2.6 SEISMOLOGY

2.6.1 INTRODUCTION AND SUMMARY

This section of the report presents the results of the engineering seismology phase of the environmental study. This phase of the study included literature research to compile a record of the seismicity of the area (References 1, 2, 6, and 8), evaluation of the geologic structure and tectonic history of the region, a program of dynamic laboratory soil testing, and analyses to evaluate the response of the foundation materials to earthquake-type loading. Field geophysical studies were performed to evaluate the in-situ dynamic properties of the foundation materials.

The site is located in a region which has experienced infrequent and minor earthquake activity. Most of the reported earthquakes are related to known faulting more than 50 miles west of the site in the Piedmont Physiographic Province. No known faults occur in the vicinity of the site. The closest earthquake (Intensity VII) which caused any structural damage occurred about 80 miles southwest of the site. Several minor shocks (no greater than Intensity V) have been reported within 50 miles of the site. Because of very limited data, it is not possible to determine whether or not these were of tectonic origin.

The foundations of major plant structures are established in dense Miocene soil which will not undergo reduction in strength or increased settlement under safe shutdown earthquake (SSE) conditions.

Significant earthquake ground motion is not expected at the site during the economic life of the nuclear facility. On a conservative basis, the power plant was designed to respond elastically, with no loss of function, to horizontal ground accelerations as high as 8% of gravity and vertical ground accelerations as high as 5-1/3% of gravity.

For safe shutdown of the reactor, a maximum horizontal ground acceleration of 15% of gravity was used in the design. A maximum vertical acceleration of 10% of gravity was used in the design. These accelerations are based on an assumed Intensity VII earthquake originating near the site.

The results of the regional study of seismicity and tectonics show that the aforementioned ground accelerations are conservative. Therefore, the nuclear power plant designed to these parameters meets all safety requirements.

It is not expected that the plant will be subjected to a significant tsunami effect. The maximum expected tsunami would not result in more than minor wave action at the site and, thus, was not significant in the design.

Geological and geophysical investigations performed since the late 1970s have led to speculation that many large Cretaceous and Cenozoic fault zones may exist in the Atlantic Coastal Plan. The closest of these are the Stafford and Brandywine fault systems, located about 45 and 29 miles west of the site, respectively.

An update of the seismic activity within 200 miles of the site focuses on two areas. The first is the occurrence of any seismic events since the last investigation that would be of greater significance than those previously considered. The second area is the evaluation of the earthquake catalog data that would lead to significant changes to the original SSE assessment. A significant earthquake catalog was developed by investigators and consultants of the Electric Power Research Institute in 1988 and the National Center for Earthquake Engineering Research in 1992. An independent evaluation of regional seismicity, performed by Bechtel Power Corporation in 1992, found that while more seismic events have been cataloged than were previously considered in the Updated

Final Safety Analysis Report, none of the additional events were larger or were in new or significantly different areas than those used to develop the SSE design basis. The basic premise of SSE specifications at Calvert Cliffs, an intensity MMI VII earthquake in the Atlantic Coast Plain province in the vicinity of the site, remains unchanged.

Reference 13 discusses the results of additional analyses of vibratory ground motion which were performed to determine the design ground acceleration level for the Diesel Generator Buildings. This supplemental information applies to the power block as well as to the Diesel Generator Buildings.

2.6.2 TECTONICS

The site is located in the Coastal Plain Physiographic Province. This province is bounded on the east by the Atlantic Ocean, and on the west by the Fall Zone and the Piedmont Physiographic Province. The Coastal Plain consists of easterly dipping Cretaceous and Tertiary sediments which are about 2,500' thick at the site. Crystalline basement rock outcrops near the Fall Zone about 50 miles west of the site. A graphical representation of the subsurface conditions at the site is shown on Figure 2.6-1, Columnar Section, Showing Geophysical Data.

On the basis of regional data, the Cretaceous and Tertiary sediments are undeformed. The absence of folding and faulting in the sedimentary strata indicates that displacements along unknown faults which may be present in the basement have been negligible.

No known faults occur within the basement rock or sedimentary deposits in the vicinity of the site. The closest known fault systems are found in the rocks of the Piedmont, more than 50 miles west and northwest of the site. The Piedmont Province consists of igneous and metamorphic rocks of Precambrian and early Paleozoic Age, with areas of sedimentary and igneous rocks of Triassic Age. Major tectonic activity that has occurred in the Mid-Atlantic Region can be related to known faults in the Piedmont Province.

2.6.3 SEISMICITY

The site is situated in a region which has experienced only infrequent minor earthquake activity. No shock within 50 miles of the site has been large enough to cause significant structural damage. Since the region has been populated for over 300 years, it is probable that all earthquakes of moderate intensity, say VI or greater, would have been reported during this period. It is very likely that all earthquakes of Intensity V or greater which occurred within the last 200 years have been reported.

The first report of earthquake occurrence in the general area of the site dates back to the late 18th Century. Since then, only 14 earthquakes with epicentral intensities of V or greater on the Modified Mercalli(a) Scale have been reported within about 100 miles of the site. None of these shocks was greater than Intensity VII. Few were of high enough intensity to cause structural damage and only one of these shocks can be considered more than a minor disturbance. This was an Intensity VII shock near Wilmington, DE in 1871 about 100 miles from the site. A list of earthquakes of Intensity V or greater with epicenters located within a distance of about 100 miles of the site is presented in Table 2-37, Significant Earthquakes within 100 miles of the site. Several smaller earthquakes, which are significant because of their proximity to the site, are also included in Table 2-37. The locations of these and other earthquakes in the region surrounding the site are shown on Figure 2.6-2, Epicentral Location Map. Several small shocks are shown on the Epicentral Location Map, but not indicated in Table 2-37. Little information is available regarding these shocks. The indicated epicentral locations are those suggested by G.P. Woollard (Reference 12).

Most of the reported earthquakes in the region have occurred in the Piedmont Physiographic Province west of the Fall Zone. The closest approach of the Fall Zone to the site is about 50 miles. These shocks were generally related to known faults in the Piedmont rocks.

There have been several large shocks with epicenters in the Coastal Plain, some of which were damaging. The largest of these is the Charleston, South Carolina, earthquake of 1886, which has an epicentral intensity of about IX. Geological and seismological research in the meizoseismal vicinity of Charleston appear to support the view that the Charleston earthquake occurred in association with a specific seismogenic structure located near Charleston, and there is no need to consider a site intensity of MMI X for seismic design at Calvert Cliffs.

While the Giles County, Virginia Seismic Zone is just over 200 miles from the Calvert Cliffs site, it is relevant to discuss this seismically active zone in that it was the location of a MMI VII intensity earthquake on May 31, 1897. However, the seismic activity around Giles County appears to be very distinct in character as compared to seismicity in the nearer Central Virginia Seismic Zone. There appears to be no reason to assume the 1897 Giles County earthquake is applicable to the Calvert Cliffs site seismicity.

The largest earthquake in the Coastal Plain close enough to the site to be of significance in the current study occurred in 1927 near the northern New Jersey coast, about 180 miles northeast of the Calvert Cliffs site. The epicentral intensity of this earthquake was VII. Three shocks were felt over an area of about 3,000 square miles from Sandy Hook to Tom’s River. Highest intensities were felt from Asbury Park to Long Branch where several chimneys fell, plaster cracked, and articles were thrown from shelves. This shock has not been related to any known geologic feature.

An earthquake which occurred near Wilmington, DE, in 1871 is the largest reported earthquake within 100 miles of the proposed plant site. It is not possible to accurately locate the epicenter of this shock with the limited data available, but it is probable that the shock occurred along the Fall Zone about 100 miles northeast of the site. The epicentral intensity of this shock is rated at VII. At Wilmington, chimneys toppled and windows broke. Damage was also reported at Newport, New Castle, and Oxford, DE. The earthquake was felt over a relatively small area of northern Delaware, southeastern Pennsylvania, and southwestern New Jersey.

Only one earthquake of Intensity V or greater has been reported within 50 miles of the proposed plant site. This shock, which had a rated epicentral intensity of V, caused no structural damage. Its epicenter was located near Seaford, DE, about 45 miles northeast of the site.

Several small shocks have been reported in the Coastal Plain in the region surrounding the site. Four such shocks were reported east and south of the site. Several other small shocks were reported in the vicinity of Annapolis, MD, northwest of the site. These reported earthquakes were considered in this investigation; however, available data regarding these shocks are limited, and it is impossible to estimate their maximum intensities or to precisely locate their epicenters.

None of these earthquakes caused structural damage and they are of interest only in that they may indicate the possible presence of unidentified faulting in the basement rock of the Coastal Plain. However, it is possible that some of these reports may refer to relatively distant earthquakes which were felt in eastern Maryland. Furthermore, it is also possible that these shocks resulted from causes other than tectonic activity. The probable epicenters of these small shocks are shown on the Epicentral Location Map, Figure 2.6-2.

An independent evaluation of regional seismicity performed in 1992, to support design of the Diesel Generator Building, identified more earthquakes than were previously identified. However, these additional earthquakes were neither larger nor in different areas than those used to develop the original SSE design basis.

2.6.4 GEOPHYSICAL INVESTIGATIONS

2.6.4.1 General

Geophysical studies were performed at the Calvert Cliffs site in order to evaluate the dynamic properties of the foundation materials. The dynamic soil properties are used in evaluating the response of the foundation materials to earthquake loading.

A seismic refraction survey and an uphole velocity survey were performed in order to measure the velocity of compressional wave propagation at the site. The shear wave velocity was estimated from the field measurements of surface waves (predominantly Rayleigh waves). Micromotions were measured in order to indicate the pattern of vibration at the site due to background "noise." These measurements assist in estimating the natural period of vibration at the site. Laboratory shockscope tests were performed for correlation with the field measurements.

Shear and compressional wave velocity measurements were derived for the upper strata during the geophysical investigations. Compressional wave velocities for the deeper strata near the site were measured during a geophysical survey performed by Ewing and Worzel in 1943. Shear wave velocities were computed from these data using an estimated Poisson's ratio. Geophysical data for the entire stratigraphic section and presented on Figure 2.6-1.

2.6.4.2 Refraction Seismic Survey

Seismic refraction surveys were performed along two lines, 2,000' and 2,100' in length, as shown on Figure 2.4-7, Plot Plan. The purpose of these surveys was to evaluate the compressional wave velocities of the sediments underlying the site. The work was conducted with an Electro-Technical Labs M4E seismograph. Dynamite charges, from 10 to 50 lbs at each end of the seismic lines, were used as a source of energy. The charges were buried at depths of 25 to 60'.

Geophones were located at intervals ranging from 20 to 100' along each line. Data from these field measurements indicate that the velocity of compressional wave propagation in the upper surficial Pleistocene silts and sands is about 2,200 fps, and in the Miocene sandy and clayey silt about 5,900 fps.

Extensive geophysical surveys in the Coastal Plain were made in 1943 by Ewing and Worzel. These surveys included measurements to the crystalline basement rock at a point several miles south of the site. The results of these measurements and the measurements made at the site by Dames & Moore are summarized in Table 2-38 Geophysical Data.

2.6.4.3 Uphole Seismic Velocity Survey

An uphole seismic survey was performed in Boring DM-4 in the proposed plant area. The purpose of this survey was to correlate the compressional wave velocities of the materials in the plant area with the compressional wave velocities measured by the refraction survey approximately 1,000' to the northwest.

The uphole seismic survey was performed using the Electro-Technical Labs ER-75-12 seismograph. The seismic energy was provided by either blasting caps or charges of one to three ounces of dynamite detonated at 10’ intervals in the boring to a maximum depth of 148’. Geophones were placed at 5 to 60’ intervals at distances up to 220’ from the boring. The results of this survey are presented on Figure 2.6-3, Uphole Seismic Survey.

2.6.4.4 Shear Wave Measurements

The velocity of shear wave propagation was evaluated at the site. The compressional wave and shear wave velocities were used to compute Poisson’s ratio and the dynamic properties of the soil. The shear waves were estimated from surface waves (predominantly Rayleigh waves) measured with a Sprengnether velocity meter. These measurements indicate that the velocity of shear wave propagation at the site is about 1,600 fps in the Miocene sediments.

2.6.4.5 Micromotion Measurements

Micromotion measurements were made at three locations at the site using the Dames & Moore Microtremor Equipment. The micromotion measuring stations are shown on Figure 2.4-7, Plot Plan. The equipment used is a highly sensitive recording device capable of magnifying ground motions up to 150,000 times and is accurate over a frequency range of 1 to 30 CPS.

The microtremor records indicate a predominant period of background vibration on the order of one-half to three-quarters of a second. The low intensity levels are consistent with what would be expected in a reasonably dense material. The predominant ground period and intensity of ambient motion at the site will present no special problems in design of the facility.

2.6.4.6 Laboratory Shockscope Tests

Several representative samples of the soil underlying the site were tested in the Shockscope. The Shockscope is an instrument developed by Dames & Moore to measure the velocity of propagation of compressional waves in soil. The velocity of compressional wave propagation observed in the laboratory was correlated with the field measurements and used as an aid in evaluating the dynamic elastic properties.

In the Shockscope test, the samples were subjected to physical impulses under a range of confining pressures while the time necessary for the shock wave to travel the length of the sample was measured using an oscilloscope. The velocity of compressional wave propagation was then computed. The results of these tests are presented in Table 2-39, Shockscope Test Data.

2.6.4.7 Diesel Generator Building Siting Surveys

Additional analyses of vibratory ground motion were performed to support design of the Diesel Generator Buildings. A significant earthquake catalog was developed by investigators and consultants of Electric Power Research Institute and the National Center for Earthquake Engineering Research. A subsequent independent evaluation of this regional seismicity was performed by Bechtel Power Corporation in 1992.

2.6.5 ASEISMIC DESIGN

2.6.5.1 Foundations

The foundations of the major plant structures are established in the Miocene sandy and clayey silts of the Chesapeake Group. These soils are apparently preconsolidated as a result of deposition and subsequent erosion of younger sediments, as well as desiccation and increase in effective pressure caused by lowering of the water table. Some appurtenant structures at the site are founded in the surficial Pleistocene silt and sand which overlies the Miocene sediments.

2.6.5.2 Operating Basis Earthquake (No Loss of Function)

On the basis of the seismic history of the area, it does not appear likely that the site will experience significant earthquake ground motion during the economic life of the proposed facility. The nuclear power plant was conservatively designed to respond elastically, with no loss of function, to horizontal earthquake ground accelerations of 8% of gravity, and vertical earthquake ground accelerations of 5-1/3% of gravity. It is not believed that this level of ground motion will be exceeded at the site during an earthquake similar to any historical event. This ground acceleration is considerably greater than what might be expected due to an Intensity V shock (Magnitude 4 on the Richter Scale[a]) close to the site, or to an Intensity VII (Magnitude 5) shock at an epicentral distance of about 15 to 20 miles.

2.6.5.3 Safe Shutdown Earthquake (Safe Reactor Shutdown)

For a safe shutdown of the reactor, the facility was designed using a horizontal ground acceleration of 15% of gravity at foundation level, and a corresponding vertical ground acceleration of 10% of gravity. It is not believed that this level of earthquake ground motion would be exceeded during the maximum potential earthquake. The magnitude of vertical ground motion was estimated on the assumption that vertical particle motions due to compressional waves have magnitudes of about one-half to two-thirds of the horizontal particle motions due to shear waves.

The SSE for the site is considered to be a shock similar to one of the following:

a. A shock equivalent to the Intensity VII, 1871 Wilmington earthquake as close to the site as its related geologic structure. This earthquake was probably a Magnitude 5. It is likely that this earthquake was related to faulting in the Piedmont west of the Fall Zone. However, since it is impossible to precisely locate the epicenter of this shock from the limited available data, and since the earthquake was felt in portions of the Coastal Plain, it was considered that the epicenter of this shock may have been located somewhat east of the Fall Zone.

b. A shock equivalent to the Intensity VII northern New Jersey earthquake of 1927 occurred close to the site. This shock occurred in the Coastal Plain and has not been related to known geologic structure. Therefore, the conservative assumption was made that it could occur along a hypothetical geologic structure in the basement rock near the site. This earthquake was probably about a Magnitude 5 to 5-1/2.

c. A shock equivalent to the Intensity IX Charleston earthquake of 1886 recurring at or near the original epicenter. An Intensity IX (Magnitude 7)

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[a] Earthquake magnitudes in this section refer to the magnitude scale developed by Dr. C. F. Richter. The magnitude scale is a means of indicating the size of an earthquake based on instrumental records. The magnitude scale is further described in Section 2.6.8.

earthquake centered near Charleston, about 480 miles southwest of the site, would not be of significance at the site.

Based on the foregoing statements, the very conservative assumption has been made that the SSE would be a shock as large as Intensity VII (Magnitude 5 to 5-1/2) originating in the basement rock close to the site.

Although a later, independent evaluation of region seismicity performed in 1992 (in support of the Diesel Generator Project) identified more recent earthquakes than those presented here, these were not larger nor were they in different areas than those used to develop the original SSE basis.

2.6.5.4 Response Spectra

Ground motion response spectra are presented on Figures 2.6-4 and 2.6-5, Response Spectra-Operating Basis Earthquake (OBE) and Response Spectra-SSE, respectively. These spectra conform to the average spectra developed by Dr. G. W. Housner for the frequency range higher than about 0.33 CPS. These average spectra were originally presented in TID-7024 (Reference 5). The spectra presented herein are based on a later revision by Dr. Housner, presented for the H. B. Robinson Nuclear Power Plant of Carolina Power and Light Company (Reference 9). The spectra for frequencies lower than about 0.33 CPS were prepared utilizing data suggested by Dr. N. M. Newmark (Reference 7).

The spectra have been normalized to a horizontal ground acceleration of 8% of gravity for the OBE and 15% of gravity for the SSE.

The response spectra indicate the estimated response of a structure subjected to earthquake ground motion. The spectra are presented over a range of frequencies corresponding to the natural frequencies of the various structural elements and represent the maximum amplitude of motion in the various elements of the structure for typical degrees of damping.

The digitalized El Centro Earthquake (1940, East-West), normalized to a ground acceleration of 0.08g horizontally and 0.053g vertically, acting simultaneously, was used in the analysis of Category I equipment. See paragraph 5.1.3.2 for description of dynamic response spectra.

2.6.6 TSUNAMIS

The occurrence of tsunamis is infrequent in the Atlantic Ocean. Other than the tidal fluctuation recorded on the New Jersey shore during the Grand Banks earthquake of 1929, there has been no record of tsunamis on the northeastern United States coast. The earthquake of November 18, 1929, on the Grand Banks about 170 miles south of Newfoundland, resulted in a tsunami which struck the south end of Newfoundland, about 750 miles northeast of the Massachusetts Coast. This tsunami occurred at a time of abnormally high tide and resulted in some loss of life and destruction of property. The effect of this tsunami was recorded on tide gauges along the east coast of the United States as far south as Charleston, SC. A tidal fluctuation of approximately nine-tenths of one foot was noted at Atlantic City, NJ and Ocean City, MD (Reference 11).

The Lisbon earthquake of November 1, 1755, produced great waves which contributed heavily to destruction on the coast of Portugal. These waves were noticeable in the West Indies. It has been reported that the Cape Ann, MA, earthquake of November 18, 1755, caused a tsunami in Saint Martin’s Harbor in the West Indies. However, there is no record of tsunami occurrence along the east coast of the United States at this time, and it appears that the Saint Martin’s Harbor report actually refers to the tsunami caused by the

Lisbon earthquake, which occurred less than three weeks before the Cape Ann shock. Some tsunami activity has occasionally followed earthquakes in the Caribbean, but none of these was reported in the United States (References 4 and 10).

It is not believed that the site will be subjected to a significant tsunami effect. The maximum expected tsunami would result in only minor wave action, and the maximum expected storm wave effect, discussed in Section 2.8.3, Hurricane Tidal Effects, was a more critical factor in the design.

2.6.7 MODIFIED MERCALLI INTENSITY SCALE

The Modified Mercalli Intensity scale of 1931 is described in Table 2-40. The intensity scale is a means of indicating the relative size of an earthquake in terms of its perceptible effect. The intensities presented in this report indicate the damage caused by an earthquake at its epicenter.

2.6.8 RICHTER MAGNITUDE SCALE

Magnitude Scale is a means of indicating the size of an earthquake based on instrumental records.

Dr. C. F. Richter developed a magnitude scale which is based on the maximum recorded amplitude of a standard seismograph located at a distance of 100 kms from the source of a shallow earthquake. The magnitude is defined by the relationship $M=\log A - \log A_o$. In this equation, A is the recorded trace amplitude for a given earthquake at a given distance written by the standard instrument, and A_o is the trace amplitude for a particular earthquake selected as a standard. The zero of the scale is arbitrarily fixed to fit the smallest recorded earthquakes. The largest known earthquake magnitude is on the order of 8-3/4. This magnitude is the result of observations and not an arbitrary scaling. The upper magnitude limit is not known, but is estimated to be about 9.

Empirical relationships between earthquake magnitude and energy release have been developed by several investigators (Reference 10). There is no exact relationship between earthquake magnitude and energy for large earthquakes, and these empirical relationships should be considered no more than approximations.

2.6.9 REFERENCES

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12. G.P. Woollard, 1958, Areas of Tectonic Activity in the United States As Indicated By Earthquake Epicenters, Transactions of the American Geophysical Union, Volume 39
13. Letter from R.E. Denton (BGE) to Document Control Desk (NRC), dated December 18, 1992, Emergency Diesel Generator Project-Civil Engineering Design Report

TABLE 2-37

SIGNIFICANT EARTHQUAKES WITHIN 100 MILES OF THE SITE

YEAR	DATE	TIME	INTENSITY	LOCATION	N. LAT.	W. LONG.	AREA FELT (sq. mi.)	DISTANCE FROM SITE (miles)
1733	June 14	--	[a]	Vicinity of Annapolis, MD	--	--	--	--
1758	April 24	--	[a]	Vicinity of Annapolis, MD	--	--	--	--
1774	Feb. 21	14:00	VI	Richmond, VA	37 1/2	77 1/2	--	80
1833	Aug. 27	06:00	VI	Central Virginia	37 3/4	78	52,000	90
1871	Oct. 9	09:40	VII	Wilmington, DE	39 3/4	75 1/2	--	100
1875	Dec. 22	23:45	VI	Near Richmond, VA	37 1/2	77 1/2	50,000	80
1876	June 19	--	[a]	Vicinity of Annapolis, MD	--	--	--	--
1879	Mar. 25	19:30	IV-V	Northern Delaware	39 3/4	75 1/2	600	100
1883	Mar. 11	18:57	IV-V	Harford County, MD	39 1/2	76 1/2	Local	80
	Mar. 12	00:00	IV-V	Harford County, MD	39 1/2	76 1/2	Local	80
1885	Jan. 2	21:16	V	Frederick County,	39 1/2	77 1/2	3,500	80
1897	Dec. 18	18:45	V	Ashland, VA	37 3/4	77 1/2	7,500	75
1906	May 8	12:41	V	Seaford, DE	38 3/4	75 3/4	400	45
1908	Aug. 23	04:30	V	Powhatan, VA	37 1/2	78	450	95
1919	Sept. 5	21:46	VI	Front Royal, VA	38 3/4	78 1/4	--	95
1930	Jan. 18	--	IV[a]	Pines of the Sermon, MD	--	--	--	--
1930	Nov. 1	01:34	I-III[a]	Anne Arundel County, MD	39.0	76.5	Local	--
1949	May 8	06:01	IV-V	Richmond, VA	37 1/2	77 1/2	1,800	80
1966	May 31	06:19	IV-V	Central Virginia	37.6	78.0	--	100

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[a] Several small shocks in Maryland are included in this table. Little information is available regarding these reports, and the indicated epicenters are uncertain. See text of report for discussion.

TABLE 2-38

GEOPHYSICAL DATA

STATION	SURFICIAL SEDIMENTS (PLEISTOCENE) COMPRESSIONAL WAVE VELOCITY (fps)	THICKNESS (ft)	UNCONSOLIDATED SEDIMENTS (TERTIARY) COMPRESSIONAL WAVE VELOCITY (fps)	THICKNESS (ft)	INTERMEDIATE SEDIMENTS (CRETACEOUS)[a] COMPRESSIONAL WAVE VELOCITY (fps)	THICKNESS (ft)	BASEMENT ROCK COMPRESSIONAL WAVE VELOCITY (fps)	DEPTH (ft)
Solomons Shoal[b]	--	--	5900	3080	--	--	15,170	3130
Solomons Deed[b]	--	--	6080	1070	6980	1900	18,100	3080
Site[c]	2200	40	5500	--	--	--	--	--
Site[c]	--	--	5900	--	--	--	--	--

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[a] These measurements refer to a "masked" arrival and the results are questionable.

[b] Adapted from Ewing and Worzel (Reference 3).

[c] Measurements by Dames & Moore.

TABLE 2-39

SHOCKSCOPE TEST DATA

BORING	DEPTH (ft)	CONFINING PRESSURE (lbs/ft^2)	COMPRESSIONAL WAVE VELOCITY (fps)
DM-2	5	0	1,000
		2000	1,200
		4000	1,400
		6000	1,700
DM-9	15	0	1,200
		2000	1,300
		4000	1,500
		6000	1,700
DM-1	30	0	1,400
		2000	1,500
		4000	1,800
		6000	2,100
DM-10	68	0	2,600
		2000	2,600
		4000	3,200
		6000	3,200
DM-10	111	0	2,600
		2000	2,600
		4000	3,000
		6000	3,000
DM-10	156	0	1,800
		2000	1,800
		4000	1,900
		6000	1,900
DM-10	211	0	1,600
		2000	1,700
		4000	1,700
		6000	1,700
DM-10	256	0	2,100
		2000	2,100
		4000	2,200
		6000	2,200
DM-10	271	0	2,000
		2000	2,200
		4000	2,300
		6000	2,600

TABLE 2-40

MODIFIED MERCALLI INTENSITY (DAMAGE) SCALE OF 1931 (Abridged)

I.	Not felt except by a very few under especially favorable circumstances. (I Rossi-Forel Scale)
II.	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (I to II Rossi-Forel Scale)
III.	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel Scale)
IV.	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably. (IV to V Rossi-Forel Scale)
V.	Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel Scale)
VI.	Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight. (VI to VII Rossi-Forel Scale)
VII.	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motorcars. (VIII Rossi-Forel Scale)
VIII.	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed. (VIII+ to IX Rossi-Forel Scale)
IX.	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX+ Rossi-Forel Scale)
X.	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks. (X Rossi-Forel Scale)
XI.	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII.	Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown upward into the air.