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STUDY OF SEISMICITY AND EARTHQUAKE ENGINEERING IN THE LONG BEAC--ETC(U)  
APR 78 C R ALLEN N00014-67-A-0094-0026

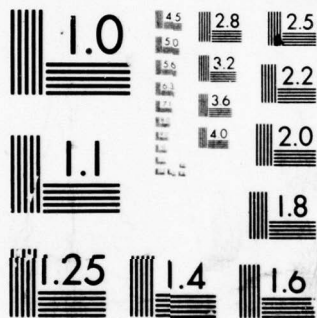
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9 FINAL TECHNICAL REPORT.  
1 Apr 1972 to 31 Jul 1975

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Contract Number: Office of Naval Research Contract No. N00014-67-A-0094-0026 ✓

Name of Contractor: *Source for this* Seismological Laboratory California Institute of Technology Pasadena, California 91125

Principal Investigator: 10 Clarence R. Allen Professor of Geology and Geophysics California Institute of Technology Pasadena, California 91125

Administered by: 15 N00014-67-A-0094-0026 Director Office of Naval Research Branch Office 1030 East Green Street Pasadena, California 91106

Title of Contract: 6 Study of seismicity and earthquake engineering in the Long Beach-San Diego coastal and offshore region, California.

Effective date of Contract: 1 April 1972

Contract Expiration Date: 31 July 1975

Amount of Contract: \$47,999.00

Date of Report: 11 15 Apr 1978

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## INTRODUCTION

Office of Naval Research Contract No. N00014-67-A-0094-0026 to the California Institute of Technology initially covered the period from 1 April 1972 to 31 March 1973. Although originally proposed as a 3-year effort, we were notified as of 13 January 1973 that owing to budget difficulties, we would have to request a no-cost extension to 31 July 1973 with hope of a renewal following that time. The second-year contract was not finally approved -- at a reduced rate -- until late March 1974. Although this renewal was retroactive to 31 July 1973, only limited work was possible prior to its expiration date of 31 July 1974, and a no-cost extension was requested and approved to 31 July 1975. Partly because of these circumstances, CIT chose not to request a third-year renewal. This report covers the entire period from 1 April 1972 to 31 July 1975, during which time the total ONR funds allocated to this project at CIT amounted to \$47,999. Many of the initial year's results have already been summarized in the renewal proposal dated 24 September 1973.

The purpose of the study was "to determine better the seismicity of the Long Beach-San Diego coastal and offshore area, and thus the seismic hazard, and to develop a more complete understanding of the engineering response to earthquakes of soils and structures of particular interest to the Navy." In addition, funds were added to the contract by ONR to cover expenses of the "ONR Natural Hazards Review Panel," which was asked to recommend courses of action for the Navy with regard to the seismic exposure of Naval facilities. This Panel, under the Chairmanship of Dr. H. Bolton Seed and including the present reporter, submitted its final report to the ONR on 1 January 1974, "General review of seismic

hazard to selected U. S. Navy installations," and will not be further considered herein.

The principal CIT effort under the contract was divided into two tasks: (1) a study of the seismicity of the offshore area, under the supervision of C. R. Allen, and (2) the emplacement of strong-motion accelerographs in sites of specific engineering interest to the Navy, under the supervision of D. E. Hudson. Partly because of the confusion and misunderstandings concerning renewal of the initial contract, Hudson chose to terminate his effort at the end of the first contract year, and unspent funds of about \$8500 were transferred to the seismicity task, with ONR cognizance. The present report, by C. R. Allen, thus concerns itself mainly with the seismicity studies. During the first year, two strong-motion accelerographs were purchased and were installed by CIT at Los Alamitos Naval Air Station and Seal Beach Naval Weapons Center. To our knowledge, these instruments are still operational and are being routinely serviced and maintained by the U. S. Geological Survey. They do not, of course, record minor continuing seismic activity in the same way as a sensitive seismograph station, but their value will be realized at times of larger felt shocks.

#### FIRST YEAR'S RESULTS

The principal seismological objective for the first year (budget: \$12,789) was to establish telemetry to Caltech from a sensitive seismograph station at Camp Elliot, near San Diego (CPE, Fig. 1). This station, then operated by the University of California at San Diego as an on-site photographically recording station, was critical to the determination of offshore seismic activity, as was explained in the original proposal. The necessary electronic equipment was purchased,

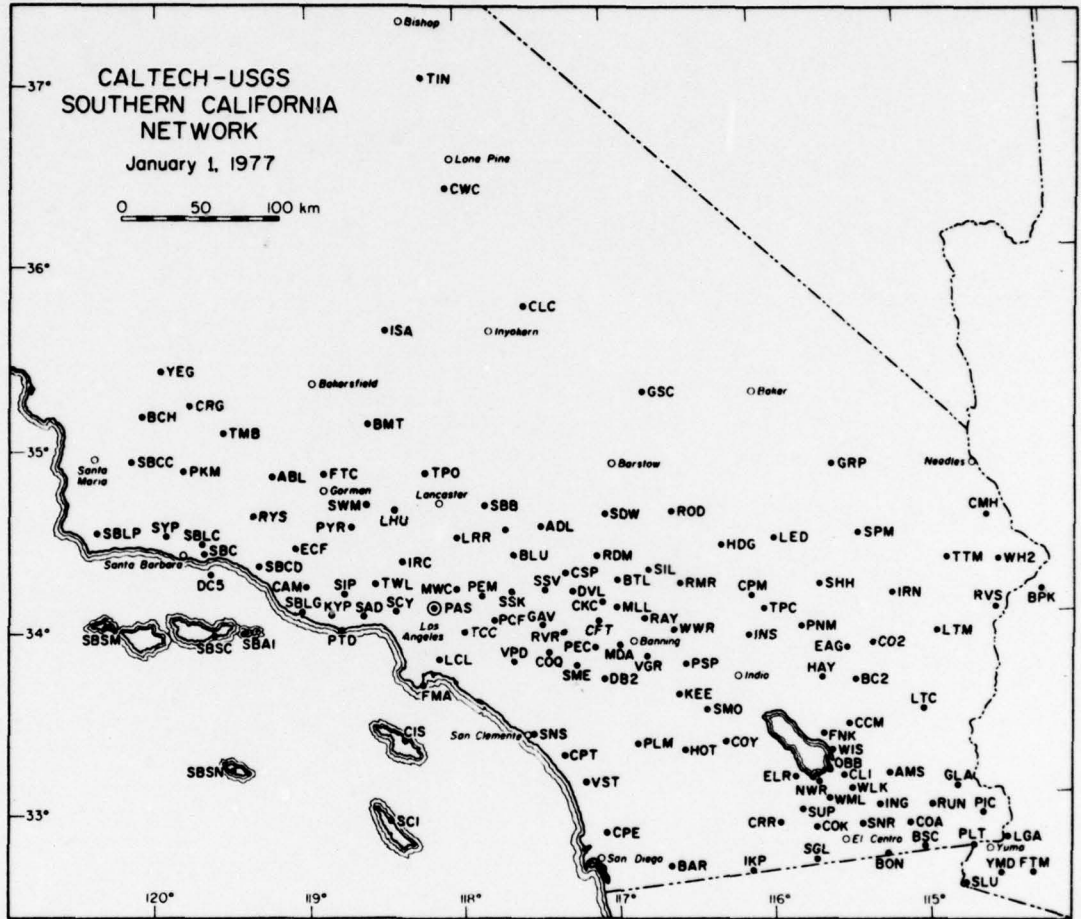


Fig. 1--Seismographic stations of the Southern California Network, as of 1 January 1977. Most of these stations continually telemeter seismic signals to the Seismological Laboratory in Pasadena on leased telephone lines.

and telemetry from Camp Elliot to Pasadena commenced on 16 November 1972, with an immediate improvement in our ability accurately to locate earthquakes in the offshore area. Critically important also was an earlier-established station on San Clemente Island (SCI, Fig. 1), whose telemetry costs were at that time supported by the Geological Survey. Because of delays by the Pacific Telephone Company in establishing the Camp Elliot-Pasadena circuit, first-year funds allocated to leased-line rental were available to help maintain telemetry during the no-cost extension period that followed.

A small proportion of the budget was also for data analysis, to aid in the Seismological Laboratory's measuring-room operation and in the production of the yearly earthquake catalogs that are the ultimate basis of seismic-risk determinations. In addition to the ONR, other groups that were contributing to this operation at that time included the Air Force, Geological Survey, National Science Foundation, National Oceanic and Atmospheric Administration, State of California, and Caltech itself. The results of this collaborative effort are given in Friedman, et al., 1976, "Seismicity of the southern California region, 1 January 1972 to 31 December 1974," copies of which are appended to the present report and should be considered part of it. It should be noted that the U. S. Navy is specifically acknowledged on page 2.

#### SECOND YEAR'S RESULTS

Funds for the second-year renewal only became available toward the end of the proposed renewal year, so the results reported in this section basically cover the 2-1/3 period from the end of the first contract year on 31 March 1973 to the end of the no-cost extension on 31 July 1975.

A principal objective during the second year was to establish a new telemetered seismographic station midway between Long Beach and San Diego, specifically in the Camp Pendleton area. Because of a number of small earthquakes that occurred at about this time near the San Onofre nuclear power generating facility, on the north border of Camp Pendleton, the Nuclear Regulatory Commission evidenced a sudden interest in the area, and funds were obtained from the NRC to establish a CIT station at San Onofre (SNS, Fig. 1). The ONR funds were then used to establish a station near the southern border of Camp Pendleton, essentially splitting into thirds the interval between San Diego and Long Beach. The ONR-supported station, at Vista (VST, Fig. 1), commenced telemetry to Pasadena on 28 January 1975, and leased-line rental was covered by contract funds until their exhaustion. A photograph of the Vista station vault is shown in Fig. 2, copies of which were earlier sent to J. G. Heacock. Subsequent to the establishment of Vista, a station was established with Marine Corps help midway between VST and SNS, but this station (CPT, Fig. 1) is an ink-writing station that is not part of the telemetered network and therefore of somewhat limited value.

In the renewal proposal, we had attempted to obtain funds for the telemetry from San Clemente Island (SCI, Fig. 1), because we had lost Geological Survey support at that time for this link. The ONR also was unable to give us such support, but we were subsequently successful in obtaining funds from the Western Oil and Gas Association for this project. Thus by the beginning of 1975, we were in relatively good shape to monitor earthquake activity in the offshore area, and epicenter maps since that time are much improved in accuracy for this region.

During the second year, the contract continued to support telemetry

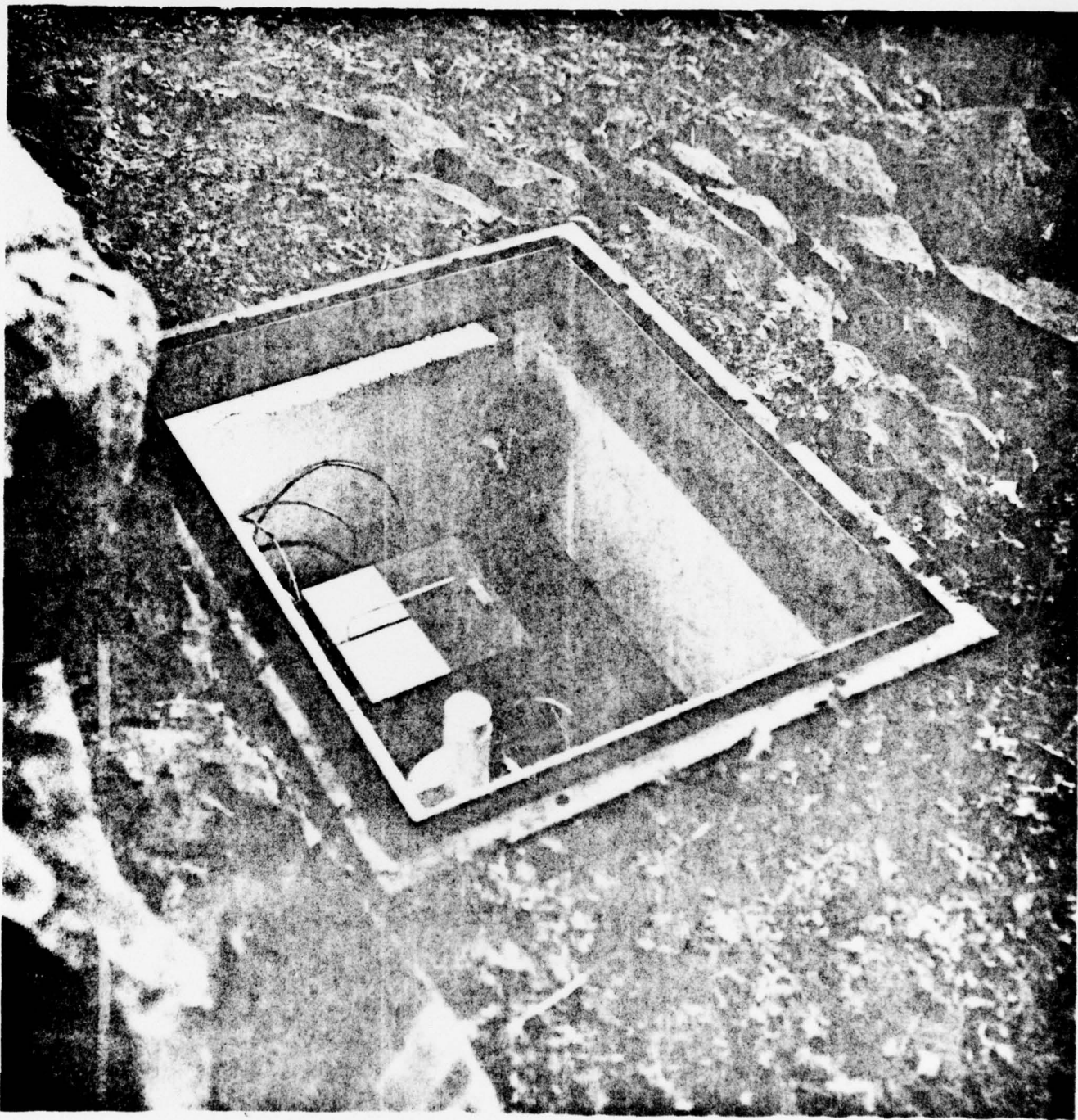


Fig. 2--Seismometer vault of ONR-financed seismographic station near Vista, California. Ranger seismometer is in near corner of vault; above it is the amplifier and voltage-controlled oscillator. Power is supplied by batteries recharged by solar panel mounted on nearby telephone pole. The FM multiplexed signal is transmitted to Pasadena on leased-line telephone circuitry.

costs from the station at Camp Elliot, in addition to the new station at Vista, and a contribution was made to the data-analysis costs at Pasadena (e.g., shared computer maintenance costs, 1/8 time of a seismological assistant, graduate-student research support).

#### SUBSEQUENT DEVELOPMENTS

Subsequent to termination of ONR support, U. S. Geological Survey support to the CIT network has gradually increased, so that the entire 160-station array is now known as the Caltech-USGS Southern California Network. Most of the Geological Survey interest has, however, been in instrumenting areas along the San Andreas fault. Furthermore, in our opinion, the installations by Caltech -- such as the ONR-supported installation at Vista -- are markedly superior in instrumental quality to those of the Geological Survey, particularly in the frequency response of the seismometers. In any event, our present capability to detect and locate earthquakes in the San Diego-Long Beach offshore area is critically dependent on stations that were initially supported by the ONR.

At the moment, support for operation of the southern California network comes from the following groups: Caltech, U. S. Geological Survey, State of California (Division of Mines and Geology), National Aeronautics and Space Administration, and the Earthquake Research Affiliates (a group of private donors to Caltech).

#### SEISMICITY OF THE COASTAL AND OFFSHORE AREA

Figure 3 shows the epicenters of all earthquakes located by Caltech in the offshore area between 1 January 1972 and 12 April 1978. This time interval includes, of course, the entire ONR contract period, as

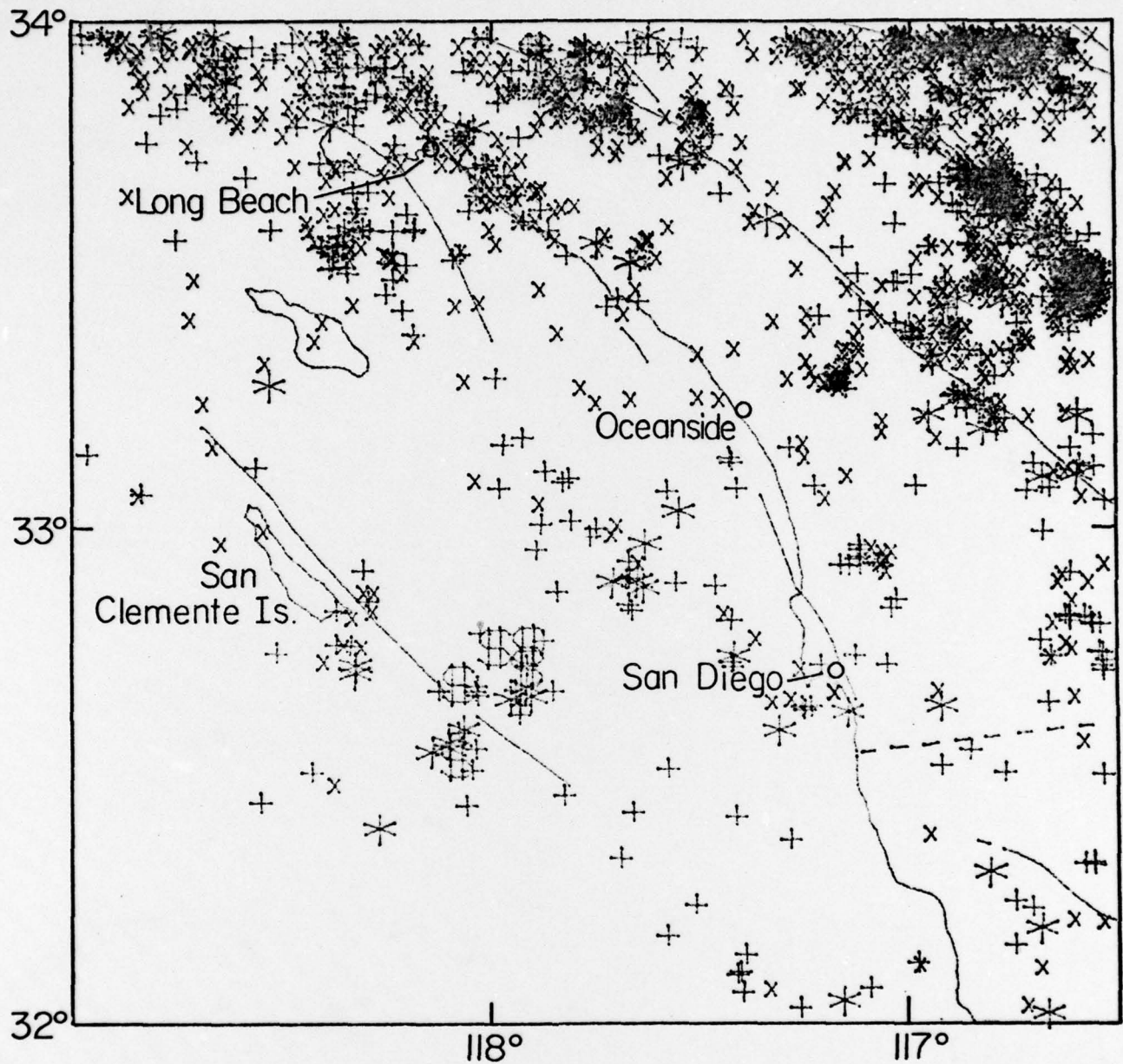


Fig. 3--Epicenters of earthquakes in the San Diego-Long Beach coastal and offshore area, 1 January 1972 to 12 April 1978. Symbols indicate magnitudes of earthquakes, as follows:

○	4.0 and larger
*	3.0 to 3.9
+	2.0 to 2.9
x	less than 2.0

well as the subsequent time. Not all epicentral locations have the same degree of accuracy, owing to a number of factors including the gradual ONR-supported improvement in the network capabilities during this interval. Larger events of earlier years, back to 1932, are plotted on Figure 7 of the accompanying 1972-1974 catalog.

Virtually everything we know about the seismicity and seismic hazard of southern California comes from the recordings of the Caltech Seismological Laboratory, in addition to the sparse historic record of earthquakes felt prior to the time of the Laboratory's first seismographic recording in 1926. In this sense, the ONR contract has directly helped to build the data base upon which our seismic-hazard evaluations are based, and the U.S. Navy -- along with a number of other organizations that are acknowledged in our catalogs -- can claim credit for making such evaluations possible. As was specifically pointed out in our original ONR proposal (p. 2), "such [seismicity] information cannot be directly translated into the determination of seismic hazard, but it represents one of the building blocks upon which an understanding of long-term seismicity must be founded."

Our data base is still too short to allow many definite conclusions concerning the seismicity of the San Diego-Long Beach coastal and offshore seismicity, but the following paragraphs summarize our current tentative thoughts about the seismicity of the region.

(1) Over the entire history of the Seismological Laboratory, the seismicity of the San Diego-Long Beach coastal and offshore area has been somewhat lower than the average for southern California as a whole, although still quieter blocks bound it on both the northeast (onshore) and southwest. We cannot be sure, of course, that this 46-year period is

representative of the long-term seismicity, but we presently have no reason to believe otherwise. The recent ONR-supported improvements in seismic detection capability for the region have not changed this evaluation.

(2) Despite the relatively low average seismicity, moderately large earthquakes can and have occurred occasionally in this region, most notably the 1933 Long Beach earthquake ( $M = 6.3$ ). Furthermore, the known geologic structure of the region reveals a number of long and continuous faults, such as the Newport-Inglewood and San Clemente faults, which must be regarded on geological grounds as capable of producing earthquakes possibly as large as magnitude 7 to 7-1/2.

(3) Since 1933, the largest earthquake recorded in the region was a magnitude 5.9 event on 26 December 1951 near the southeastern tip of San Clemente Island; this earthquake would have caused considerable damage in a populated area. Although the shock occurred in an area of many subsequent Navy-induced underwater explosions, we have no reason to think that this event was not natural. It probably occurred because of displacements on the San Clemente fault, which lies along the steep northeast face of the island and continues for many miles both to the northwest and southeast.

(4) Since the beginning of the ONR contract, the largest earthquake recorded in the offshore region was a magnitude 4.3 event on 12 January 1975, centered about 20 miles southeast of San Clemente Island -- possibly also on the San Clemente fault. Although not damaging because of its offshore location, it was felt from south of the international border to Los Angeles.

(5) The greatest cluster of contemporary activity in the offshore area

appears to be concentrated in the area southeast of San Clemente Island -- including 5 shocks of magnitude greater than 4.0 since 1972. This is also an area in which we are aware of a number of large underwater explosions detonated by the Navy during the same time interval. We are by no means sure that all of the events shown on Figure 3 in this area are in fact natural earthquakes.

(6) In some parts of California, improvements in seismic detectability have led to a tendency for epicenters to become strongly aligned along faults, whereas this correlation had not been obvious with the earlier and less precise data. Good examples have been in the San Francisco Bay area and in the Imperial Valley. For example, one can note the tendency of epicenters to be aligned along the Imperial fault (south of the Salton Sea) in Figure 6 of the accompanying 1972-74 catalog. We were thus particularly interested in seeing whether the improved seismic-detection capability in the offshore area would reveal heretofore unsuspected epicentral alignments along offshore fractures such as the Newport-Inglewood and San Clemente faults. To date we see only one suggestion of such an alignment -- not along the San Clemente or Newport-Inglewood zones, but instead along a parallel trend about half way between them. This alignment does not correspond to a particular single fault shown on the Geologic Map of California (1977), but it does lie in part along the San Diego trough and its steep southwestern escarpment (which presumably is fault controlled). Although the Newport-Inglewood fault has been the subject of considerable recent controversy because of its proximity to the San Onofre nuclear reactor, there is little suggestion of current activity along it in the offshore area. One certainly cannot jump to the conclusion that it is necessarily therefore "safe," however,

because a similar absence of aligned activity occurs along parts of the San Andreas fault that we consider particularly hazardous at the present time.

(7) Of particular concern in this study has been the problem of seismic hazards to San Diego, with its large concentration of Naval facilities. At the moment, we see no reason to alter the conclusions earlier submitted to the ONR by the ONR Natural Hazards Review Panel in its report of 1 January 1974, "General review of seismic hazard to selected U. S. Navy installations." The study was supported by this contract, and the following excerpt from the report was written primarily by the present reporter:

There is a feeling in some quarters that earthquake hazards in San Diego are considerably less severe than in other areas of California such as Los Angeles and San Francisco. There are several reasons for this apparent complacency, all of which need critical re-examination.

San Diego has never experienced in recent years a really damaging earthquake comparable to those that have hit parts of the other major metropolitan areas of the state. Most people have long forgotten major shaking associated with such shocks as that of 1892 (Intensity VII in San Diego). Seismologists now recognize that our short historic record in California is not a valid guide for estimating long-term seismicity, and the absence of major earthquakes in San Diego during the past 100 years is not necessarily a cause for great comfort for the future. Many people have referred to Allen et al. (1965) in pointing out that the San Diego block appears geologically and seismically stable as compared to adjoining blocks, although Allen et al. (1965) went on to emphasize that, even in the absence of numerous active faults in the San Diego area itself, nearby seismicity was sufficiently high so that seismic hazard from shaking in San Diego was probably not grossly different from that in most parts of Southern California. However, even the conclusion of Allen et al. (1965) concerning the relative geologic stability of the San Diego block itself has been shown in recent years to be at least

partially incorrect. For example, numerous breaks of late Quaternary age have now been documented by Artim and Pinckney (1973), Ziony and Buchanan (1972) and Moore (1973). Furthermore, it has been claimed that the Newport-Inglewood fault (locus of the 1933 Long Beach earthquake) is continuous with the Rose Canyon fault in La Jolla, and thence continues south through San Diego Bay and into Mexico (Wiegand, 1970; Moore and Kennedy, 1970). This extrapolation seems to be a matter of some controversy, but its significance is very great; a fault of this length and continuity could presumably generate a large earthquake squarely within the San Diego metropolitan area, with possible faulting directly through the Coronado bridge. Brune (1972) feels that a magnitude 6-1/2 earthquake within the San Diego area is a "risk that must be considered in conjunction with the risk from the possibility of moderate and large earthquakes at some distance."

Brune (1972) and McEuen and Pinckney (1972) have recently attempted to evaluate seismic risk in the San Diego area, and their papers should be read by interested parties. Based upon their work, as well as that of a number of other workers, our preliminary evaluation is as follows:

Although numerous Holocene faults have now been recognized in the San Diego area, neither their lengths nor their apparent degrees of activity suggest that they are as pertinent to the evaluation of seismic hazard as are the offshore faults to the southwest, and the members of the San Andreas system to the northeast. Ziony and Buchanan (1972), for example, state that along both the Rose Canyon (Newport-Inglewood?) and La Nacion faults, topographic features such as sag ponds or well-defined scarps, which are commonly associated with Holocene faulting elsewhere in Southern California, have not been observed. Furthermore there is considerable doubt concerning the continuity of the Newport-Inglewood fault through the San Diego Bay area and into Mexico, although assuredly this question is so important that the Navy--of all groups--should be supporting research work to demonstrate its presence or absence.

Of perhaps greatest concern in a practical sense are the faults offshore from San Diego to the southwest. The Coronado escarpment, 25 km southwest of North Island, is one of the major fault-produced escarpments of the continental borderland (Emery, 1960; Moore, 1969), and it is probably a continuous feature with the Agua Blanca fault of

Baja California (Allen, Silver, Stehli, 1960). The Aqua Blanca fault shows fresh topographic features of faulting comparable to those of the San Andreas, and it is a likely locus of the 1892 earthquake ( $M = 7-1/2+?$ ). Furthermore, the offshore area near the Coronado escarpment has been a region of moderate seismic activity over the years, and gradual improvements in our seismic networks (such as those now being supported in this area by the ONR) will help to pinpoint the specific active features. Even farther offshore is the San Clemente Island fault zone, which is 65 km southwest of North Island. A magnitude 5.9 shock occurred on this fault near San Clemente Island in 1951. Certainly a shock of magnitude 7 is a reasonable event on either of these faults. McEuen and Pinckney (1972) assign a magnitude of 7.7 to the "maximum credible earthquake" on the San Clemente Island fault. The assignment of a specific probability to such an event, however, is beyond our capabilities at the present time; any estimate based on recorded seismicity during the past 40 years would be founded on such minimal statistics as to be almost meaningless. An educated guess--based on the regional geology and its comparison with other similar areas--would indicate that a magnitude 7 earthquake might occur on one of these two faults in the area opposite San Diego perhaps once every 200 years.

Also of significance to the seismicity of the San Diego area are the active faults of the San Andreas system to the northeast, the closest principal branch of which is the Elsinore fault at a distance of 65 km. A magnitude 6 earthquake in 1910 was probably centered on the Elsinore fault, but in general, it does not appear as active either geologically or seismically as is the San Jacinto fault still farther east. Earthquakes similar in magnitude to those on the off-shore system are certainly possible, but it seems likely that the off-shore faults are more active. In a recent evaluation of the seismicity of the Mt. Palomar Observatory area (70 km northeast of San Diego and 7 km east of the Elsinore fault), Allen and Hanks (1973) estimated that a magnitude 7+ earthquake might occur within 50 km of the Observatory once every 140 years, but the chances are higher that this earthquake would be east of the Observatory (on the Agua Tibia, Agua Caliente, or San Jacinto faults) rather than on the Elsinore fault itself. Major earthquakes on the San Jacinto fault zone occur rather frequently, but

its distance from San Diego (100 km) is sufficiently great that closer but less frequent shocks are probably of greater design importance for critical structures in San Diego. McEuen and Pinckney (1970) calculate that the maximum probable earthquake on the Elsinore fault in a 60-year period is a magnitude 7.3 event, although this is questionable since it is based on an extrapolation from the far-more-active Imperial Valley area.

On the basis of the preceding review of the geology and seismicity of the San Diego area, it seems reasonable to believe that the effects of the following types of earthquakes should be considered in the design of important engineering facilities in the area:

- (a) A magnitude 7 shock occurring about 15 miles from San Diego in the Coronado escarpment.
- (b) A magnitude 7+ earthquake occurring on the Elsinore fault.
- (c) A magnitude 6-1/2 earthquake occurring within the San Diego area itself.

In addition, there is some possibility of a major fault extending through San Diego Bay.

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