threatened, and endangered species.

Environmental Concerns

Any hard structure introduced into the beach environment is likely to degrade habitat for wildlife in general, but specific concerns about rare, threatened, and endangered species are necessary to address. Proponents of such projects should contact Endangered and Non-Game Species Program (ENSP) and U.S. Fish and Wildlife Service representatives early in planning. Even in areas that do not currently support rare, threatened, or endangered species, hard structures are likely to preclude the formation of the most optimal habitats during future storm events. In some locations, hard structures may be the only cost-effective alternative to safeguard human lives and property from future storms. However, the adverse effects of such structures in precluding the formation of optimal habitats for federally listed species must be accounted for under the Endangered Species Act through coordination with the U.S. Fish and Wildlife Service. For example, for the recent installation of sheetpile in Mantoloking, project proponents (in consultation with Service representatives) provided offsite compensatory mitigation.

All developed portions of the New Jersey coast designated as piping plover nesting areas, including all “protected zones” and “precautionary zones,” are

Figure 17. Portions of the New Jersey coast designated as piping plover nesting areas. Based on FWS NJ map.

delineated in the Beach Management Plans (BMPs) (Figure 17). ENSP and the U.S. Fish and Wildlife Service also recommend the following general conservation measures as means for achieving the habitat targets listed in Table 1. Where they are deemed essential to protection of beachfront developments or other infrastructure (and where overwashes or blowouts have not formed), sand fences should be placed as far landward as possible to minimize the amount of sparsely vegetated and gently sloping beach that will be replaced with steep dunes and dense vegetation. The number of rows of sand fence should be minimized to decrease the extent of habitat loss. Beach managers should work with ENSP staff on site-specific sand fence configurations. Only native herbaceous vegetation should be planted, and the areal extent and density of plantings should be minimized.

Dune Characteristic	Target
Dune slope	$\leq$ 13% (management intervention at $\geq$ 17%)
Dune height	$\leq$ 1.1 m (management intervention at $\geq$ 1.6 m)
Vegetative cover: primary dune	13% (management intervention at $\geq$ 22%)
Vegetative cover: back beach	$\leq$ 10% (management intervention at $\geq$ 17%)
Shell/pebble cover: back beach	17-18%

Table 1. Management targets for Dune Characteristics in all developed portions of the New Jersey coast designated as piping plover nesting areas (Figure17), including all "protected zones" and "precautionary zones" (based on Maslo et al. 2011). Typically, these targets are best achieved by leaving the beach/dune system to evolve on its own without any vegetation planting or sand fencing.

Adverse effects can be further reduced if conservation commitments include periodic thinning of planted beach grass (see targets in Table 1). Both mechanical and chemical (herbicidal) thinning treatments can be considered during those times of year when rare, threatened, and endangered species are not present. Managers should also avoid creating dunes that would provide suitable den or burrow sites for predators such as foxes (*Vulpes vulpes*) and ghost crabs (*Ocypode quadrata*), and avoid installation of solid posts or other structures that provide perches for avian predators such as crows (*Corvus spp.*) and gulls (*Laridae spp.*). Woody species should not be planted in or near rare, threatened, and endangered species areas (not even in backdune areas), as they provide perches for avian predators.

Section 7(a)(2) of the Endangered Species Act (ESA) requires Federal Agencies that authorize, fund, or carry out projects within coastal ecosystems to consult with the U.S. Fish and Wildlife Service if a proposed action may affect any federally listed species. Section 9 of the ESA applies to both Federal and non-Federal activities and prohibits unauthorized taking of listed species, including significant habitat modification or degradation that results in the killing or injury of listed wildlife by significantly impairing essential behavioral patterns, such as breeding, feeding or sheltering. The U.S. Fish and Wildlife Service and the ENSP assist local beach managers in complying with the Endangered Species Act and related laws and regulations. Most municipalities have worked with the ENSP and the U.S. Fish and Wildlife Service to develop a BMP for rare and listed species.