SEISMIC EVALUATION OF THE DIABLO CANYON SITE

Hugo Benioff and Stewart Smith

Objectives

The objectives of this report are: 1) to provide a historical summary of earthquake activity in the immediate vicinity of the reactor site and in adjacent areas where an earthquake might be expected to produce secondary effects within the site area, and 2) to provide an estimate of the "size" of earthquakes that can be expected to occur in these regions during the lifetime of the reactor.

The results that such earthquakes may be expected to produce in the site area due to shaking or seismic sea waves will be treated in separate reports by others.

Methods

Historical and instrumental records of seismic activity in a region are important for the prediction of future occurrences of earthquakes in that region. The distribution of number of earthquakes versus their magnitude provides one convenient way of summarizing the seismic activity of a region. Use of such data, however, can produce misleading results if the region considered is too small or if the data cover too short a span of time. In particular, extrapolations from data on small earthquakes to predict the occurrence of larger ones are unreliable. To avoid some of these problems, and provide an estimate of the largest possible earthquakes that can be expected, we have used the following approach. On faults where there is seismic activity and evidence of large earthquakes in the past, we assume that the largest of such events will recur in the near future. On faults where there is no evidence of major seismic activity in the historic record, we assume that a large earthquake, although unlikely, cannot be ruled out.

In the case of such a fault, two methods can be used to estimate the maximum "size" earthquake that can occur, the known behavior of other faults of similar dimensions and the observations of the maximum aftershock that might be induced on a minor fault due to a great earthquake on a nearby major fault.

In this report the terms fault, or fault system, are applied to discontinuities in the earth along which regional or large-scale stresses are relieved in connection with the occurrence of earthquakes. Discontinuities due to the folding of sedimentary rocks, gravity sliding, or other local effects are not pertinent to the seismic evaluation of the site.

Earthquake Size

The size of an earthquake can be described by its magnitude on the Gutenberg-Richter scale, total energy, maximum acceleration, frequency spectrum, fault length and slip, region of severe shaking, duration of shaking, stress drop or strain release. Although magnitude is the most common way of classifying earthquakes, it is not necessarily the best measure of those earthquake characteristics, such as the frequency spectrum, which are most important for engineering purposes. This is true because the magnitude measurement is essentially an estimate of the seismic energy at only a single frequency. No means are available for predicting the effect of a magnitude change on the over-all frequency spectrum. For this reason the "design" earthquake described in this report will be given in terms of those parameters which are most closely related to the frequency spectrum; they are fault length, depth, slip, and duration of strong shaking.

Seismicity

During the time covered by available historic records, seismic activity within about 20 miles of the Diablo Canyon site has been very low. In the "Catalog of California Earthquakes" by H. O. Wood,[1/] only one earthquake is listed as having caused damage within this area. This was a shock in 1830 which damaged a church in San Luis Obispo. Since no other damage is reported, this earthquake was probably quite small. The Earthquake and Epicenter Fault Map prepared by the Department of Water Resources, State of California,[2/] a portion of which is appended to this report, shows several small shocks of magnitude 4 to 4.4 with epicenters distant about 20 miles from the site. On November 4, 1927 a fairly large earthquake, listed by Gutenberg and Richter[3/] with a magnitude of 7.3, occurred off the coast some 60 miles southwest of the site, presumably on the western extension of the east-west trending fault system which includes the Santa Ynez Fault on land and the source of the June 29, 1925 (magnitude 6.3) and July 1, 1941 (magnitude 6.1) Santa Barbara earthquakes offshore.

The nearest seismically significant fault system to the site, the Nacimiento Fault, is some 20 miles distant. The largest earthquake known to have been associated with this fault occurred on November 22, 1952 at an epicentral distance to the site of about 44 miles. It is listed with a magnitude of 6.0. Although the activity of the Nacimiento fault system has thus been very low during the past century and a half, we have no means as yet of determining the character of its behavior pattern, and consequently, it must be assumed that an earthquake of significant size may have its origin on

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1/ Bulletin Seismological Society of American, Vol. VI, pages 1 - 180, 1916

2/ Dept. of Water Resources Bulletin No. 116-2, Crustal Strain and Fault Movement Investigation, January, 1964.

3/ Seismicity of the Earth, Princeton University Press, Princeton, N.J., 1949 this fault during the life of the reactor. Considering the length of the fault system -- about 120 miles -- and the behavior of other similar minor faults in California and Nevada, the largest earthquake which can be expected to be generated on this fault would be similar to the 1952 Tehachapi or the 1954 Fairview Peak earthquakes. Thus it would have a fault displacement of 3 to 10 feet at its maximum point, a break of about 60 miles in length and a duration of about 10 seconds. This corresponds to a shock of about 7-1/4 magnitude on the Gutenberg-Richter scale. However, since for earthquakes greater than about 6.5 the magnitude scale is indeterminate within ± 1/2 magnitude, and as previously noted the physical effects are not necessarily predictable from the magnitude, we prefer to specify the estimated fault slip, length of break and duration of strong shaking rather than to specify a particular magnitude.

At its closest point the San Andreas fault passes some 48 miles from the site. This point is also the approximate northern terminus of the 1857 earthquake break. The 150-mile-long segment extending from here north to San Juan Bautista has had no major slip since the advent of the white man. Two small shocks, March 10, 1922, magnitude 6.5, and June 8, 1934, magnitude 6, occurred on this segment. The most recent significant earthquake in this region was the June 28, 1966, event at Cholame of magnitude about 5.4 which produced several inches of fault displacement. None of these events was large enough to relieve any significant amount of strain. Since the strain on this segment has been accumulating for more than 150 years, it is very likely greater on this segment than on any other, and consequently this is the segment most likely to be involved in the next great earthquake on the

San Andreas fault. Therefore, we must assume that during its life the reactor will be subjected to an earthquake due to movement on the San Andreas fault similar to the movement that occurred in 1857 and 1906. In these shocks the maximum fault offset was about 20 feet in the horizontal direction and 3 feet in the vertical direction. The fault break was about 200 miles long and the duration of strong shaking was about 40 seconds.

An earthquake of this size can be expected to produce numerous aftershocks on adjacent faults ranging in size up to about one magnitude less than the principal shock. Thus such a maximum aftershock could occur on the Nacimiento fault system and thus account for the maximum shock considered in the previous paragraph for this fault. Should a great earthquake occur on the San Andreas fault there might be a wide distribution of aftershocks extending out to distances of about 50 miles from the San Andreas fault. These aftershocks may occur either on or away from existing fault systems. Those occurring on existing fault systems could have magnitudes ranging up to about 7-1/2 and could produce surface faulting along existing faults. Those occurring away from existing faults would have magnitudes ranging up to about 6-3/4. The probability that these particular aftershocks would produce new surface faults where none now exist is extremely remote. Experience with California and Nevada earthquakes indicates that such aftershocks not associated with existing fault systems will be restricted to depths of about 6 miles or more. Thus, in the event of a great earthquake on the San Andreas fault, large aftershocks may occur anywhere within about 50 miles of the San Andreas fault, but those which are not located on existing faults would be restricted to depths of about 6 miles or more and magnitudes of about 6-3/4 or less.

Offshore Earthquakes

The seaward extension of the Santa Ynez fault is the closest significant fault system that may be responsible for large offshore earthquakes. Using earthquake epicenters and submarine topography to determine the western limit of this fault, the maximum offshore fault length is found to be about 80 miles. This fault's point of closest approach to the site is fifty miles. Using the methods previously described, we estimate that an 80 mile fault break with a horizontal slip of 10 feet could occur offshore on this system, producing an earthquake of magnitude 7-1/2.

The offshore extension of the San Andreas fault northwest of Cape Mendocino, although a distance of more than 420 miles from the site, may have to be considered for possible seismic sea wave generation. There are two distinct concentrations of offshore seismic activity in this region: One zone trends northwesterly along an extension of the San Andreas fault and the other trends east-west along the Gorda Escarpment. Using earthquake epicenters to estimate the length of the fault system that is active, we estimate that a 100 mile fault with horizontal offsets of about 10 feet could occur on the northwesterly extension of the San Andreas fault equivalent to a magnitude 7-1/2 earthquake. The largest offshore earthquake recorded in this region was a magnitude 7.3 event of 1 February 1922. There were no reports of a seismic seawave due to the earthquake.

The activity on the Gorda Escarpment appears to be limited to magnitudes of about 6.0 and below; however, the zone of activity is large enough to support a 40 mile fault break with offsets of about 5 feet equivalent to a magnitude 7 earthquake. In view of the submarine topography in this region, it is possible that the offset for such an earthquake could be in the vertical direction.

The possible generation of seismic sea waves by such earthquakes and the resulting effects at the reactor site will be treated in a separate report by others.

Summary and Conclusions

The maximum size earthquakes that can be expected to occur during the life of the reactor are listed below:

1) A great earthquake may occur on the San Andreas fault at a distance from the site of more than 48 miles. It would be likely to produce surface rupture along the San Andreas fault over a distance of 200 miles with a horizontal slip of about 20 feet and a vertical slip of 3 feet. The duration of strong shaking from such an event would be about 40 seconds, and the equivalent magnitude would be 8-1/2.

2) A large earthquake on the Nacimiento fault at a distance from the site of more than 20 miles would be likely to produce a 60 mile surface rupture along the Nacimiento fault, a slip of 6 feet in the horizontal direction, and have a duration of 10 seconds. The equivalent magnitude would be 7-1/4.

3) Possible large earthquakes occurring on offshore fault systems that may need to be considered for the generation of seismic sea waves are listed below:

Location	Length of Fault Break	Slip	Magnitude	Distance to Site
Santa Ynez Extension	80 miles	10' horizontal	7-1/2	50 miles
Cape Mendocino, NW Extension of San Andreas Fault	100 miles	10' horizontal	7-1/2	420 miles
Gorda Escarpment	40 miles	5' vertical or horizontal	7	420 miles

4) Should a great earthquake occur on the San Andreas fault as described in paragraph 1) above, large aftershocks may occur out to distances of about fifty miles from the San Andreas fault, but those aftershocks which are not located on existing faults would not be expected to produce new surface faulting, and would be restricted to depths of about 6 miles or more and magnitudes of about 6-3/4 or less. The distance from the site to such aftershocks would thus be more than 6 miles.

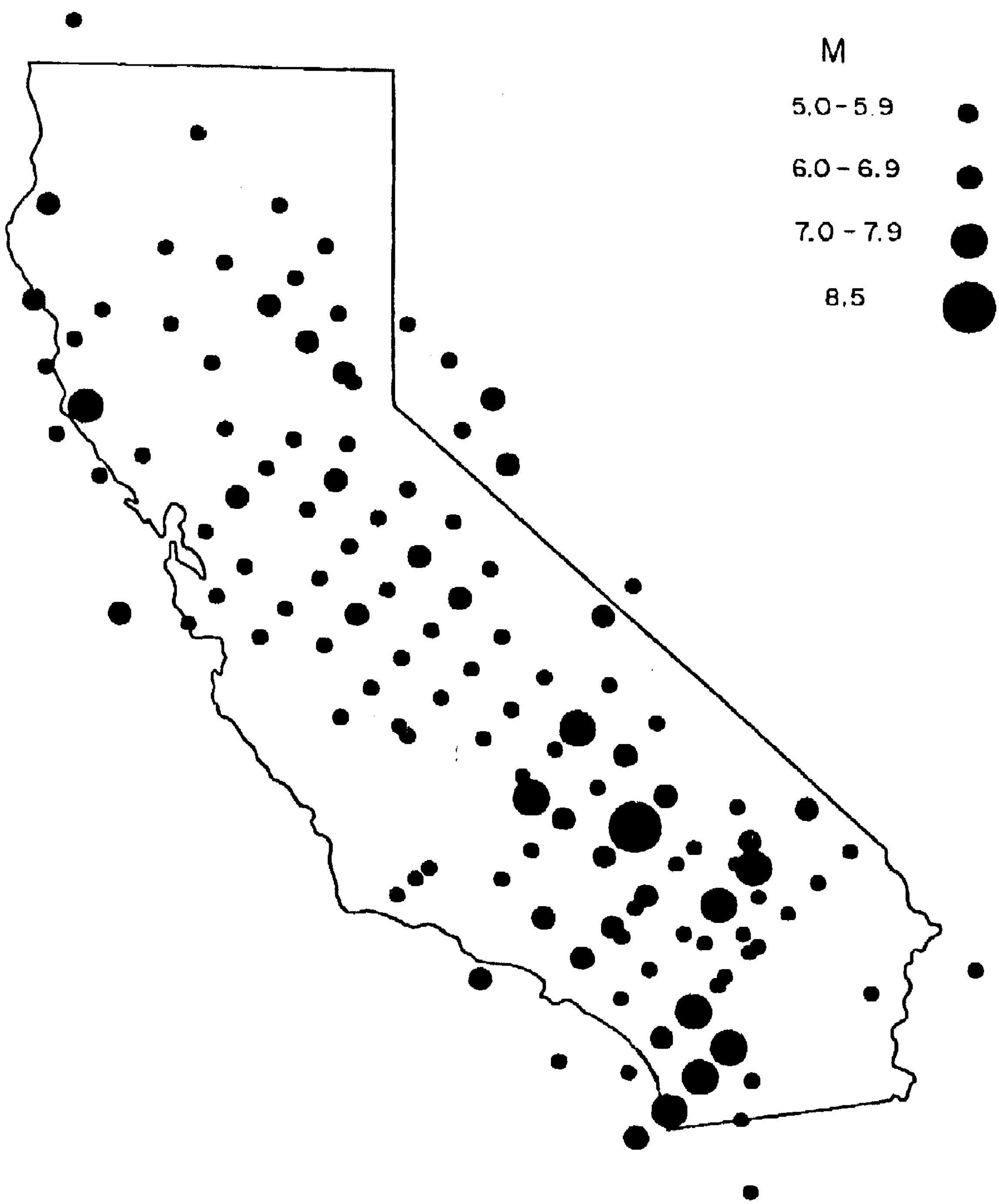

Figure 9. Plot of main shock and aftershocks of the M 8.5 Chilean earthquake of 1960, superimposed on an outline of California. This plot was the basis for Benioff and Smith's postulation of an earthquake as large as M 6.75 (earthquake D), potentially occurring on an unknown, concealed source structure located beneath the Diablo Canyon site.