THE PERIODIC OCCURENCE OF NEVADA EARTHQUAKES

A Thesis

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by

David R. Oxley, Jr.

The Ohio State University

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Approved by

Charles E. Corbato

Charles E. Corbato

Adviser

Department of

Geology and Mineralogy

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INTRODUCTION

This investigation has attempted to correlate the occurence of earthquakes with periodic physical forces which might trigger earthquakes. Briefly, Fourier Series Harmonic Analysis and Spectral Analysis were used to examine a histogram of the data for strong cycles of occurence. The agent believed responsible for triggering the earthquakes is stress in the earth's crust from tidal effects (Zetler, 1966; Ryall, VanWormer, and Jones, 1968; Tamrazyan, 1968; Knopoff, 1969), variations in the earth's rotational velocity (Simpson, 1967b), and the Chandler Wobble (Mansinha and Smylie, 1968; Myerson, 1970).

METHOD

The date and location of occurence of 1396 Nevada earthquakes having magnitudes greater than 4.0 (Slemmons, Jones, and Gimlet, 1965) were punched on computer cards. A curve was then computed which represented the number of earthquakes occuring per time interval (i.e., frequency) vs. time elapsed since the beginning of the record. Three different curves were plotted using six day, three day, and one day intervals. The starting date of each of the curves and the total number of earthquakes they contained were respectively July 24, 1927, 1089; November 15, 1928, 1070; August 15,1928, 1076; however, the starting date of the one day interval curve used in the Spectral Analysis and the number of events it contained were October 14, 1950, 479. For comparison purposes, a curve of similar length was also calculated using random numbers for the earthquake frequencies.

First, the curves were analyzed using a double precision form of the IBM supplied subroutine FORIT. This Fourier Series analysis tells both which cycles strongly affect the shape of the curve and on what dates these cycles peak. These dates were than compared with the various dates on which the stresses that may have triggered the earthquakes were at a maximum. Next, the curves were analyzed using a Spectral Analysis subroutine (Rayner, 1972). This analysis tells what bands (i.e., sets of all cycles with periods between two limits) strongly affect the shape of the curve yet reveals nothing about when the peaks of these bands occur.

DISCUSSION and RESULTS

The Fourier Series may be written as

$$f(x) = a_0/2 + \sum_{n=1}^{\infty} c_n \sin(nx + \phi_n)$$

when the function (e.g., the curve plotted from the data) being examined is continuous between the endpoints which are taken as 0 and 2π radians (Weast, 1969). In the formula, $a_0/2$ represents the average value of the function, n the frequency of the particular sine wave, c_n its amplitude, and ϕ_n its phase angle which is the distance the wave must be moved to the right or left in order to fit properly; this angle when converted to days tells on what dates the strength of the particular wave is at a maximum. ϕ_n and c_n may be calculated from two other constants a_n and b_n (i.e., the Fourier Coefficients) using the relations $\phi_n = \arctan(a_n/b_n)$ and $c_n = \sqrt{a_n^2 + b_n^2}$. The Fourier Coefficients were obtained using the subroutine DFORIT, which employs the recursive technique (Ralston and Wilf, 1960) for calculating these two coefficients. The formula is explained graphically by Figures 1,2, and 3 where it is seen that the five harmonics in Figure 2 will add together to produce the curve in Figure 3 which represents an 83% fit to the original curve in Figure 1. As more and more harmonics of the correct amplitude and phase angle are added, the percent fit would increase to 100. Therefore, with the Fourier Series one may demonstrate the existance of periodicity within a curve by using the Power Spectrum (i.e., the square of the amplitude) of a harmonic as a measure of its affect upon the shape of the curve: the larger the harmonic's power spectrum, the greater its affect.

Spectral Analysis was also used to examine the data because of two improvemants it has over Fourier Analysis (Rayner, 1971). First, it takes into account the possibly incorrect assumption made by Fourier Series that the curve being analyzed is the same beyond the two limits between which it is being examined, as it is within these limits. In other words, a series of continuous events is being viewed through a window, and errors may be introduced if certain events are assumed to occur on either side of the window where they cannot be viewed. Also, Spectral Analysis slightly smoothes the curve being examined before analyzing it thereby removing noise (i.e., points on the curve which do not truly represent the data) and producing more valid results. The curve analyzed with Fourier Series Analysis may be thought of as a line connecting the tops of a series of spikes, Figure A; the curve analyzed with Spectral Analysis (after smoothing) may be thought of as a line connecting the tops of a series of blocks, Figure B.

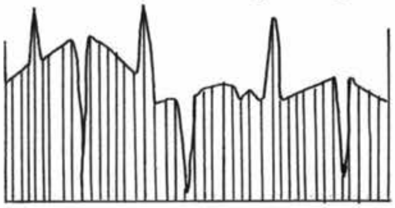

Figure A

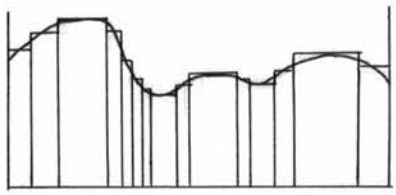

Figure B

Many workers have suggested that earthquakes might be triggered by tidal stresses in the earth's crust; however, because of the small size of the accelerations involved (e.g., 0.1 mgal by the moon and 0.05 mgal by the sun) this suggestion has not gained wide acceptance. Tamrazyan (1968) has also used the Nevada earthquake data in an attempt to correlate earth tides and earthquakes, and using a method different from this investigation, he found an interesting correlation between the two. Also, he noted a correlation between the frequency of earthquake occurence and the magnetic activity of the sun. Ryall (1968) by examining one-hundred afterschocks during a sixteen day period found a statistically significant correlation between the occurrence of the shocks and an earth tide record covering the same period. Knopoff (1969) found a correlation at the 99% confidence level between the fortnightly components of the earth tides and the worldwide catalog of events having magnitudes greater than six but when aftershocks were eliminated so was the correlation after the confidence level dropped below 75%. Simpson (1967a) too has shown using worldwide data that the occurence of earthquakes follows a random pattern with regard to earth tides. However, he later suggests (Simpson, 1967b) a correlation between earthquake triggering and solar flare activity believing that the triggering effect might be achieved through changes in the earth's angular velocity induced by magnetohydrodynamic coupling between the sun and earth magnetic fields. Further, others believe that earthquakes cause the Chandler Wobble (Mansinha and Smylie, 1968) or that either the stresses produced by the wobble trigger the earthquakes or that both are parallel effects of another cause (Myerson, 1970). Clearly no cut and dried explanation of earthquake triggering has been found; this no doubt is related to the complexity of earthquake mechanisms. As Zettler (1966) points out, different fault planes have different orientations; therefore, they are affected to different degrees by various crustal stresses which are vector quanities.

Displays of this investigation's results are located in the Appendix. The presence of several major cycles within the data is indicated. These cycles, on the basis of their strengths and the correlation between the times when their strengths peaked and the strengths of known cycles peaked, may be ranked in order of greatest to least amount of confidence in their affect upon the shape of the data curve: 18 year, 440 day, 220 day, 27 day, 4000 day, 2000 day, 1350 day, 1100 day, 800 day, 170 day. Several possible interpretations exist for these cycles:

18 year-- 18.6 year period for the oscillation of the moon's orbit, 19 year period of eclipse repetition;

440 day-- 441 day period of the Synodic/Anomalistic tide cycle, 428 day period of the Chandler Wobble;

220 day-- the 180 degree phase lag of the Synodic/Anomalistic tide cycle;

27 day-- 27.55 day period of the Anomalistic tide cycle;

4000 day-- 11 year period of the sunspot cycle.

At this time no explanations of the remaining cycles have been discovered. The analysis of the curves generated from random numbers (i.e., white noise curves) indicate certain cycles having greater strength; however, these stronger cycles are evenly distributed throughout all the periods. This is interpreted as evidence for the distribution of random function values along the curve.

CONCLUSIONS

This investigation reveals some interesting correlations between the occurence of earthquakes and certain earth tides, solar cycles, and the Chandler Wobble. The lack of random occurence of Nevada earthquakes and also the presence of an eighteen to nineteen year cycle of occurence may be inferred with a degree of certainty. However, further study is required to establish conclusively the presence or absence of other periodicities.

ACKNOWLEDGMENTS

I wish to express my thanks to the following persons: Dr. Charles E. Corbato, for originally suggesting this investigation to me and for his advice on the use of the computer; Dr. Wayne L. Hamilton for his encouragement and interpretations of the results; and Dr. John N. Rayner, for the use and explanation of his Spectral Analysis program. Also this work has been supported by the Departments of Geology and Mineralogy, and Computer and Information Science of The Ohio State University.

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APPENDIX

FIGURE 1

Graph of a curve. Horizontal axis: value of function 3.0-13.0. Vertical axis: number of degrees 0-360.

FIGURE 2

Graph of five sine curves which most affect the shape of the curve en Figure 1. Horizontal axis: values of functions 3.0-13.0. Vertical axis: number of degrees 0-360.

FIGURE 3

Graph of curve which is the sumation of the curves in Figure 2. Horizontal axis: value of function 3.0-13.0. Vertical axis: number of degrees 0-360.

TABLE 1

Data used in this investigation. Dates upon which an earthquake occured and the number of days elapsed since the first earthquake.

FIGURE 4

Graph of Power Spectra calculated from a Fourier Series Analysis of a curve representing the frequency of earthquakes during six day intervals over a period of 13,170 days ending September 26,1961. Horizontal axis: value of Power Spectra times 2,000; printed just to right of the period. Vertical axis: period in days of particular cycle; printed in column farthest to the right.

TABLE 2

Dates upon which the strength of particular cycles were at a maximum. Calculated for the cycles shown in Figure 4.

FIGURE 5

Same as Figure 4 except the curve covered 12,003 days in three day intervals, and Power Spectra have been multiplied by 10,000.

TABLE 3

Same as Table 2 except done for cycles shown in Figure 5.

FIGURE 6

Same as Figure 4 except the curve covered 12,095 days in one day intervals , and the Power Spectra have been multiplied by 100,000.

TABLE 4

Same as Table 2 except done for cycles shown in Figure 6.

TABLE 5

Some dates upon which full moon, new moon, and moon at perigee occured.

FIGURE 7

Graph of Power Spectra calculated from a Fourier Series Analysis of a curve generated by plotting 2,196 random numbers between 0 and 50 along equal time intervals. Horizontal axis: values of Power Spectra times 70; printed just to the right of the period. Vertical axis: period in days of particular cycle assumming the curve was 13,170 days long; printed in last column to right.

FIGURE 8

Graph of the variance of a particular band of cycles calculated with Spectral Analysis of a curve representing the frequency of earthquakes during six day intervals over a period of 12,000 days ending September 26, 1961. Horizontal axis: amount of variance also printed in column to right. Vertical axis: periods of bands. The limits of the band periods whose variance is shown are determined by finding the mean values between the band being examined and the bands on either sise of it (e.g., the upper and lower limits of the band whose period is 1440 days are 2160 days and 1200 days respectively). The red tick marks on either side of the variance values represent a 90% confidence level that a band is or is not separate from the bands on either side of it. The black lines to the right represent points where two adjacent bands may be considered significantly different. The stars between the black lines indicate groups of bands which are judged to significantly affect the shape of the curve which has been analyzed.

FIGURE 9

Same as Figure 8 except that the curve being analyzed was made of three day intervals covering a period of 12,000 days.

FIGURE 10

Same as Figure 8 except that the curve being analyzed was made of one day intermals covering a period of 4,000 days.

FIGURE 11

Same as Figure 8 except that the being analyzed was made by plotting 2,000 random numbers between 0 and 50 at equal intervals along a length taken as 12,000 days.

PROGRAM 1

A Double Precision Fortran Subroutine to calculate the Fourier Coefficients of a tabulated function.

PROGRAM 2

A Fortran Subroutine to calculate the number of days between two calander dates.

PROGRAM 3

A Fortran Subroutine to calculate the number of chronologically ordered events occurring per time interval.

PROGRAM 4

A Fortran Subroutine to calculate the calander date a given number of days away from another given calander date.