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ENGINEERING FEATURES OF THE SANTA BARBARA EARTHQUAKE of August 13, 1978

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16. Abstract (Limit: 200 words)
Several features of the Santa Barbara earthquake were unusual and interesting from an engineering point of view: the geographical asymmetry of strong ground shaking; the large peak accelerations recorded by strong motion instruments; and the differences in reported magnitudes for the event. This earthquake also provided a picture of the performance of modern California buildings in a moderate earthquake. Preliminary investigations of some of these features are presented in this report. None of the hospitals, fire and police stations, or public schools in the area of the strong shaking received serious damage. An emergency power supply system fueled by natural gas was activated at the Goleta Valley Community Hospital. If the earthquake had severed the gas lines, however, the system would not have been functional. Emergency systems should not rely on public utilities. An area where public school safety could be improved is in anchoring of acoustical ceilings to prevent their collapse, and in using fasteners to lock light fixture diffusers positively in place. Wood and steel structures generally sustained less severe damage than concrete and masonry structures, although some well-designed reinforced concrete structures survived with no apparent damage. The most common form of structural damage sustained by multistory buildings consisted of diagonal cracking of shear walls, particularly those aligned along the north-south direction and in the lower stories.

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1. GENERAL FEATURES AND SUMMARY

At four o'clock in the afternoon on Sunday, August 13, 1978, an earthquake struck near the Southern California coastal community of Santa Barbara, which is approximately 160 kilometers northwest of Los Angeles (Fig. 1.1). The earthquake was centered in the Santa Barbara Channel 5 to 8 kilometers south of downtown Santa Barbara. The resulting ground motion displayed a marked directional asymmetry which had an important bearing on measurements and overall effects of the earthquake. This asymmetry resulted from primarily thrust faulting which began at the epicenter and propagated west-northwest toward the neighboring community of Goleta for a total length of about 8 kilometers. Seismometers in Southern California reported a Richter magnitude of 5.1 for the event, while instruments in Northern California reported 5.7.

The most intense ground motion occurred in the Goleta area (about 16 kilometers west of Santa Barbara) between Turnpike Road and Winchester Canyon Road (Fig. 1.2). Within this area much of the damage occurred at the campus of the University of California, Santa Barbara (UCSB), which is actually located in Goleta, as shown in Fig. 1.2. The terminus of the rupture may have been as close as 4 kilometers from the campus. A U.S.G.S. investigator assigned a Modified Mercalli intensity of VIII to the community of Isla Vista which borders the campus, and VII to downtown Santa Barbara. The California Division of Mines and Geology reported a maximum Modified Mercalli intensity of VII near the campus. Strong motion instruments recorded a peak ground acceleration of about 0.45g on the campus, and about 0.21g in downtown Santa Barbara. The duration of strongest shaking was about 2 to 3 seconds.

About 65 persons required treatment for injuries caused by the earthquake, but there were no fatalities. Most of the injuries occurred in the Goleta area where 54 patients were treated as emergency cases at Goleta Valley Community Hospital. In Santa Barbara, 10 patients received emergency treatment at Cottage Hospital. The most serious injury was a broken back which resulted when a person fell while taking a shower. Other serious injuries included second and third degree burns from scalding water, and many cases of cuts and lacerations from broken glass. Most patients complained of injuries to the back, neck, and face, and most were able to drive or walk to the hospital. Many of the minor injuries occurred in grocery and liquor stores in Goleta.

Transportation facilities received the most obvious immediate effects of the earthquake. Several rock slides blocked traffic on San Marcos Pass (State Highway 154) in the steep mountains behind Santa Barbara, leaving motorists stranded but uninjured. About 10 minutes after the earthquake, a north-bound freight train was derailed near the intersection of U.S. Highway 101 and Hollister Avenue (Fig. 1.2). The derailment sent a set of train wheels across the south-bound lane of the highway into the divider strip. The derailment resulted from fill failure and involved 30 train cars, but no one was injured. (It is likely that many people would have been injured had the derailment occurred to the Amtrak passenger train which was scheduled to come through later that afternoon.) At the Santa Barbara Municipal Airport, a power failure affected the runway lights and passenger terminal, but

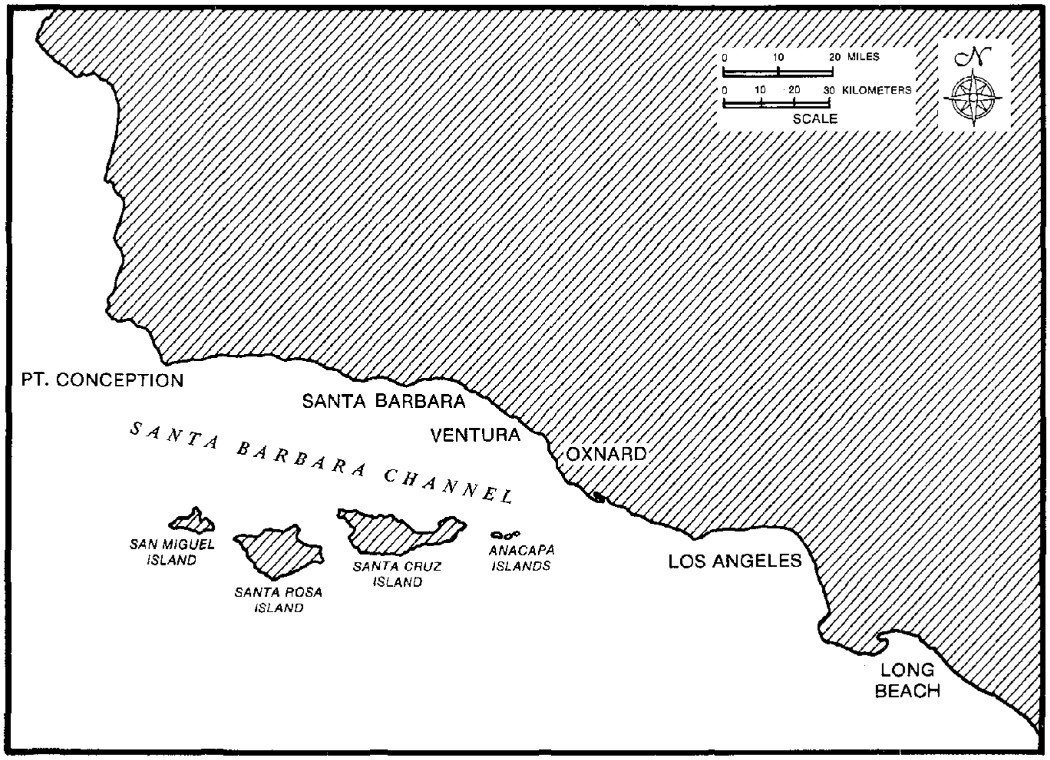

Fig. 1.1 The Southern California Coastline and the Santa Barbara Channel.

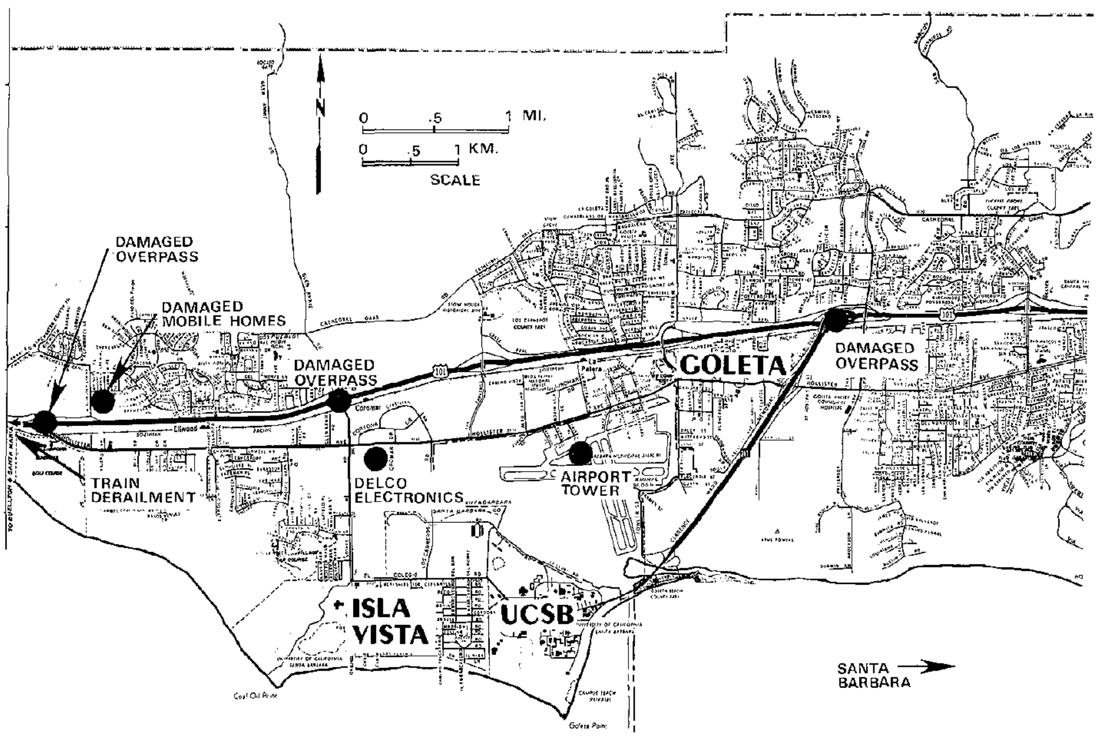

Fig. 1.2 Map showing earthquake damage in Goleta, 16 km west of Santa Barbara (Copyright Automobile Club of Southern California. Reproduced by permission).

the control tower (which sustained significant structural damage) continued to operate on backup power. Minor structural damage was sustained by 4 highway overcrossings in the area (one of which was closed temporarily for inspection), but U.S. Highway 101 (the major coastal route) remained open in both directions.

In the residential community of Goleta, 324 mobile homes were damaged by the earthquake. Many of these homes were knocked from their pedestal foundations and fell to the south, rupturing gas, water, and electrical connections in the process. Four such homes were rendered uninhabitable, and one was destroyed by fire which resulted from a gas leak. By comparison, relatively minor damage was received by conventional residential housing, with cracked plaster, broken glass, and loosened plumbing to hot water heaters being the most common type of damage.

At the UCSB campus several of the multistory reinforced concrete structures received moderate diagonal cracking of the shear walls in the lower stories. Some of the rooftop mechanical equipment on campus was severely affected, and instruments and supplies were destroyed in some laboratories. Damage to light fixtures, ceilings, and plaster occurred throughout the campus. Approximately one-third of the UCSB library's 1.2 million volume collection spilled onto the floor, but the book shelves, which were braced at the top for lateral support, did not fall. Similar but generally less severe damage occurred in the commercial district in Goleta (which has no high rise buildings), and in the Santa Barbara area (where ground motion was less intense).

The total financial loss caused by the earthquake is estimated to be $7.31 million, of which $4.95 million in damages was sustained by public buildings and facilities, and $2.36 million in the private sector. These figures are based upon surveys conducted by the County Emergency Services Coordinator and the Federal/State Damage Assessment Team, with revisions to reflect current estimates of the damage to the UCSB campus.

Of the $4.95 million in damages sustained by the public sector, $3.44 million was sustained by facilities at the UCSB campus. (Goodspeed, 1978). Included in this figure are $3.14 million in damages to buildings, elevators, and utilities, and an additional $300,000 to departmental equipment, chiefly laboratory supplies.

Of the $2.36 million in damages to the private sector, $1.62 million was sustained by mobile homes in the area. It was reported that 1 such home was destroyed, 219 received major damage, and 104 received minor damage. It was also reported that about 80 percent of the mobile homes damaged or destroyed have insurance coverage. The remaining $740,000 in damages to the private sector were attributed to minor damage to 148 businesses. It is noteworthy that 68 of these 148 businesses were apartment buildings with an average of 6 units each. Many of the remaining damaged businesses were stores, and very few of these stores had earthquake insurance to cover their losses. No major damage to conventional residential houses was reported, and no reliable estimate of the financial loss is available (Buck and Baird, 1978).

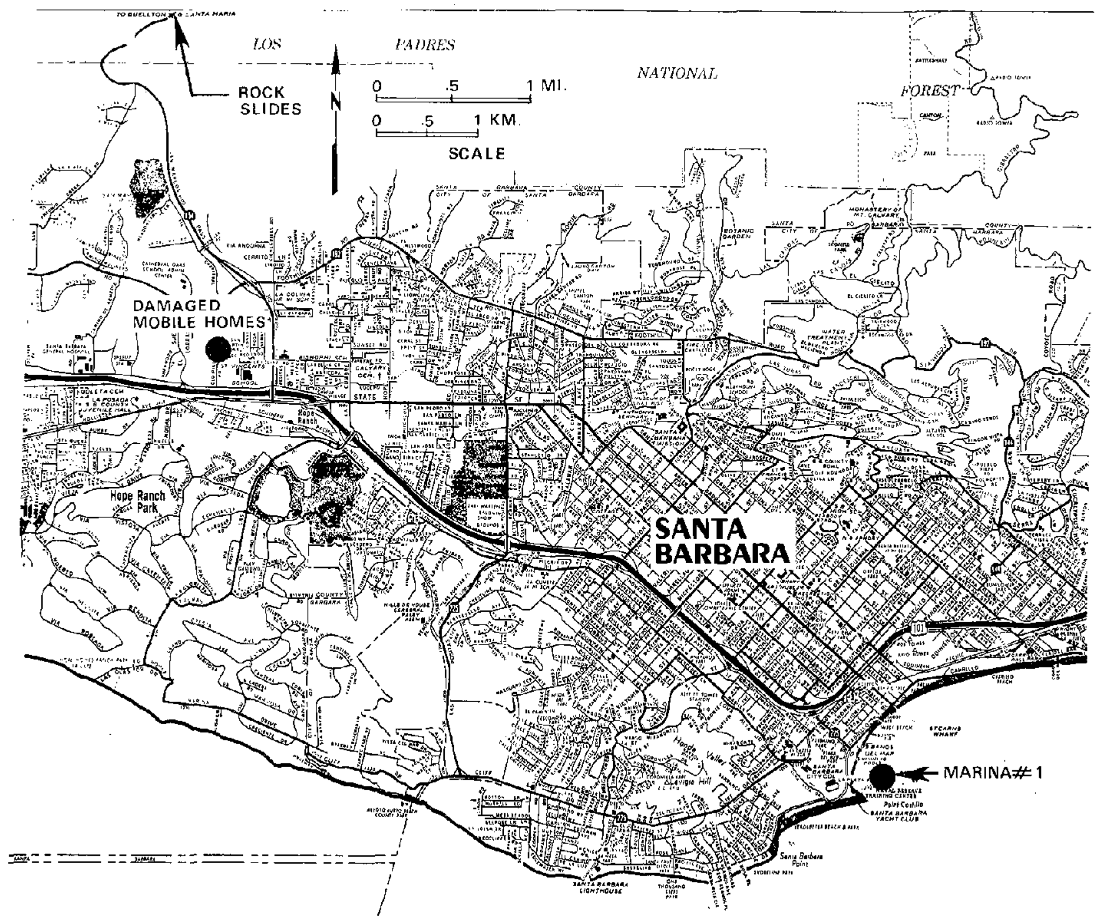

Fig. 1.3 Map showing earthquake damage in Santa Barbara (Copyright Automobile Club of Southern California. Reproduced by permission).

The Southern Pacific Railroad Company reported about $500,000 in damages due to the train derailment. The California State Department of Transportation (Caltrans) reported $200,000 in damages to highway overpasses. Southern California Edison Company and Southern California Gas Company reported $35,000 and $6,000 in damages, respectively. General Telephone Company reported no significant damage. Santa Barbara City College and the public schools in the area received only minor damage and reported no financial estimate of the loss. However, the St. Vincent Residential School for Disabled Children, a private school, reported $200,000 in non-structural damage. Facilities of the County of Santa Barbara received about $500,000 in damages and an additional $136,000 was sustained by facilities of the City of Santa Barbara, including $30,500 at the Marina and $25,000 at the Municipal Airport.

Details of the geological features, strong motion records, and effects of the earthquake on the various facilities in the area will be presented in the following chapters. Of particular seismological interest is the apparent asymmetry of the earthquake and the large peak ground accelerations recorded in Goleta. Of particular engineering interest is the general performance of modern California buildings during a moderate earthquake, and in particular the performance of North Hall on the UCSB campus, which is a well instrumented 3 story rehabilitated structure which received peak structural accelerations of nearly 1g at the roof.

2. GEOLOGIC FEATURES

2.1 Regional Structural Setting

A report by the U.S. Geological Survey (1976) described the regional structural setting of the Santa Barbara Channel as follows:

> The Santa Barbara Channel is the seaway that occupies the submerged western part of the Transverse Ranges province of Southern California. Throughout that province, the major folds and faults generally trend east-west (Fig. 2.1), as do the metamorphic fabric of pre-Cretaceous basement rocks, and the fabric and petrochemical trends of the late Mesozoic batholithic rocks of the province (Baird and others, 1974). In some parts of the province, east-west structural trends may have controlled the orientation of sedimentary deposits of early Tertiary age. For example, thick Eocene sandstones in the Santa Ynez Mountains may have accumulated in south-flowing fans from an east-west-trending high area to the north (Stauffer, 1965). In other parts of the province (for example, the Santa Monica Mountains-Simi Hills area), northerly trends may be inferred for the shorelines and isobaths of sedimentary environments of Late Cretaceous through early middle Miocene age (Yerkes and Campbell, 1971) and east-west structures controlling depositional environments are not clearly evident prior to late middle Miocene time. Also about late middle Miocent time the Ventura Basin, whose Paleogene ancestry is indistinct, became an important basin of deposition. Great thicknesses of marine sediments accumulated in this rapidly subsiding narrow trough from late Miocene through early Pleistocene time. These basin strata have been folded and faulted along east-west structural trends by north-south compressive stresses, beginning in mid-Pleistocene time. Tectonic deformation continues to the present, as indicated by the historic seismicity of the region, geodetic measurements of differential vertical movement, and the evidence of deformed Holocene beds and geomorphic features (section II.B.6).

2.2 Seismicity and Earthquake History

The Santa Barbara Channel is one of the more seismically active areas of California (Allen and others, 1965; Lee and others, 1978), and one great earthquake ($M \cong 8$) is believed to have occurred there in 1812. Moreover, the channel has been a region of great tectonic activity throughout the last 65 million years (Hamilton and others, 1969). The historical seismic record shows that nearby areas have also experienced strong shocks, such as the Point Arguello earthquake of 4 November 1927 ($M = 7.5$).

Shown in Figure 2.2 is a graph of the average number of earthquakes per year in the eastern Santa Barbara Channel, for the period 1900-1970 (Sherburne, 1975). Four prominent peaks may be identified in 1925, 1941, 1950, and 1968. On 29 June 1925, a magnitude 6.3 earthquake

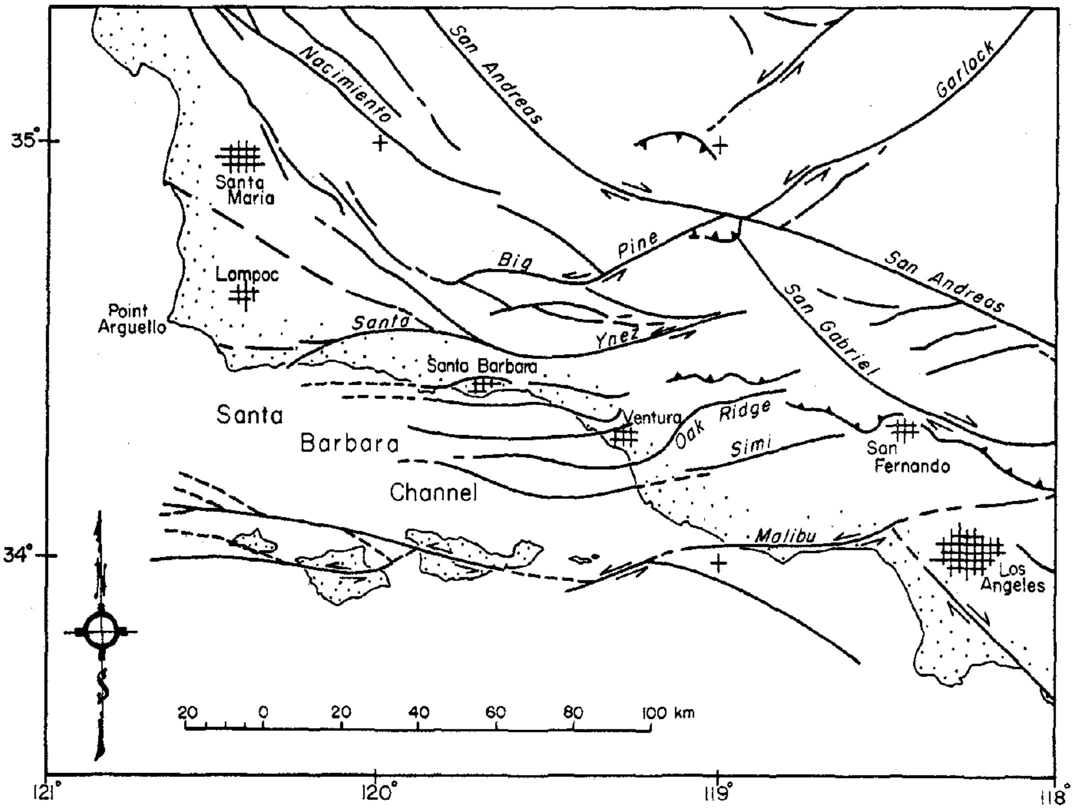

Figure 2.1 Index map showing the geometry of the principal east-west trending faults of the Transverse Range province and the northwest-southeast trending faults of the San Andreas system. (From Sylvester and others, 1970, with revisions).

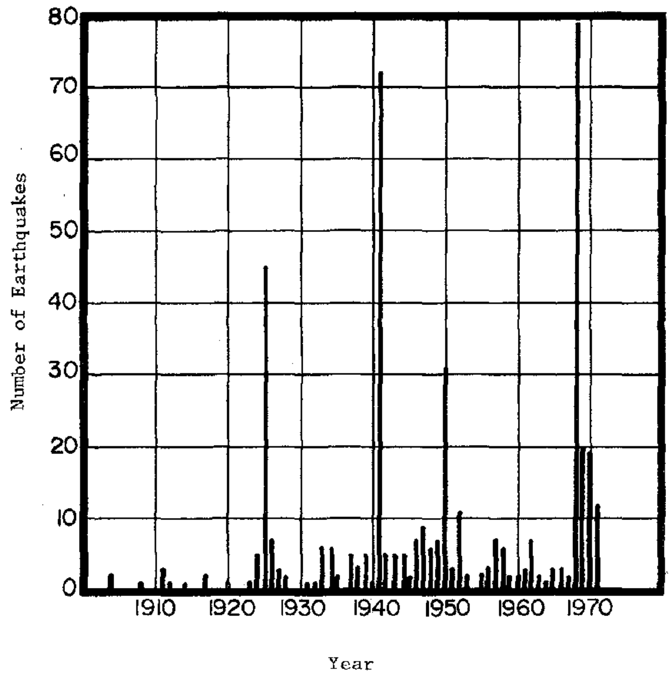

Fig. 2.2. The annual number of earthquakes in the eastern Santa Barbara Channel from 1900 to 1971. (From Sherburne, 1975).

occurred in the channel, and was followed by at least 40 aftershocks which were felt. On 30 June 1941, a magnitude 5.9 earthquake occurred in the channel and was followed by approximatey 60 aftershocks. The peaks in 1950 and 1968 resulted from earthquake swarms (Sylvester and others, 1970). An earthquake swarm also occurred in the channel in March and April of 1978.

Some basic data on the most important earthquakes which have affected the Santa Barbara Channel area are given in Table 2.1 (Olsen and Sylvester, 1975). The Kern County earthquake of 21 July 1952 also affected structures in the channel area (Steinbrugge and Moran, 1954).

2.3 Location, Magnitude, and Asymmetry of Ground Shaking

A few seconds before 3:55 p.m. (PDT) on Sunday, August 13, 1978, a moderate earthquake occurred in the Santa Barbara Channel approximately 5 to 8 kilometers south of the city of Santa Barbara. The lattitude and longitude of the epicenter have been reported as 34^{o} 22.2'N and 119^{o} 43.0'W, respectively (Lee and others, 1978). The focal depth was about 12.5 km ($\pm$ 3 km). The location of the epicenters of the main event and of the aftershocks which occurred within the first 20 minutes are shown in Fig. 2.3.

The resulting intensity of ground shaking was markedly asymmetrical, being much stronger to the northwest of the epicenter than to the south-east. This asymmetry is reflected in the reported Richter magnitudes for the event, with seismographic stations in the southern part of the state reporting about 5.1, and in the northern part about 5.7. Shown in Tables 2.2 and 2.3 are the seismographic data recorded in the southern and northern parts of the state, respectively. It is customary in seismology to assign a single magnitude value to an earthquake by averaging the values obtained at different locations. If this is done for the Santa Barbara earthquake an average magnitude of about 5.4 or 5.5 is obtained. However, it is clear from the spatial distribution of strong ground shaking in this earthquake that a single magnitude number does not give a reliable indication of the intensity of shaking. Similar asymmetry in intensity of motion has been observed in some past earthquakes and has been attributed to directional radiation of seismic waves. The explanation usually given is that when slipping starts at the hypocenter and progresses in one direction along the fault at a propagation velocity close to the shear wave velocity, the effect is analogous to that of a moving source. In such a case the amplitude of waves generated will be greater in regions in front of the moving source than in regions behind the moving source. Judging from the location of the eipcenter and the distribution of aftershocks shown in Fig. 2.3, it appears that the rupture initiated at the epicenter and propagated toward Goleta for a distance of about 8 kilometers. The earthquake had a markedly greater effect on the Goleta area than on Santa Barbara, even though Santa Barbara is closer to the epicenter. Hence the Santa Barbara earthquake appears to be an extreme example of this type of asymmetry.

Because of the differences in magnitudes recorded by Wood-Anderson torsion seismometers around the state, estimates of the local magnitude were calculated from seismoscope records obtained in the region of

TABLE 2.1 IMPORTANT EARTHQUAKES OF THE SANTA BARBARA CHANNEL AREA (Olsen and Sylvester, 1975)

Date	Maximum intensity of Modified Mercalli scale (MM) or Richter Magnitude (M)	Epicenter	Damage	Fatalities
12 Dec. 1812	X (?) MM. Believed to be 1 of the strongest earthquakes in California's history.	Santa Barbara Channel (tsunami waves perhaps up to 15 m high; inland flow in some narrow canyons up to 1 km.)	Destroyed Mission La Purisima (near present site of Lompoc). Severe damage to other missions in 150 km range.	None recorded
27 June to 12 Dec. 1902	VIII-IX MM at Los Alamos, 50 km northwest of Santa Barbara. At least 3 earthquakes of VIII MM felt at Los Alamos.	Undetermined.	Unusually widespread swarm of felt earthquakes which almost totally destroyed Los Alamos and drove the entire population away.	None recorded
29 June 1925	6.3 M	Not well located; believed to be in the Santa Barbara channel.	Estimates of damage range from $6 million to $20 million at Santa Barbara and outlying areas.	13
29 June 1926	VIII MM	Undetermined.	Aftershock (?) exactly 1 year after main 1925 Santa Barbara earthquake. Moderate damage.	1
4 Nov. 1927	7.5 M	On submarine fault west of Pt. Arguello. Generated a tsunami 1.5-2.5 m high near Pt. Arguello.	Slight damage.	None
30 June 1941	5.9 M	Approximately 10 km southeast of Santa Barbara.	Estimated $100,000 damage to downtown Santa Barbara and outlying areas.	None
Summer 1968	Swarm of 66 earthquakes greater than 1.5 M; maximum 5.2 M.	East-central part of Santa Barbara channel.	22 shocks felt in Santa Barbara-Goleta area in 6 week period. Estimated $12,000 damaged caused by 3 earthquakes greater than 4.2 M.	None

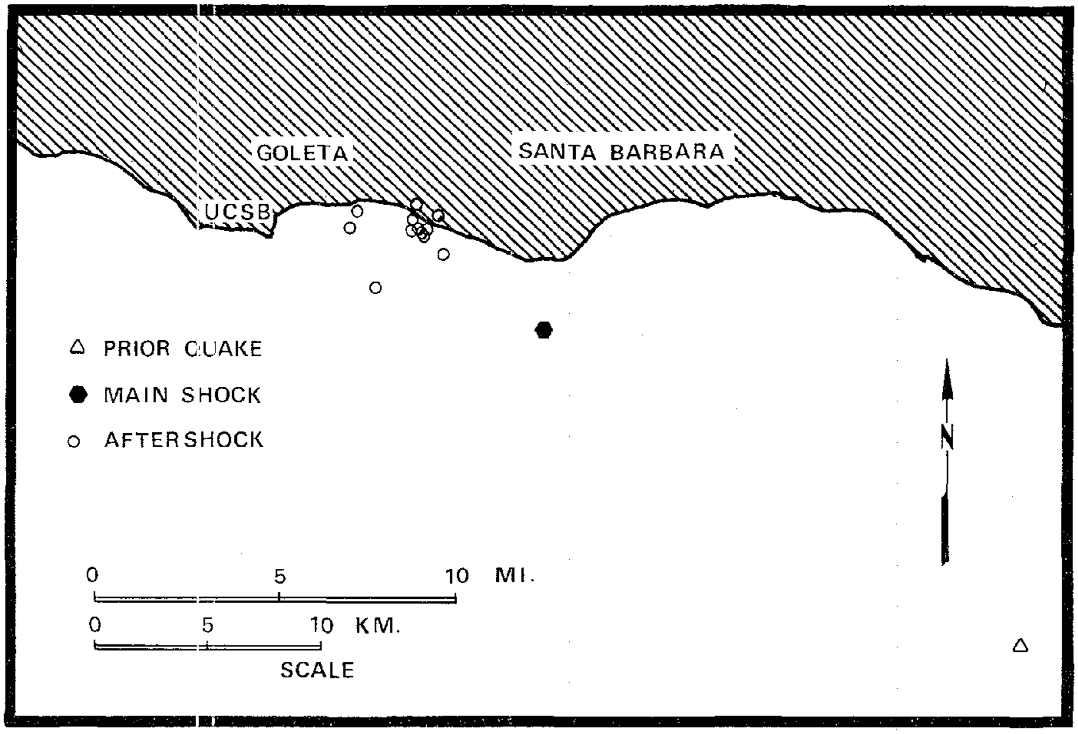

Fig. 2.3 Location of Epicenters of Preceding Earthquake, Main Event, and Significant Aftershocks within 20 minutes, 13 August 1978 (based on data reported by Lee and others, 1978).

strong shaking (Jennings, 1978). The two seismoscope records used for these calculations are shown in Figs. 3.15 and 3.16, and were recorded at Biological Sciences II, UCSB, and at the Santa Barbara County Courthouse (See Fig. 3.1 for building locations). The average local magnitude corresponding to the Courthouse record is 5.8, using either the distance to the eipcenter or to the center of the aftershock zone shown in Fig. 2.3. The UCSB record yields a local magnitude of 6.0 using the distance to the epicenter, and 5.9 using the distance to the center of the aftershock zone. However, as discussed in Chapter 3, it is likely that the UCSB seismoscope was struck during the earthquake by a falling door so that this magnitude estimate is subject to some uncertainty. These magnitude estimates seem consistent with the extent of damage to buildings reported in Chapter 7.

There are many faults in the vicinity of the epicenter in the Santa Barbara Channel which trend in the general direction indicated by the alignment of epicenters in Fig. 2.3. No confident identification has yet been made of the particular fault which was responsible for the earthquake.

An interesting feature of the earthquake is the fact that a small earthquake to the south and east preceded the main event by about 3 hours and 52 minutes. This prior quake had an estimated Richter magnitude of 2.5, and occurred in the Santa Barbara Channel at a latitude of 34^{o} 14.5'N and a longitude of 119^{o} 30.2'W. The estimated focal depth of the prior quake was 8.6 km. The epicenter of this preceding shock is located in Fig. 2.3, where it is shown to be well aligned with the main shock and aftershocks. The relationship between this prior shock and the main event, if any, is not known.

TABLE 2.2

MAGNITUDE DATA FROM SEISMOGRAPHS IN SOUTHERN CALIFORNIA

(Provided by the Seismological Laboratory, California Institute of Technology)

Wood-Anderson Torsion Seismometers

Station	M_L (E-W)	M_L (N-S)
BAR	-	5.0
CWC	5.2	5.2
PAS	5.2	5.0
PLM	5.1	5.2
RVR	5.1	5.0
SBC	offscale	offscale
TIN	inoperative	inoperative

Strong Motion Wood-Anderson Torsion Seismometers

Station	M_L (E-W)	M_L (N-S)
PAS	5.5	5.2
SBC	4.9	5.0
RVR	5.0	-

Simulated Torsion Seismometers

Station	M_L (E-W)	M_L (N-S)
GLA	5.0	5.6
ISA	5.0	5.0

TABLE 2.3

MAGNITUDE DATA FROM SEISMOGRAPHS IN NORTHERN CALIFORNIA

(Provided by the Seismographic Station, University of California at Berkeley)

Wood-Anderson Torsion Seismometers

Station	M_L (N-S and E-W averaged)
BKS	5.9
MHC	5.7
MIN	5.6

2.4 Parameters of the Focal Mechanism

A preliminary investigation of the focal mechanism of the main event was performed by researchers at the Seismological Laboratory of the California Institute of Technology. Based on their preliminary results, the following parameters of the focal mechanism have been estimated.

The fault motion was primarily of thrust type, with a minor left lateral strike component. The projection of the slip vector onto a vertical plane through the fault trace was approximately 20° off the vertical. The motion apparently occurred on a fault which dips approximately 30° to the northeast, with Goleta on the hanging wall.

The fracture apparently propagated laterally west-northwest from the epicenter toward Goleta for a rupture length of approximately 8 km. The terminus of the fault was approximately 4 km from the UCSB campus.

2.5 Acknowledgments

The comments of Professors George W. Housner and Paul C. Jennings of the Earthquake Engineering Research Laboratory at the California Institute of Technology are gratefully acknowledged, as are the comments of Professor A.G. Sylvester of the Department of Geological Sciences of the University of California, Santa Barbara. The authors are grateful for the preliminary seismic data from the Seismological Laboratory of the California Institute of Technology which were provide by Dr. Kate Hutton, Dr. Carl Johnson, and Mr. Ed Corbett. The authors are also grateful for the preliminary seismic data from the Seismographic Station of the University of California, Berkeley which were provided by Professor B.A. Bolt.

3. STRONG MOTION RECORDS

3.1 Strong Motion Records from Land-Based Instruments

Several strong motion accelerographs and seismoscopes obtained records of the earthquake. In particular, accelerograms were obtained from two well-instrumented multistory buildings: North Hall on the campus of the University of Caifornia, Santa Barbara (UCSB), near Goleta, and the Freitas Building at 200 E. Carrillo Street in downtown Santa Barbara (see Fig. 3.1). Each of these buildings was instrumented with a 9 channel accelerograph. In addition, accelerograph records were obtained from triaxial instruments located in Building 340 on the UCSB campus (Goleta Free-Field), in the Goleta Substation of the Southern California Edison Company, and the Santa Barbara County Courthouse at the corner of Anacapa and Anapamu Streets in downtown Santa Barbara.

Very small amplitude accelerograph records were obtained by triaxial instruments at the crest and in the valve house of Bradbury Dam (Lake Cachuma), and by instruments at Juncal Dam and Gibraltar Dam (see Fig. 9.11). A very small amplitude record was also obtained by an accelerograph on the roof of the Holiday Inn on U.S. Highway 101 in Ventura, but the nearby free field instrument did not trigger.

Accelerographs located at Casitas Dam and at Point Conception did not trigger. An inspection after the earthquake showed that these instruments were fully operational.

Significant seismoscope records were obtained from two locations: in the basement of Biological Sciences II on the UCSB campus, and near the accelerograph in the Santa Barbara County Courthouse.

Copies of the strong motion records are presented in this report in the best available form at the time of writing. Some records are presented in uncorrected form, and in such cases the nominal scale factors are reported.

North Hall, U.C.S.B.

North Hall is located on the UCSB campus near the intersection of Ocean Road and Mesa Road, as shown in Fig. 3.2. North Hall is a three story reinforced concrete shear wall structure which was designed in 1960 and partially rebuilt in 1975 by adding interior shear walls for additional seismic resistance. The added shear walls are in accordance with the earthquake resistance provisions of the 1976 version of the Uniform Building Code. A photograph of the structure is shown in Fig. 3.3. A floor plan and elevation of the structure locating each of the nine accelerometers is shown in Fig. 3.4. The exterior reinforced concrete and concrete block columns are 48" x 16" and mounted upon caissons. The floor is a 4" thick reinforced concrete slab with 12" x 18" reinforced concrete tie beams. In addition to the exterior columns, there are two rows of ten interior columns which are 14" x 10" and made of reinforced concrete. Upper floors consist of 2.5" reinforced concrete slabs supported by longitudinal reinforced concrete joists spanning between transverse reinforced concrete floor beams. Details of the structural sections are provided later in Chapter 7.

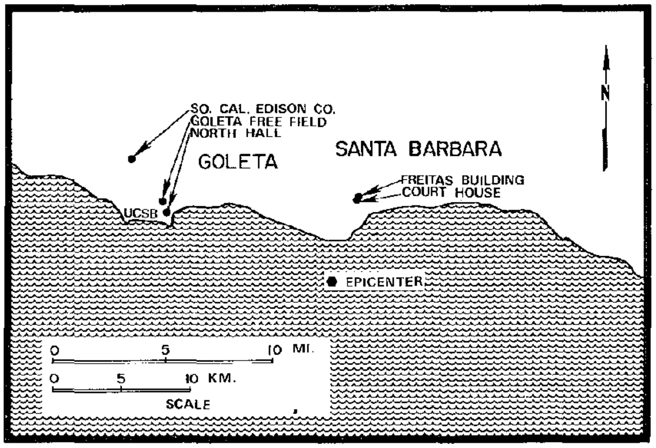

Fig. 3.1 Location of Strong Motion Instruments in the Santa Barbara-Goleta area.

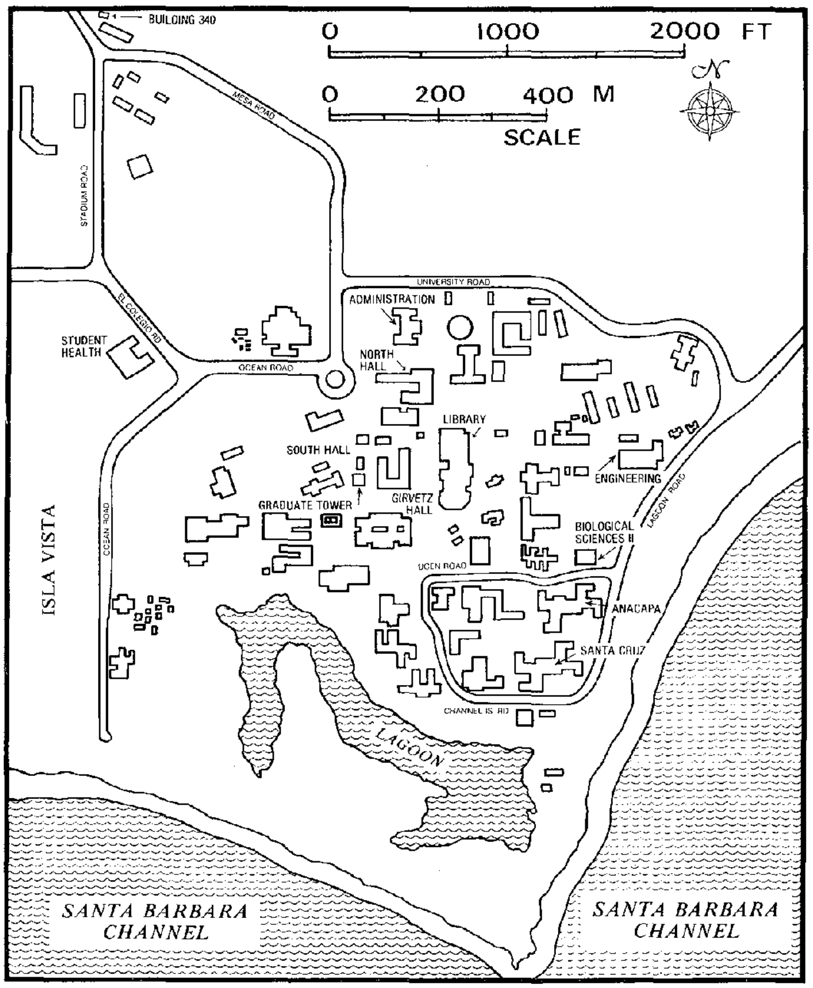

Fig. 3.2 The Campus of the University of
California, Santa Barbara

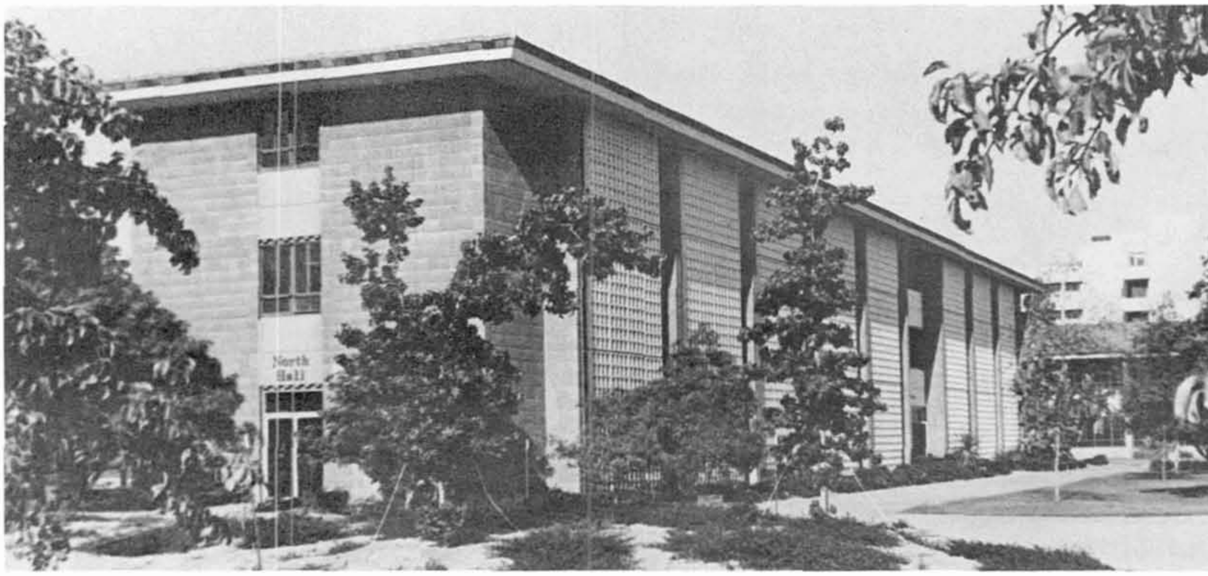

Fig. 3.3 Elevation of North Hall, UCSB. (View from southwest).

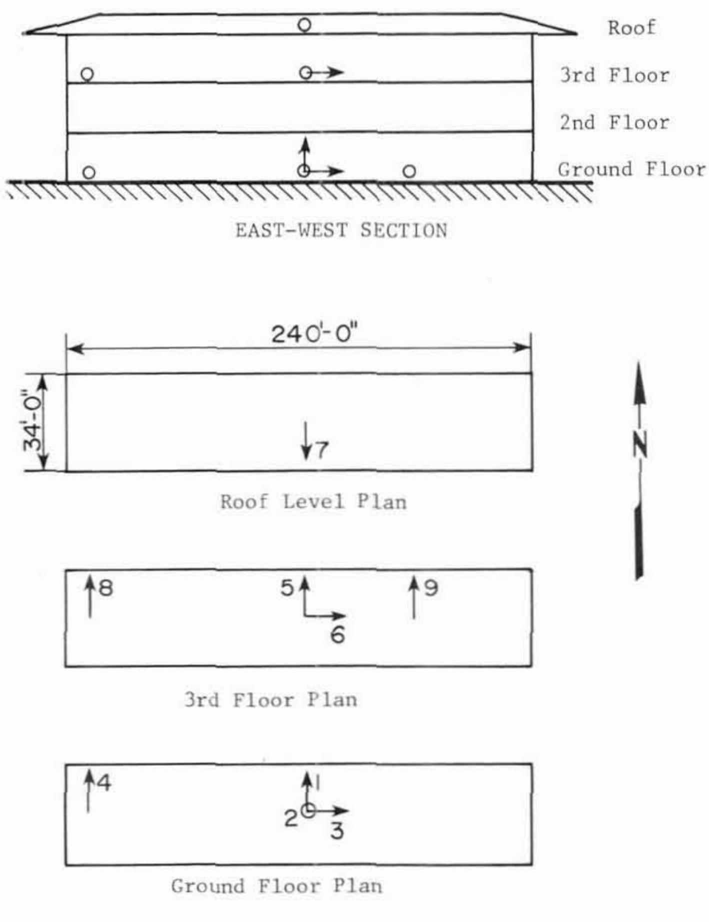

Fig. 3.4 Location of accelerometers within North Hall, UCSB.

An extensive series of forced vibration tests was performed on this structure both before and after the seismic rehabilitation in 1975 (Hart and others, 1978). Mode shapes, damping ratios, and natural frequencies were measured for fundamental modes in translation in the N-S and E-W directions, and in torsion. Measurements of soil-structure interaction were also made. It was found that the upper floor slabs do not behave as rigid diaphragms during vibration, but rather they sustain significant in plane deformations. An ambient vibration test was performed on this structure after the earthquake (October 1978), and the results will be reported in a future publication.

The strong motion records recorded by instruments in North Hall are shown in Fig. 3.5. As observed from these records, it appears that the duration of strongest motion was approximately 2 to 3 seconds, with largest amplitudes in the N-S direction. The peak acceleration in the N-S direction on the ground appears to be about 0.45g and at the roof about 0.94g. These structural accelerations are among the largest ever recorded, and were accompanied by significant diagonal cracking of the newly constructed N-S shear walls throughout the structure, as reported in Chapter 7. The severity of cracking tended to diminish in the upper stories, but was still noticeable.

Freitas Building

The Freitas Building is located at 200 E. Carrillo Street in down-town Santa Barbara. A photograph of the structure is shown in Fig. 3.6. The structure is a 4 story steel frame with isolated exterior reinforced concrete shear walls. The foundation consists of spread footings with belled caissons under the shear walls, and the structure has a half basement. Floors in the upper stories consist of steel decking with 2.5" concrete topping. A floor plan and elevation of the structure locating each of the nine accelerometers is shown in Fig. 3.7.

The strong motion records from the Freitas Building are shown in Fig. 3.8. As observed from these records it appears that the strongest ground motion occurred in the E-W direction with a duration of strongest shaking of approximately 2 seconds. The peak acceleration in the E-W direction on the ground appears to be about 0.21g. The record shows a large acceleration in the E-W direction on the roof, in a trace with some unusual high frequency components. This structure sustained very few diagonal cracks in the shear walls, and the damage was generally less severe than that sustained by North Hall.

Goleta Free Field (Building 340, UCSB Campus)

The so-called Goleta free field instrument is located in Building 340 in the northwest corner of the UCSB campus (see Fig. 3.2). Building 340 is a single story storage structure of plan dimensions 30' x 50' with a concrete floor slab. A photograph of the structure is shown in Fig. 3.9. The structure consists of a steel frame with a steel roof and siding, and is founded on soft alluvial soil which borders on the Goleta slough. A substantial collection of soil borings is available for this site.

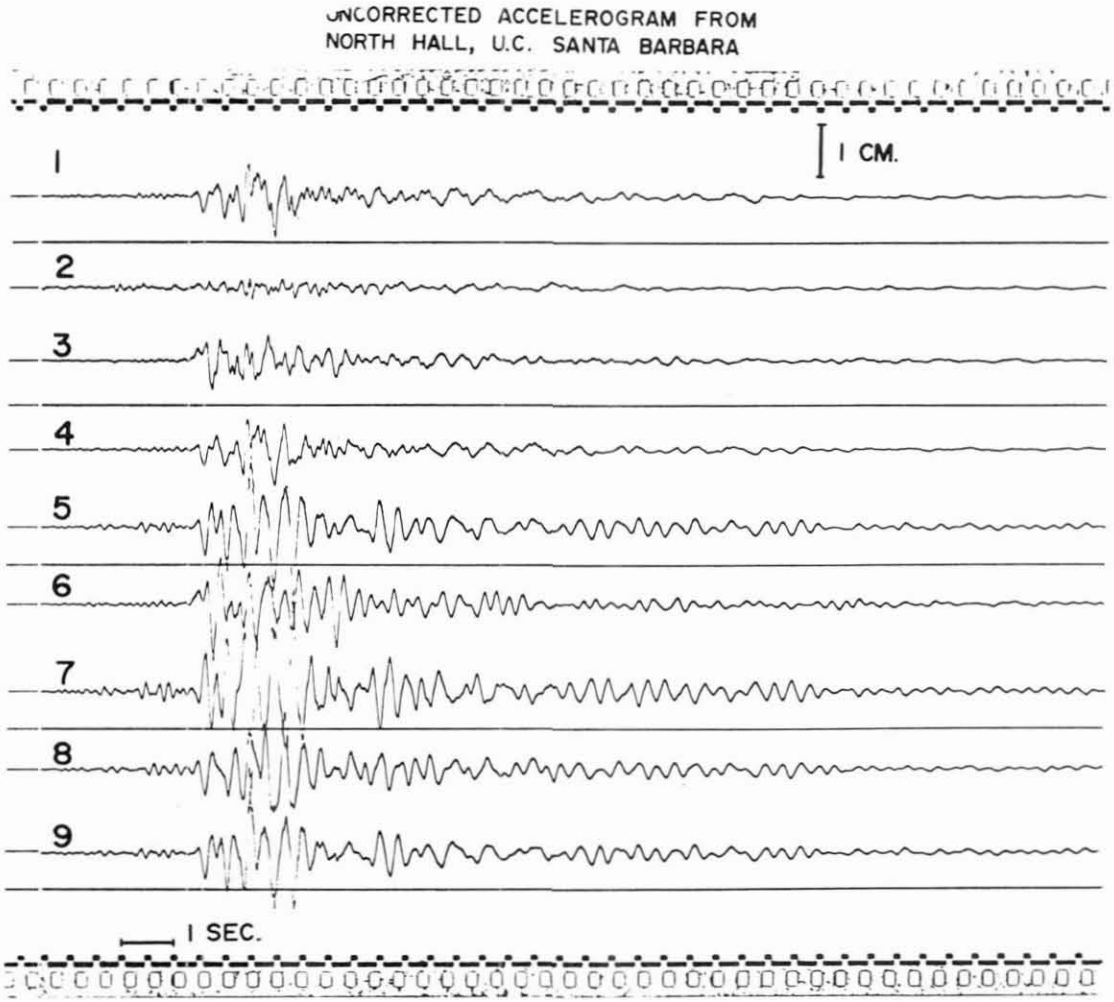

Fig. 3.5 Uncorrected Raw Accelerogram Recorded at North Hall, UCSB. 1.8 cm ≅ 1g. (Obtained by Office of Strong Motion Studies, California Division of Mines and Geology).

Fig. 3.6 Freitas Building, 200 E. Carrillo Street, Santa Barbara.

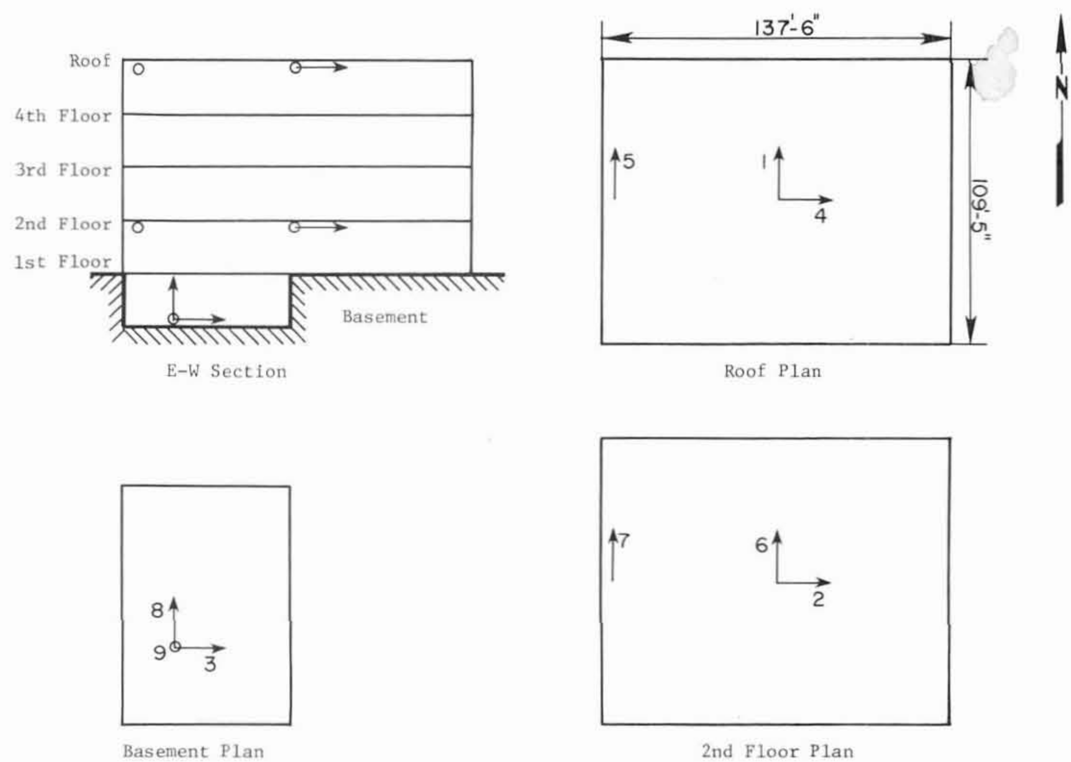

Fig. 3.7 Location of accelerometers within Freitas Building, Santa Barbara.

ENGINEERING FEATURES
OF THE
SANTA BARBARA EARTHQUAKE OF AUGUST 13, 1978

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UCSB-ME-78-2

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Santa Barbara, California

December 1978

PREFACE

Although the Santa Barbara earthquake was only a moderate seismic event, several of its features were unusual and interesting from an engineering point of view. Included among these features are the geographical asymmetry of strong ground shaking, the large peak accelerations recorded by strong motion instruments, and the differences in reported magnitudes for the event. This earthquake also provided a picture of the performance of modern California buildings in a moderate earthquake.

Presented in this report are preliminary investigations of some of the more striking engineering features of the earthquake. Chapters 4, 5, 6 and 8 were contributed by the second author (Stephen F. Felszeghy) and the remaining chapters were contributed by the first author (Richard K. Miller), but the final draft was a joint effort. Assistance was provided by Mr. Bahram Fatemi and Mr. Hoi Tran, graduate students in the Department of Mechanical and Environmental Engineering of the University of California, Santa Barbara. Accurate and prompt typing of the manuscript was performed by Mrs. June Finney and Mrs. Susie O'Rourke, Departmental secretaries. Assistance with manuscript layout, publishing, and distribution was provided by Mr. David J. Leeds with the Earthquake Engineering Research Institute.

The timely financial support of the Applied Science and Research Applications Division of the National Science Foundation, the Office of Research Development and the Department of Mechanical and Environmental Engineering of the University of California, Santa Barbara, and the Earthquake Engineering Research Institute are gratefully acknowledged.

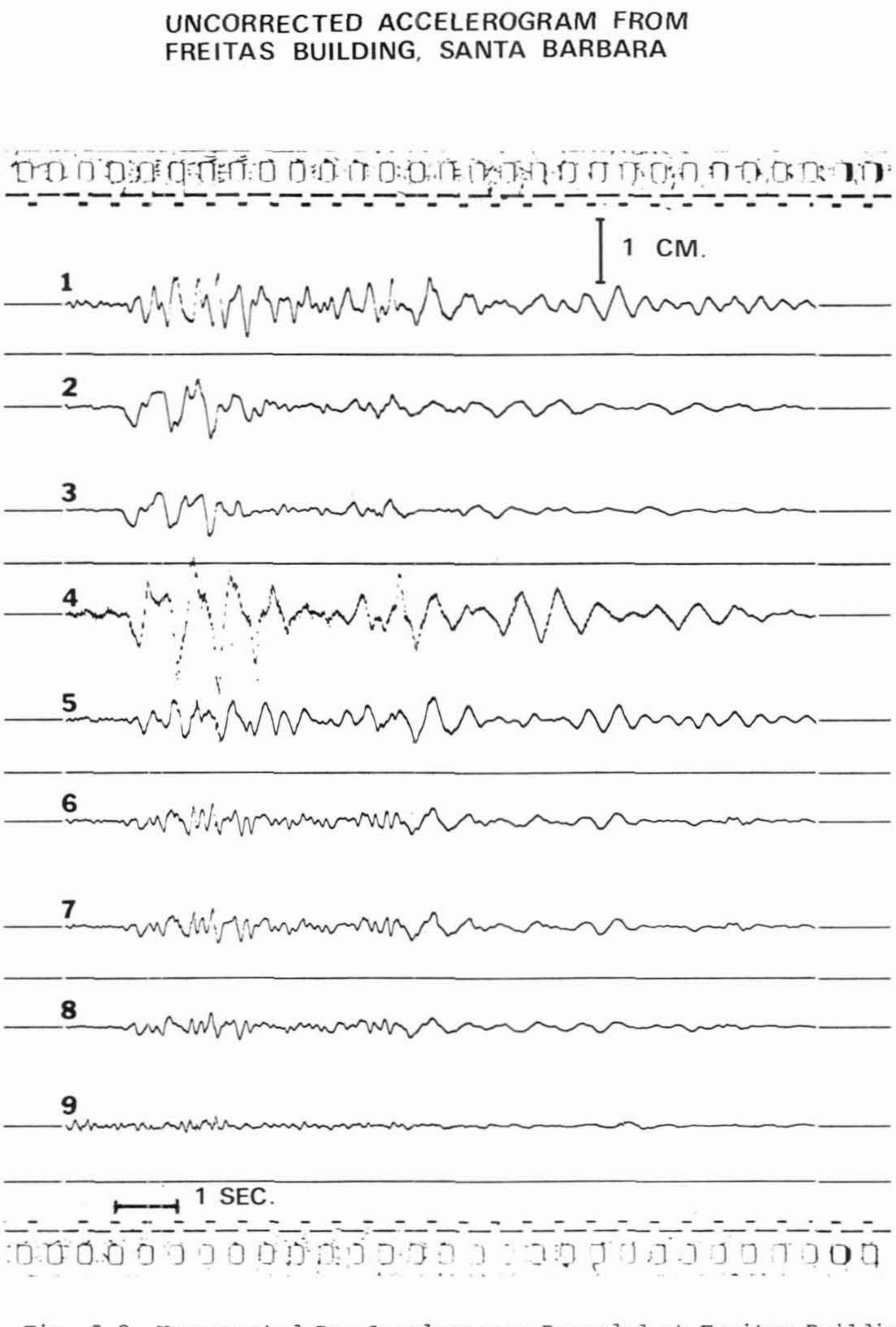


Fig. 3.8 Uncorrected Raw Accelerogram Recorded at Freitas Building, Santa Barbara. 1.8 cm ≅ 1g. (Provided by Office of Strong Motion Studies, California Division of Mines and Geology.)

The strong motion records recorded at Building 340 are shown in Fig. 3.10. Again it appears that the duration of strongest ground motion was approximately 2 to 3 seconds. The peak acceleration appears to be about 0.39g.

Goleta Substation, Southern California Edison Company

The Goleta Substation of the Southern California Edison Company is located approximately 1.6 kilometers north of U.S. Highway 101 on Glenn Annie Road. Details of the location of the instrument within the substation were not available at the time this report was written.

The accelerogram recorded at this site was corrected, digitized, and plotted at Kinemetrics, Inc. of Pasadena, California. A copy of the corrected accelerogram is shown in Figs. 3.11 a, b, and c. The duration of strongest ground motion was again approximately 2 to 3 seconds. The maximum acceleration at this site near the base of the Santa Ynez Mountains is reported as 0.286g.

Santa Barbara County Courthouse

The Santa Barbara County Courthouse is located at the corner of Anacapa and Anapamu Streets in downtown Santa Barbara (Figs. 3.1 and 1.3). A photograph of the structure is shown in Fig. 3.12. The accelerograph was located in the basement.

The strong motion records from this location are shown in Figs. 3.13 a, b, and c. The duration of strongest motion appears to have been approximately 2 seconds. The peak acceleration is 0.20g in the S 42° W direction.

Bradbury, Juncal, and Gibraltar Dams

The accelerograms recorded at these locations had very small amplitudes and are not included in this report.

Seismoscope Records

Seismoscope records of strong motion were obtained from instruments at two locations. One record was obtained from a seismoscope in the basement of Biological Sciences II on the UCSB campus (see Fig. 3.2). A photograph of this multistory reinforced concrete structure is shown in Fig. 3.14. A copy of the seismoscope record from this instrument is shown in Fig. 3.15. The unusual high frequency motion in the lower right of the figure is believed to have resulted when a 3 ft by 7 ft unhung door fell on the instrument during the earthquake. This loose door was propped against a nearby wall before the earthquake, and was found lying on top of the instrument by an elevator inspector after the earthquake. The door was evidently removed by maintenance personnel before the U.S.G.S. inspector arrived, and it made no marks on the instrument case.

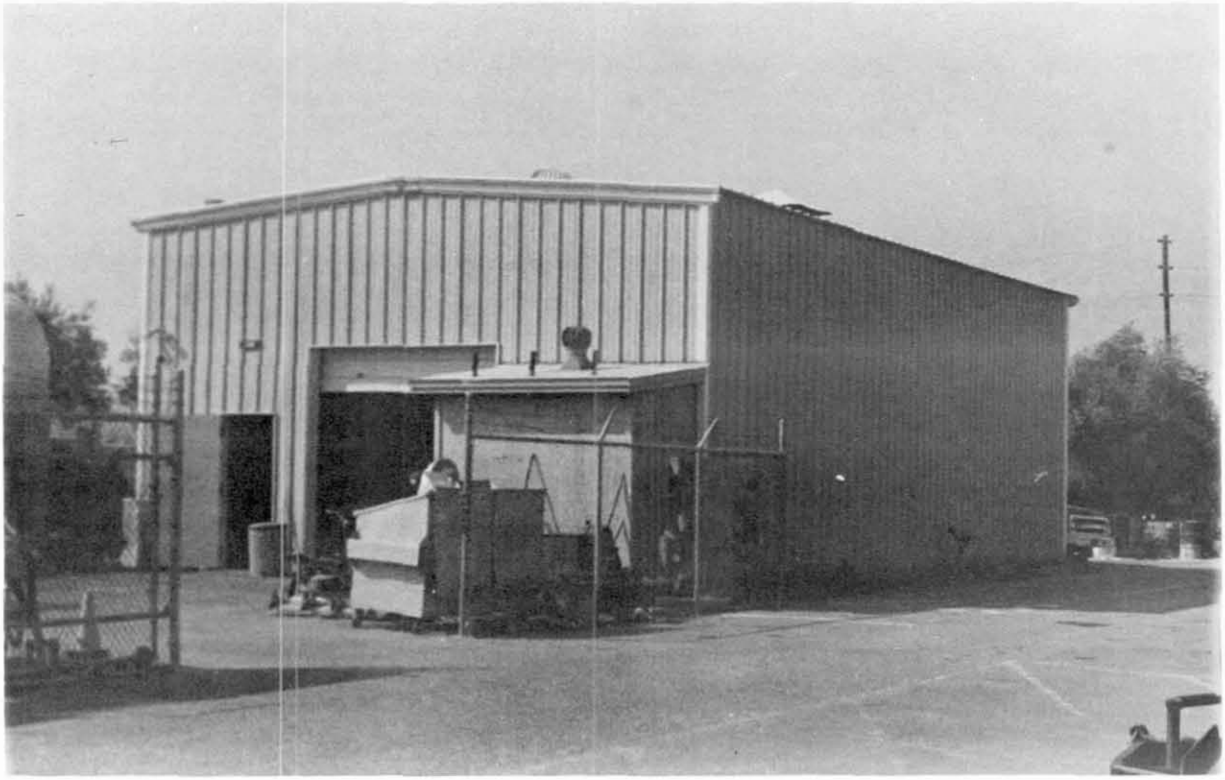


Fig. 3.9 Building 340, UCSB campus. (Location of Goleta Free Field instrument).

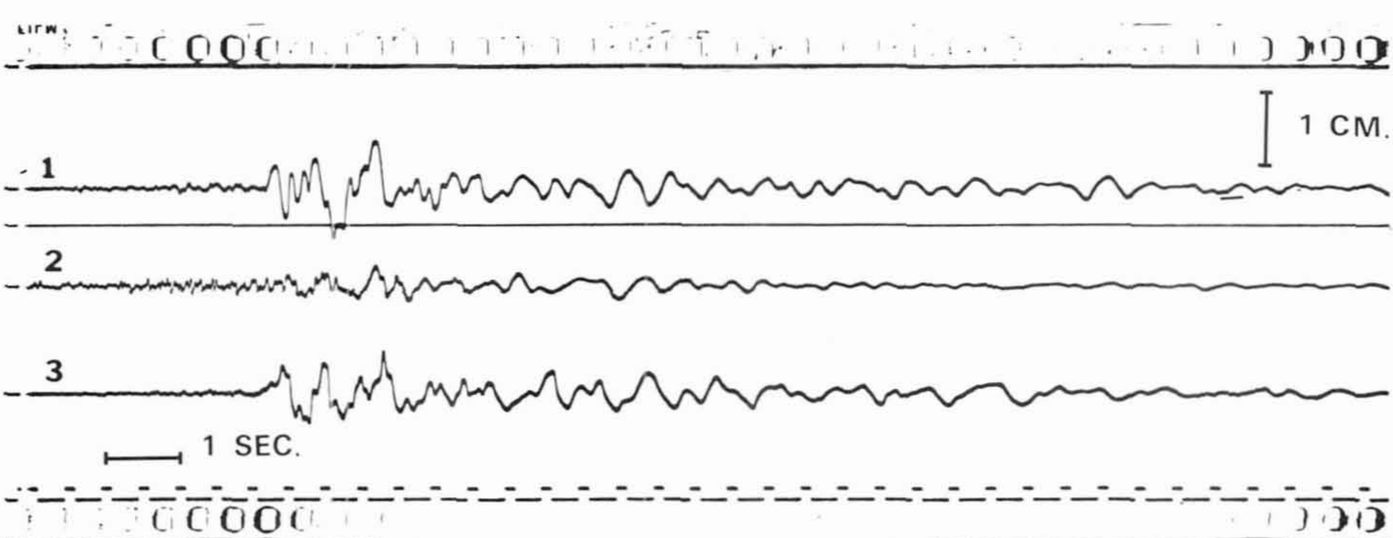


Fig. 3.10 Uncorrected Raw Accelerogram Recorded at Building 340, UCSB (Goleta Free-Field.) Traces 1 and 3 are horizontal and 2 is vertical. 1.8 cm ≊ 1g. (Provided by Office of Strong Motion Studies, California Division of Mines and Geology.)

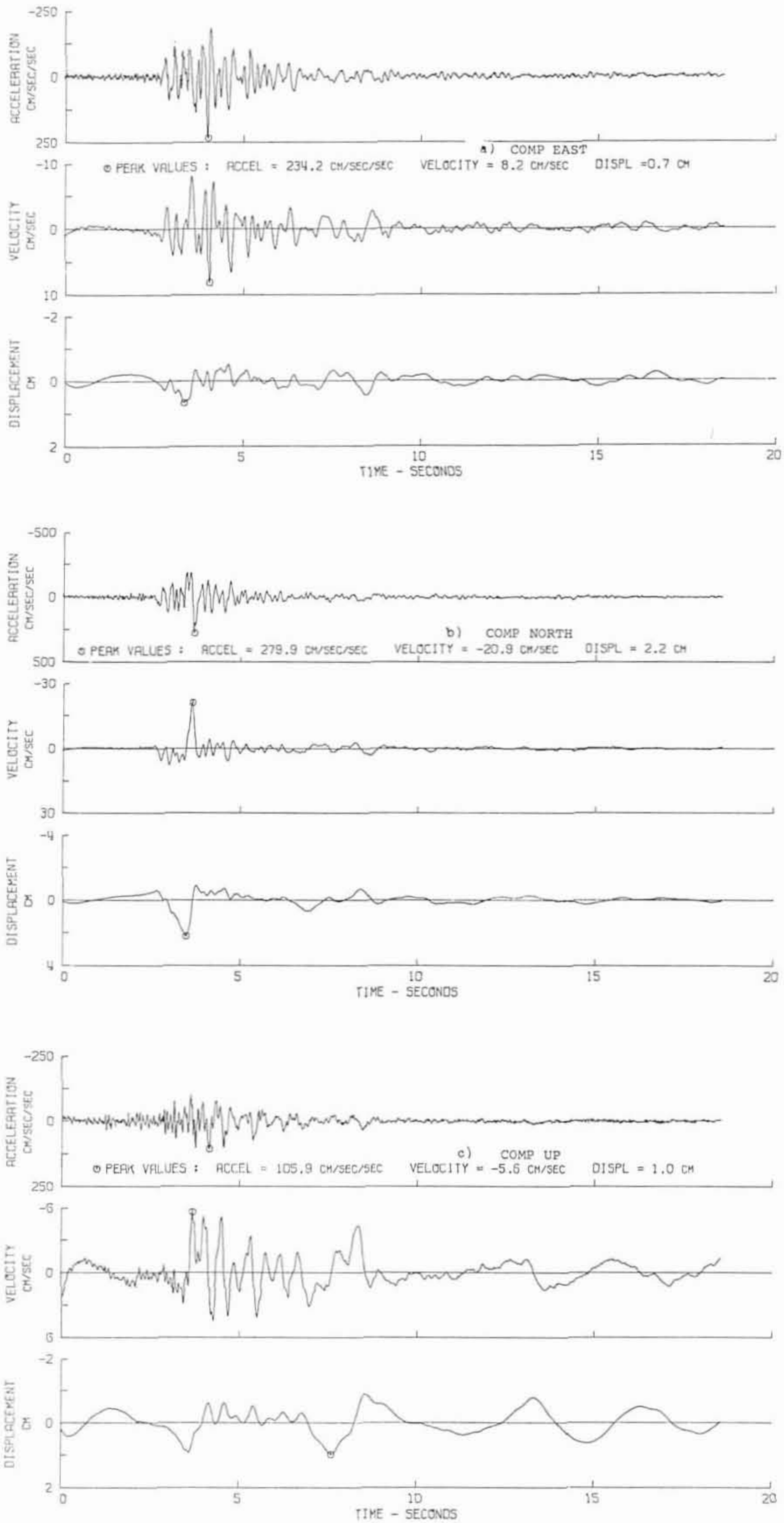


Fig. 3.11 Strong motion record from Goleta Substation, Southern California Edison Company - (Provided by Southern California Edison Company and Kinemetrics, Inc.)

Fig. 3.12 Santa Barbara County Courthouse, Anacapa and Anapamu Streets, Santa Barbara.

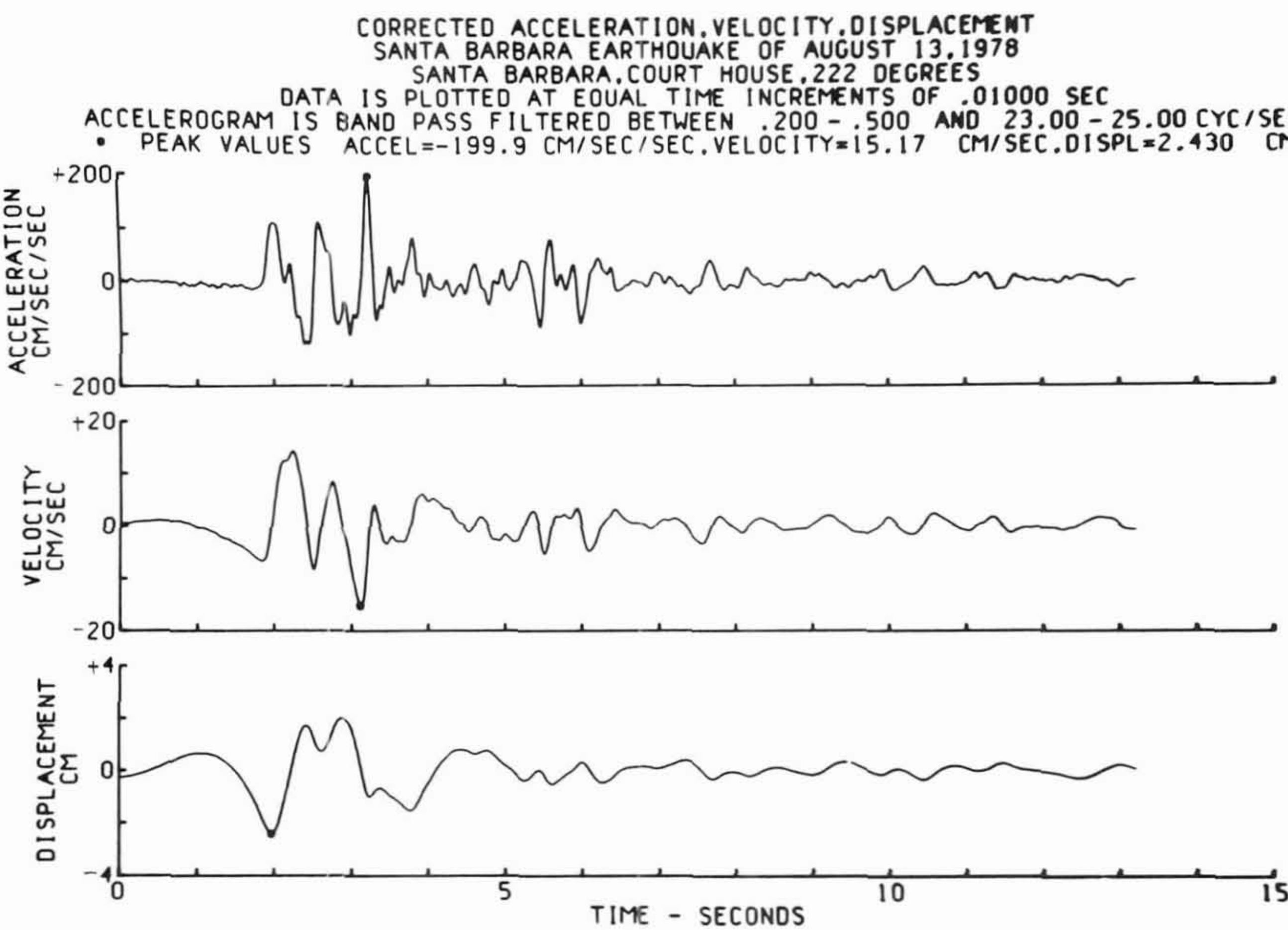


Fig. 3.13a Strong motion record from Santa Barbara County Courthouse S 42° W component. (Provided by Seismic Engineering Branch, U.S. Geological Survey).

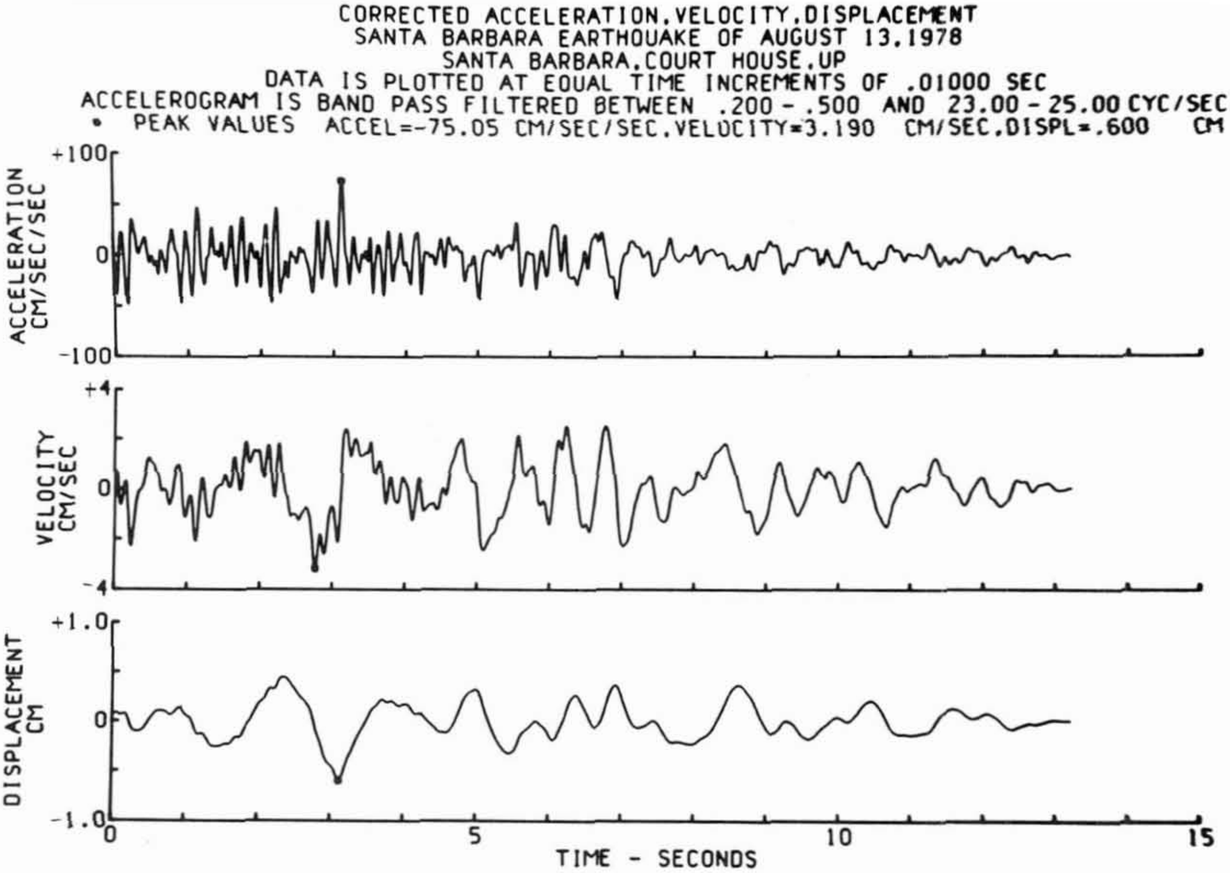


Fig. 3.13b Vertical component.

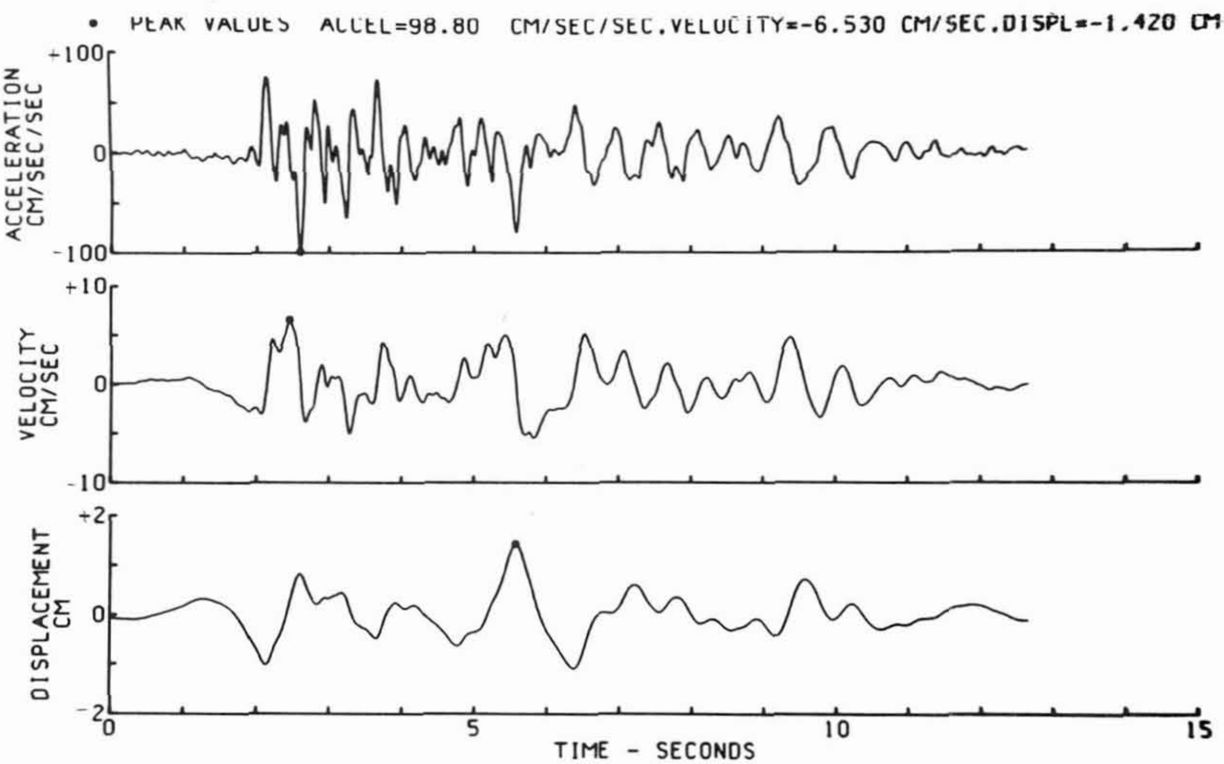


Fig. 3.13c Strong Motion Record from Santa Barbara County Courthouse, S 48° E Component. (Provided by Seismic Engineering Branch, U.S. Geological Survey).

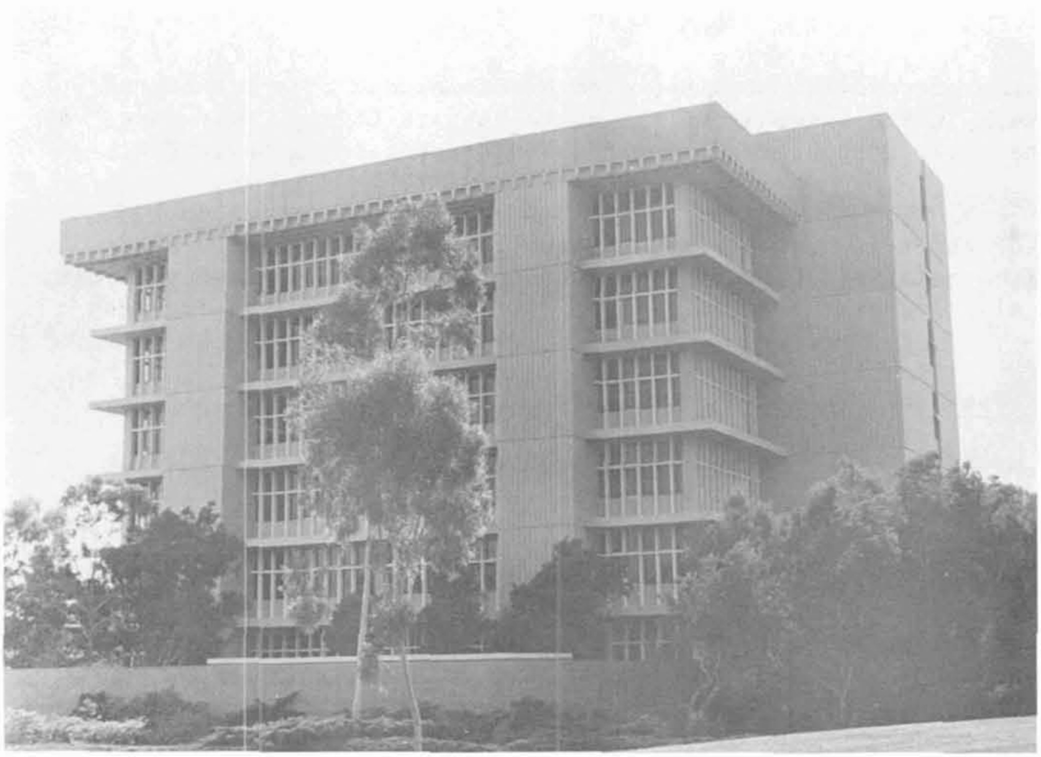


Fig. 3.14 Biological Sciences II, UCSB. (Seismoscope located in basement).

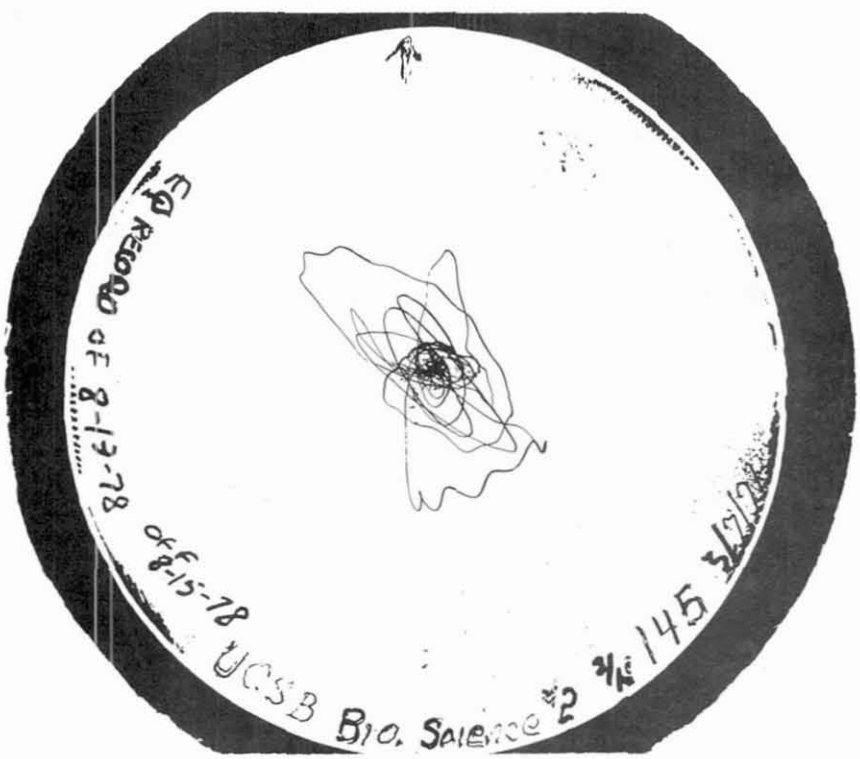


Fig. 3.15 Seismoscope record from Biological Sciences II, UCSB. Arrow points N 00° E. (Provided by Seismic Engineering Branch, U.S. Geological Survey). High frequency motion at lower right probably caused by impact with a falling door.

The other record was obtained from a seismoscope adjacent to the accelerograph in the basement of the Santa Barbara County Courthouse. A copy of the seismoscope record from this instrument is shown in Fig. 3.16.

Both of the seismoscope records shown in Figs. 3.15 and 3.16 were obtained from enlarged photographs of the original curved glass etchings. The original glass plates had a diameter (white circle in the figures) of 63 mm.

3.2 Peak Accelerations

Some areas in Goleta experienced peak ground accelerations of at least 0.45g, more than twice as large as the 0.21g recorded in downtown Santa Barbara. Furthermore, the peak acceleration of 0.94g on the roof of North Hall on the UCSB campus is among the largest ever recorded. These large accelerations were recorded in Goleta in spite of the fact that Goleta is about 13 kilometers from the epicenter, while Santa Barbara is only about 6 kilometers away. In order to correlate this irregular pattern of peak ground accelerations with the magnitude and distance to the fault requires consideration of the special geological features of this earthquake.

As discussed in the previous chapter, the pattern of seismic waves generated by this earthquake was highly asymmetrical. Stations northwest of the epicenter generally experienced more intense ground shaking than stations to the southeast. Consequently, stations in the northern part of the state reported a Richter magnitude of 5.7, while stations in the southern part reported 5.1. Due to this asymmetry, the use of a single average magnitude value does not give a reliable indication of the intensity of ground shaking at all locations. Furthermore, the rupture apparently began at the epicenter and propagated northwest toward Goleta, stopping about 4 or 5 kilometers from the UCSB campus.

In view of these geologic conditions, it would be reasonable to use a magnitude of about 5.7 when correlating magnitude and peak acceleration for locations northwest of the fault, and a magnitude of 5.1 for locations southeast. In particular, a magnitude of about 5.7 and a distance of about 4 kilometers would be reasonable for the UCSB campus.

It should be pointed out, however, that from a practical earthquake engineering point of view, a large peak acceleration does not necessarily imply a proportionally large destructive potential (Housner and Jennings, 1977). A large destructive potential is the result of generally high acceleration amplitudes throughout a record of extended duration. The duration of strongest ground shaking in the present earthquake was only 2 to 3 seconds.

3.3 Performance of Accelerographs on Offshore Platforms

Several of the offshore platforms in the Santa Barbara Channel were instrumented with strong motion accelerographs at the time of the earthquake.

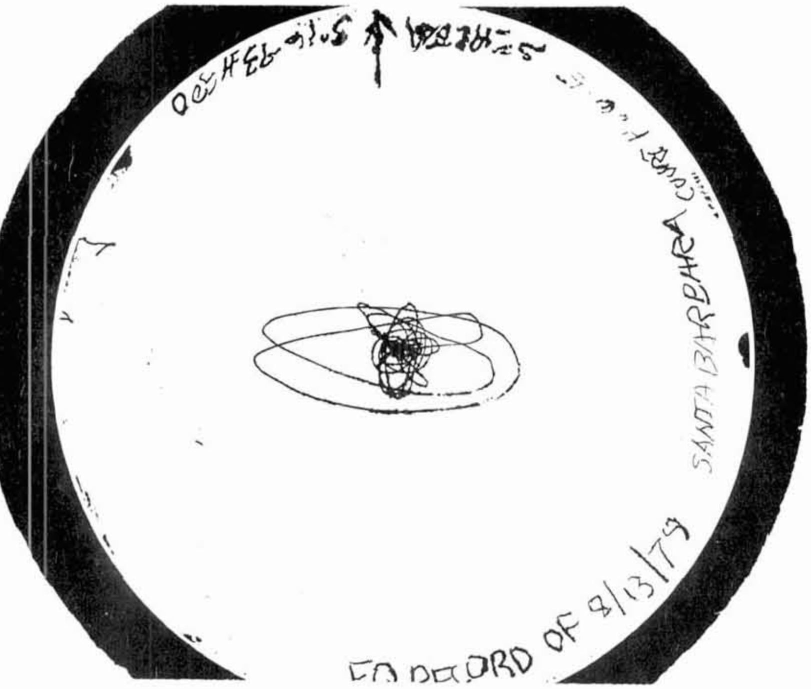


Fig. 3.16 Seismoscope record from Santa Barbara County Courthouse. Arrow points N 48.5° W. (Provided by Seismic Engineering Branch, U.S. Geological Survey).

Specifically, platforms Hondo, Holly, Hope, A, and B were instrumented by various oil companies (see Fig. 10.1). However, due to a common weakness in the instrumentation and its maintenance, not one record of the earthquake was obtained. This is particularly unfortunate in view of the proximity of some of the platforms to the epicenter in the channel, and also the need for experimental data to verify assumptions used in the seismic design and analysis of the platforms themselves.

The instrument difficulties in every case were apparently the result of an overly sensitive trigger mechanism. The instruments had typically triggered so frequently on nonseismic events that no recording material was left unused when the earthquake occurred. It is clear that the operation of the trigger mechanism must be improved, and additional attention must be given to the maintenance of these instruments if they are to provide any useful data in future earthquakes.

3.4 Acknowledgments

The comments of Professors George W. Housner, Donald E. Hudson, and Paul C. Jennings of the Earthquake Engineering Research Laboratory at the California Institute of Technology are gratefully acknowledged. Also, the cooperation of many governmental and industrial officials in providing their strong motion data is gratefully acknowledged. In particular, thanks are due to Dr. A.G. Brady of the Seismic Engineering Branch of the U.S. Geological Survey, Mr. Dennis Ostrom of the Southern California Edison Company, Mr. K.L. Benuska, Vice President of Kinemetrics, Inc., and Mr. Tom Wootton, Chief of the Office of Strong Motion Studies of the California Division of Mines and Geology.

4. EARTHQUAKE EFFECTS ON HOSPITALS, SCHOOLS, FIRE AND POLICE STATIONS

4.1 Effects on Hospitals

Of the several large hospitals serving the greater Santa Barbara area, one, namely Goleta Valley Community Hospital, is located in Goleta, the area that was hardest hit by the earthquake. More than fifty persons injured in the earthquake sought emergency treatment at the Goleta hospital. The most serious injuries consisted of a broken back, second and third degree burns from scalding water, and numerous cases of lacerations from shattering glass. Cottage Hospital in downtown Santa Barbara reported more than ten cases of earthquake related injuries.

None of the hospitals in the quake area suffered any serious damages to buildings or equipment. As a precaution against potential injuries from aftershocks, and also to aid quake victims, Goleta Valley Community Hospital instituted an emergency plan following the earthquake. According to this plan resident nonambulatory patients were wheeled to safety outdoors, and an emergency treatment center was set up temporarily outdoors with signs directing the injured to specific types of treatment. The single story Goleta Hospital building sustained some light plaster cracking. In addition, a 10,000 lb chiller in the hospital basement was thrown off its vibration isolation supports, and some pipes were broken. The earthquake activated the emergency power supply system of the hospital even though a power outage had not occurred.

4.2 Effects on Public Schools

The public elementary and high schools in the Goleta area generally performed very well, and only minor damages occurred. The damages were exclusively architectural in nature, and not structural. As observed in previous earthquakes, the seismic resistance of public school structures demanded by the Field Act was sufficient to prevent structural damages. No injuries resulted from the architectural damage because schools were not in session. Some window panes were broken and shattered, plaster walls were cracked, and acoustical ceilings were dislodged. Damages to the acoustical ceilings occurred typically at the periphery of the T-bar networks supporting the acoustical tiles, where the T-bars abut against the side walls. In those cases where the T-bars were anchored to the walls, only the tiles were shaken loose. However, in those cases where the T-bars were not anchored, both T-bars and tiles fell to the floor. Some acoustical tiles glued to ceilings and side walls were also dislodged by the earthquake.

4.3 Effects on Private Schools

St. Vincent's School for Disabled Children, a private school, suffered extensive architectural damage to its residential building constructed in 1924. This school building varies between two and three stories in height and is of concrete construction, with a concrete frame and concrete floors. As a result of the earthquake, the building's unreinforced tile filler panel walls cracked through the mortar. Damages were estimated to be over $200,000. Private schools in California do not have to meet the earthquake resitance criteria of the Field Act.

An old two story adobe school house also received significant damage. This private school house, located in Goleta on the west campus of UCSB is currently used as a student residence hall. The interior and exterior adobe walls suffered cracks in localized areas on the second floor which potentially weakened the bearing capacity of the walls.

4.4 Effects on Fire and Police Stations

No significant damages were reported by city and county police and fire stations. Firefighters were able to respond to calls for assistance following the quake in a routine manner. Under a mutual aid agreement, fire engines were brought in from neighboring Ventura County, but they were not used. Most calls for assistance were from homeowners requiring help with gas and water leaks.

4.5 Acknowledgments

The authors wish to thank Mr. J.F. Meehan, with the Office of the State Architect, for providing his reconnaissance report on earthquake damage suffered by public schools.

5. EARTHQUAKE EFFECTS ON TRANSPORTATION FACILITIES

5.1 Effects on Railroads

Railway service in Santa Barbara and to areas north and south is provided by the Southern Pacific Transportation Company. The company operates a single track main line in this part of the state. The line parallels the coastline and is used for both freight and passenger service. As a result of the earthquake, a major freight train derailment occurred along this line in an unpopulated area at the location shown in Fig. 1.2. The consequent financial loss was one of the largest single losses resulting from the earthquake. The freight train was north-bound enroute from Los Angeles to Watsonville. It carried 49 empty cars and nine loaded cars containing non-hazardous freight. The train was rounding a curve at about 50 mph when the derailment occurred. The engineer reported that following the earthquake he saw a "kink" ahead in the tracks but that the train could not be stopped in time. Subsequent investigation showed that the kink may have been a result of roadbed fill failure. The south-bound evening Starlight Amtrak passenger train would have passed the same location an hour later. Damage to the derailed train was estimated to be $380,000 and damage to the track was set at $40,000. No injuries resulted from this accident which derailed thirty cars (Fig. 5.1) and sent a pair of wheels flying across U.S. Highway 101 which borders on the track, as seen in Fig. 5.2. The line was reopened to normal train traffic about 24 hours later.

5.2 Effects on Highways and Bridges

Santa Barbara is separated from the Santa Ynez River basin to the north by the Santa Ynez Mountains which run parallel to the coastline and range in height from two to over four thousand feet. California State Highway 154, a two-lane highway, cuts directly across these mountains in a north-westerly direction from the city, rising to over 2,000 feet at San Marcos Pass. Several rock-slides of the type shown in Fig. 5.3 occurred along this heavily weekend-travelled route, closing it to through traffic for more than 24 hours. No injuries resulting from the rock-slides were reported. On the Santa Barbara side of the mountains, where the highway appraches the foothills, earth settlement was noted at one location along the highway shoulder, 9 to 10 feet from the edge of the pavement, creating a gap of about 2 inches. This was at a place where the ground on the settlement side of the road drops 200 feet.

U.S. Highway 101, which is the major coastal highway route between northern and southern California, passes through the center of Santa Barbara. A short state highway spur in Goleta designated as California State Highway 217, but better known locally as Ward Memorial Boulevard, merges with Highway 101 and carries traffic to and from the UCSB campus area. Highway 101, as well as Ward Memorial Boulevard, are divided freeways with two lanes in each direction. Several major thoroughfares in Goleta cross Highway 101 and the adjacent Southern Pacific track on roughly north-south oriented bridge overpasses. One such thoroughfare is Ward Memorial Boulevard where it merges with Highway 101 on curved and banked overpasses as shown in Figs. 5.4 and 5.5.

Fig. 5.1 Derailed freight train west of Goleta. View looking north toward highway. (Santa Barbara News-Press photo. Reproduced by permission).

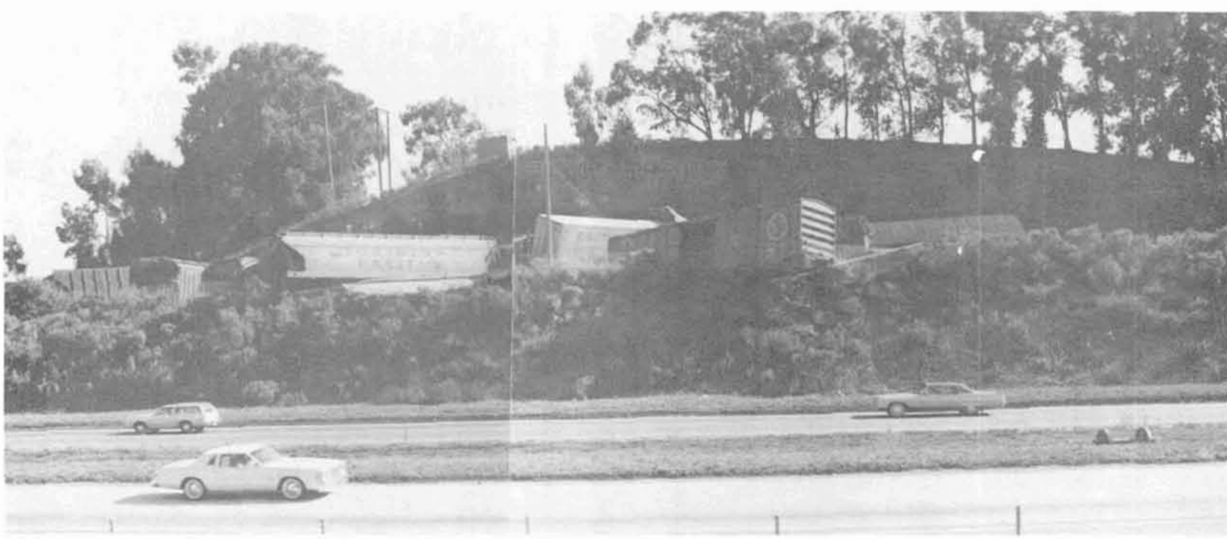


Fig. 5.2 Derailed freight train west of Goleta. (see Fig. 1.2 for location). View looking south across U.S. Highway 101. Note train wheels on highway median.

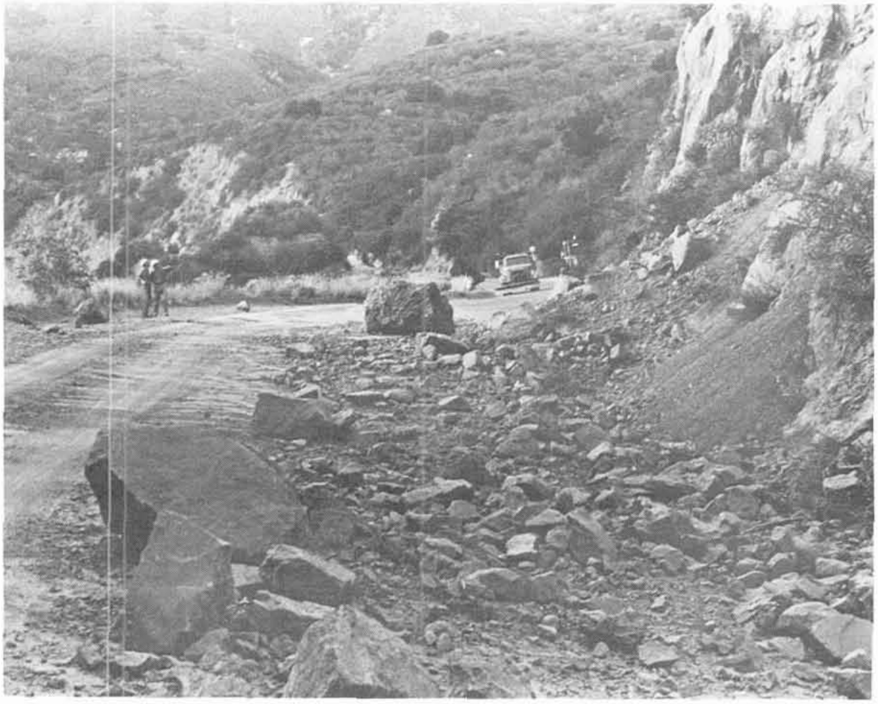


Fig. 5.3 Rockslide on California State Highway 154, near San Marcos Pass (see Fig. 1.3 for location). (Santa Barbara News-Press photo. Reproduced by permission).

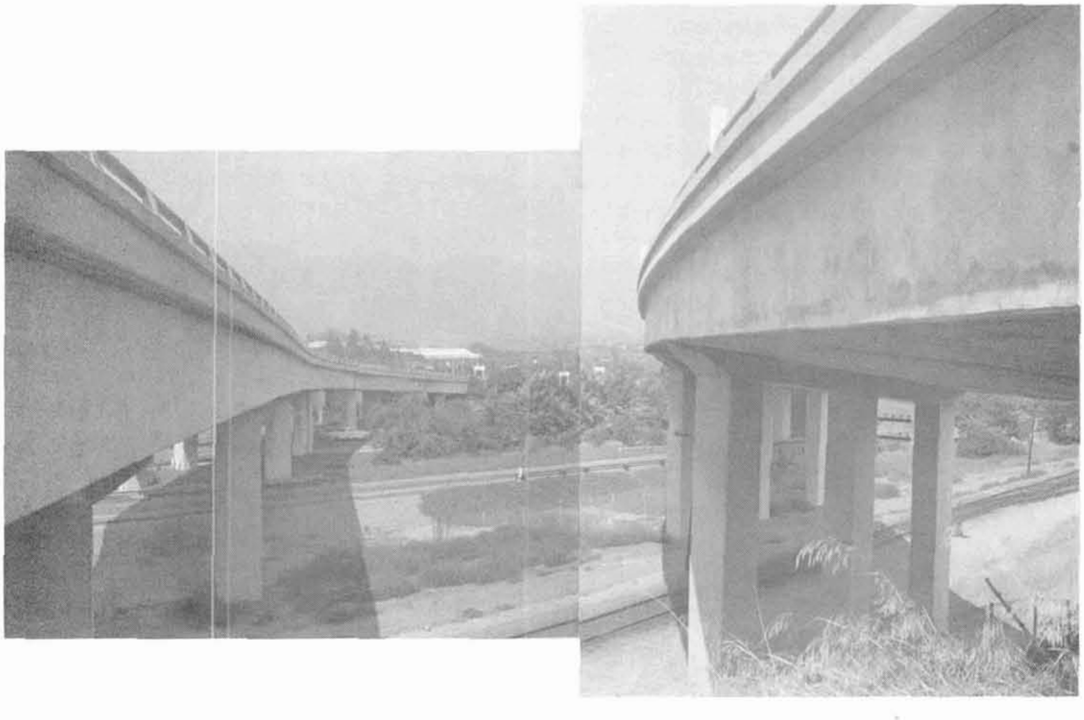


Fig. 5.4 Ward Memorial Boulevard bridges over U.S. Highway 101 (see Fig. 1.2 for location). View looking north from southern abutment.

A total of four overpasses crossing Highway 101, all steel-reinforced concrete structures, suffered significant earthquake damage (see Fig. 1.2 for locations). Specifically, these include the two adjacent curving bridges on Ward Memorial Boulevard (where the boulevard meets Highway 101), one bridge on the western end of Hollister Avenue, and another on Glenn Annie Road. All except the last bridge named are state owned; the last bridge is a county bridge. The most extensive damage was sustained by the Ward Memorial bridges and the least by the Glenn Annie bridge. All the damaged bridges share a common design feature in that all have rocker bearing supports at the abutments. One of the Ward Memorial bridges has rocker bearings at some of its intermediate support points as well. In general, the earthquake subjected the bridges to considerable transverse motion which shifted the superstructures relative to the abutments causing the concrete to crack and spall at a number of places.

As mentioned, the most significantly damaged bridges were the two adjacent Ward Memorial bridges. The damage to these bridges occurred at several places and was relatively minor. The bridges are visible in Fig. 5.4, which is a view north along the sides of the bridges, and in Fig. 5.5, which is a view south. The bridges share a common abutment at their southern ends. The bridge on the left in Fig. 5.4 is 660 feet long and consists of eight spans. The spans are continuous reinforced concrete box girder structures except for two intermediate spans over Highway 101 which are single precast-prestressed concrete I girders. The bridge is supported by a series of two and three column bents that are sharply skewed. At the abutments, as well as at some of the precast-prestressed girder support points, the bridge deck rests on steel rocker bearings. The bridge on the right in Fig. 5.4 is 482 feet long and has six spans. The spans are continuous reinforced concrete box girder structures and there is only one intermediate hinge. The bents under this bridge have two columns each and are sharply skewed. The bridge deck rests on rocker bearings at the abutments.

Since the earthquake induced shifting of all damaged bridge decks was most evident at the rocker bearing supports, a more detailed description of these supports will be given next. Typically, where a bridge deck rests on rocker bearings, there are five bearings equally spaced across the width of the bridge. The bearings are cylindrical in shape, with an oblong cross-section, and are placed on edge between 1" thick steel plates, with the bottom plate fastened to the supporting substructure (called the masonry plate) and the top plate fastened to the bridge deck (called the sole plate). A view of a rocker bearing installation is shown in Fig. 5.6, which is the installation at the southern-most abutment of the Ward Memorial bridge on the left in Fig. 5.5. A close-up is shown in Fig. 5.7. The rocker bearing surfaces in contact with the plates are rounded to a radius of 8". The axes of the bearings are always oriented normal to the bridge centerline. Thus, functionally, the bearings permit the bridge deck to move longitudinally, parallel to the bridge deck centerline. The bearings are held captive laterally by loosely fitted 1" thick keeper plates that are bolted with 1" bolts to the masonry and sole plates at the two ends of the bearings, as can be seen from the damaged installation in Fig. 5.7. Notches in the keeper plates mesh with vertical keys protruding from the end faces of the

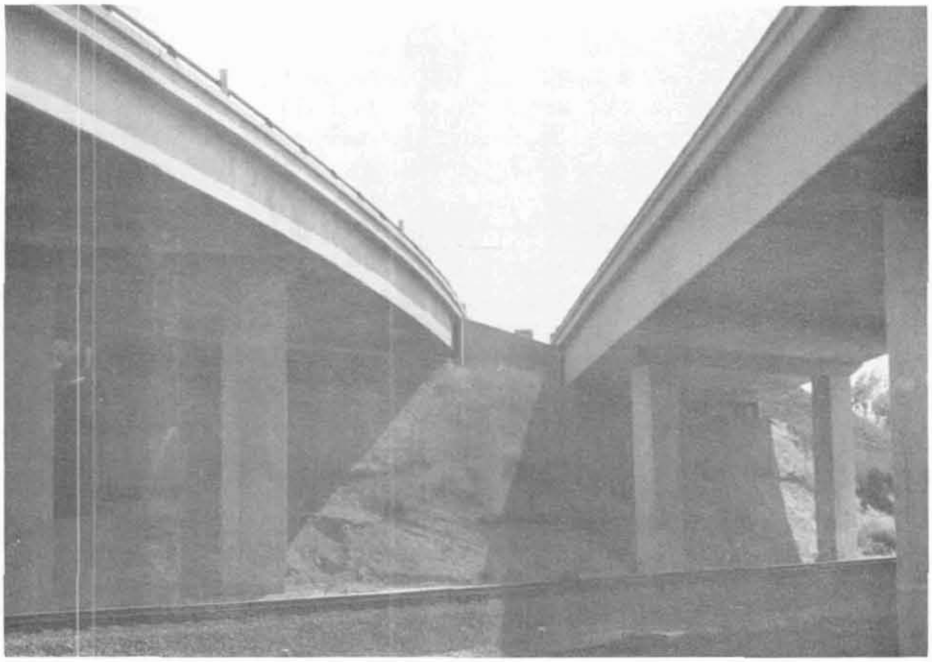


Fig. 5.5 Ward Memorial Boulevard bridges. View looking south towards southern abutment.

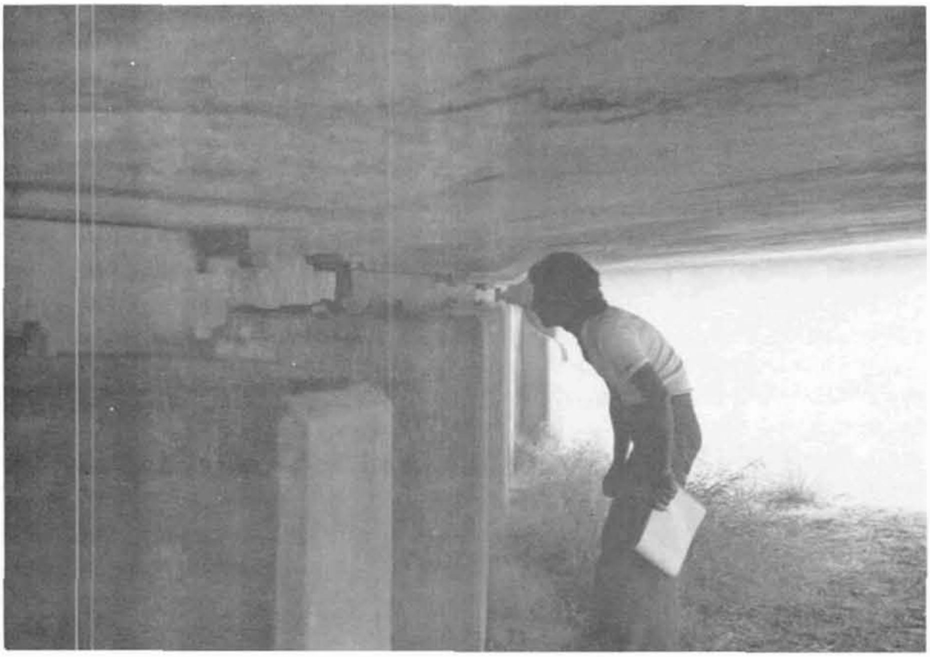


Fig. 5.6 Support of Ward Memorial Boulevard bridge deck at southern abutment. View shows piers capped by damaged rocket bearing assemblies under bridge on left in Fig. 5.5.

bearings as seen in Fig. 5.8. Additional lateral restraint is provided by two 1" anchor bolts that protrude from the masonry plate in front and back of the bearing.

On both of the Ward Memorial bridges, some bolts holding the keeper plates were sheared at the southern-most abutment. More specifically, it was found that the bolts holding the keeper plates to the sole plates were sheared at the eastern ends of the bearings, as can be observed from Figs. 5.7 and 5.8. Some keeper plate bolts were also sheared at the northern abutment of the bridge on the right in Fig. 5.4, and at the intermediate supports of the bridge on the left in Fig. 5.4. Although the pattern of failure at these locations was more random than at the southern-most abutment, the overall evidence pointed to an earthquake induced clockwise rotation of both bridge decks when viewed from above. The magnitude of the permanent lateral shift at the southern abutment, measured between masonry and sole plates, was found to be more than one inch. The deck rotation caused the bridge decks to slam against the southern abutment thereby cracking the abutment backwalls, and cracking, spalling, and pushing away the wingwalls and curtain walls. A close-up of a broken curtain wall alongside the bridge on the left in Fig. 5.5 is shown in Fig. 5.9. The rotational motion also displaced the concrete bridge decks at the expansion joints. A typical example is shown in Fig. 5.10, which shows a view north from the southern abutment along the edge of the bridge on the right in Fig. 5.4. Figure 5.11 shows a wingwall that cracked due to the bearing action against it of the abutment backwall. There was also evidence of considerable longitudinal motion at the southern abutment as seen from Fig. 5.12 which shows the disengagement of an aluminum pipe railing at a sleeve joint in the vicinity of the deck expansion joint. The movement there must have exceeded 3" to cause the separation. The gaps between the expansion joints at the southern abutment were found to have widened indicating that the abutment backwalls were pushed towards the approach fill. In general, the shifting of the decks caused adjacent deck sections to impact at several expansion joint locations which cracked and spalled the concrete along the deck edges. An example is shown in Fig. 5.13.

Most of the Ward Memorial bridge bents sustained damages that ranged from light cracking, incipient spalling, to localized deep spalling that exposed reinforcement bars. The location of these damages was generally confined to the tops of columns extending sometimes to the vertical sides and soffits of the bent caps. The spalling and cracking were almost always at diagonally opposite corners of the columns oriented transversely to the bridge centerline. Deep spalling that exposed rebars occurred at corner locations of three columns, of which two are shown in Figs. 5.14 and 5.15. Note the exposed #10 rebars which have been bent out.

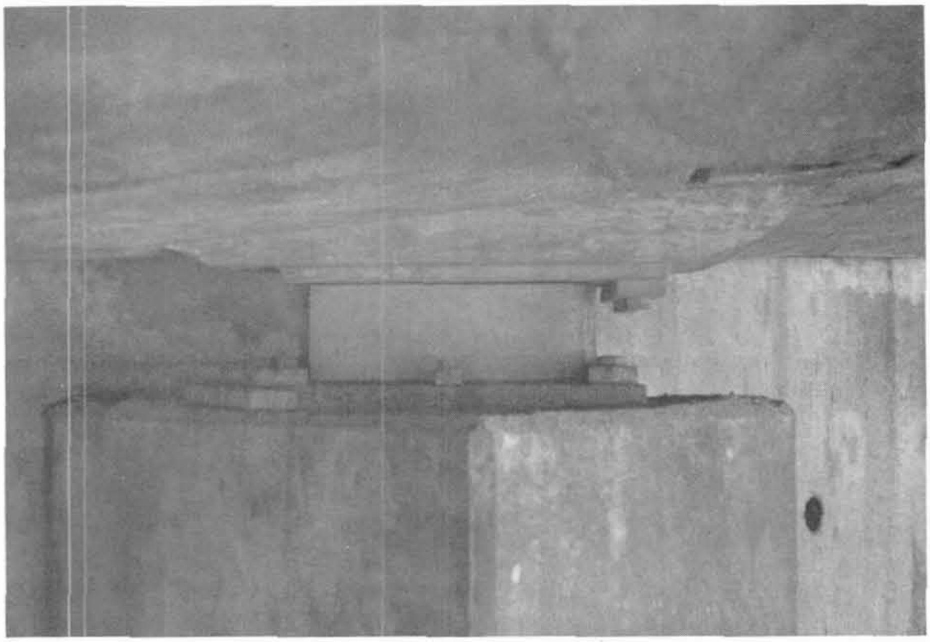


Fig. 5.7 Rocker bearing resting between sole plate above and masonry plate below, with missing keeper plate at top left (eastern end of bearing).

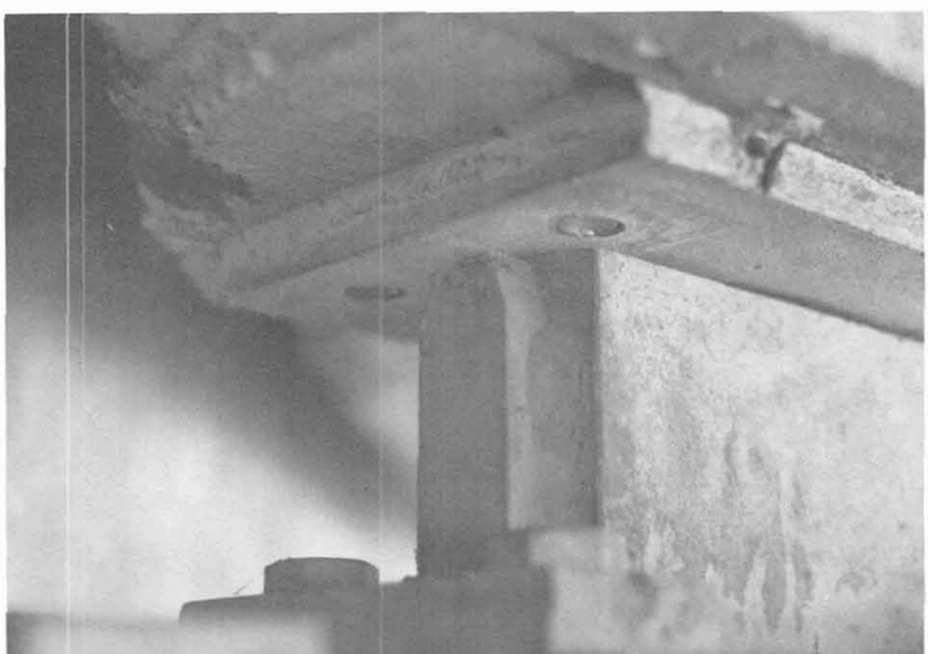


Fig. 5.8 Close-up of rocker bearing showing remnants of sheared keeper plate bolts at top.

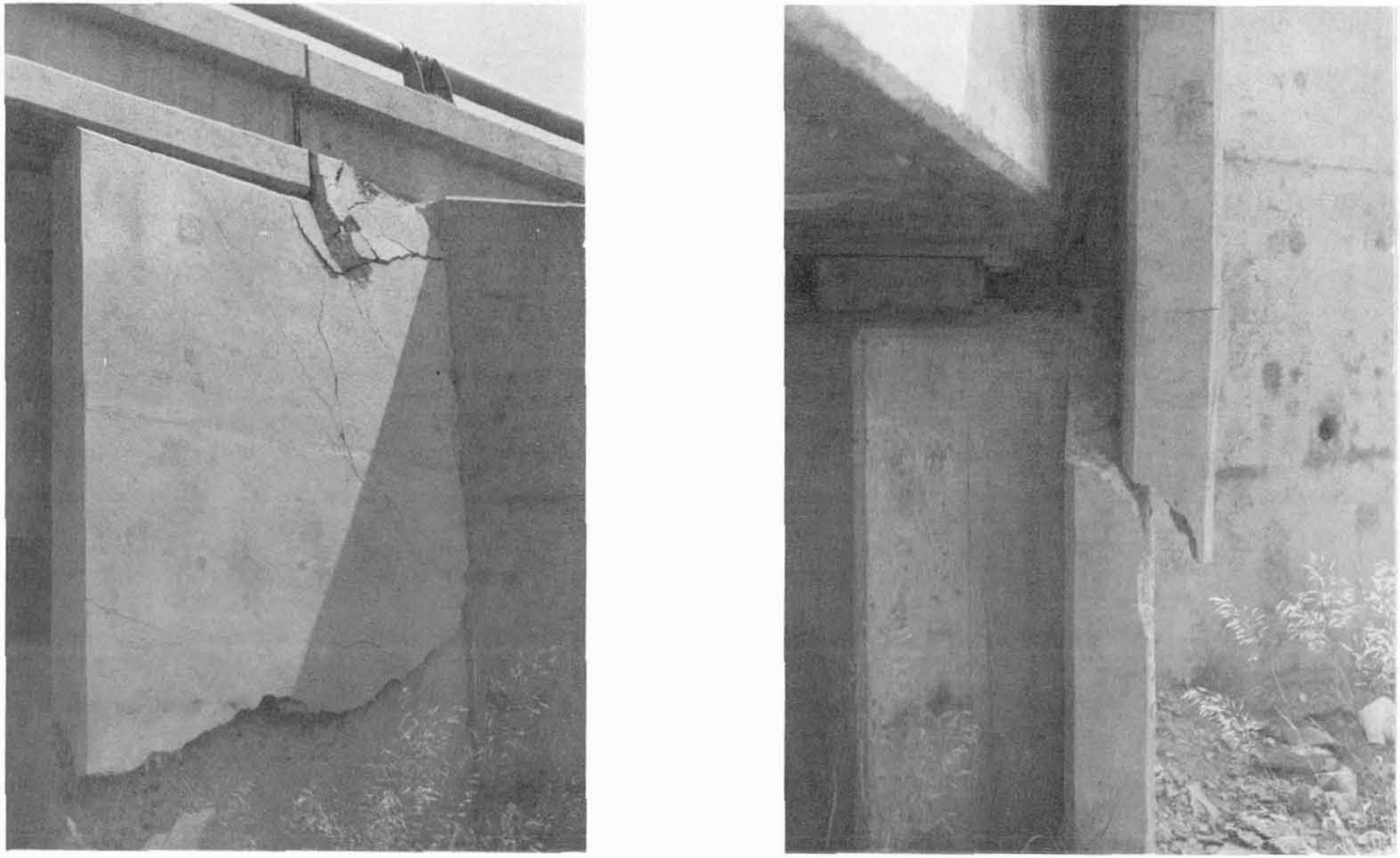


Fig. 5.9 Cracked curtain wall of Ward Memorial Boulevard bridge at southern abutment joint, curtain wall visible in Fig. 5.5 against left bridge.

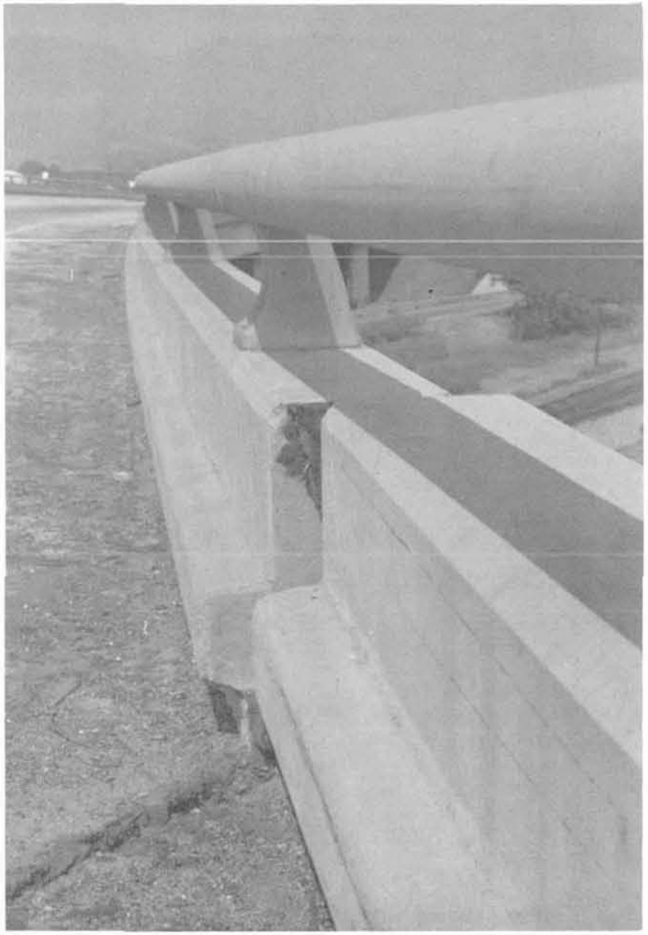


Fig. 5.10 Transverse displacement of Ward Memorial Boulevard bridge deck at southern abutment joint. (Bridge on right in Fig. 5.4). View looking north along railing. Offset is three inches.

Fig. 5.11 View looking west at joint shown in Fig. 5.10. Vertical crack is on line with face of abutment backwall.

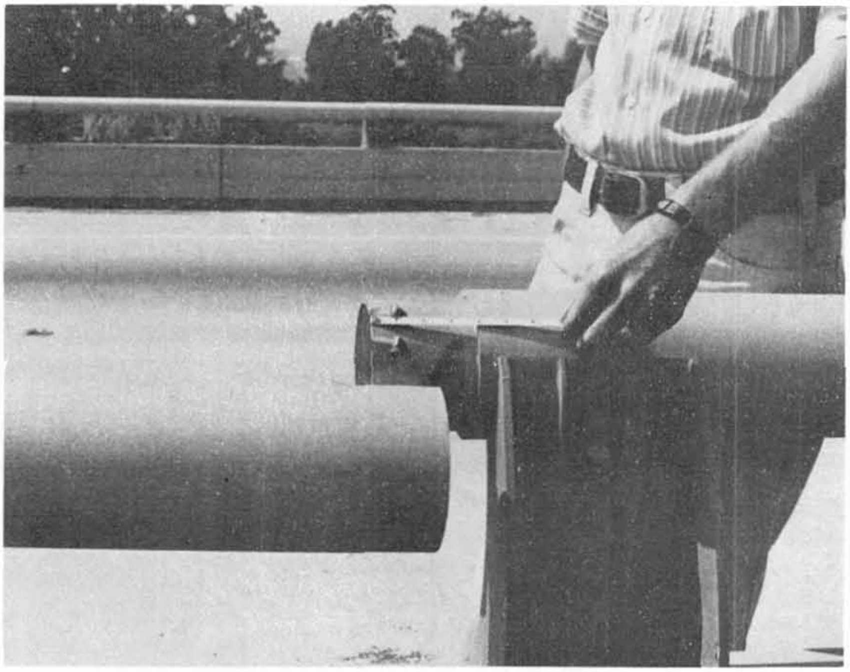


Fig. 5.12 Railing separation along Ward Memorial Boulevard bridge at southern abutment joint, view looking west across bridge on right in Fig. 5.5.

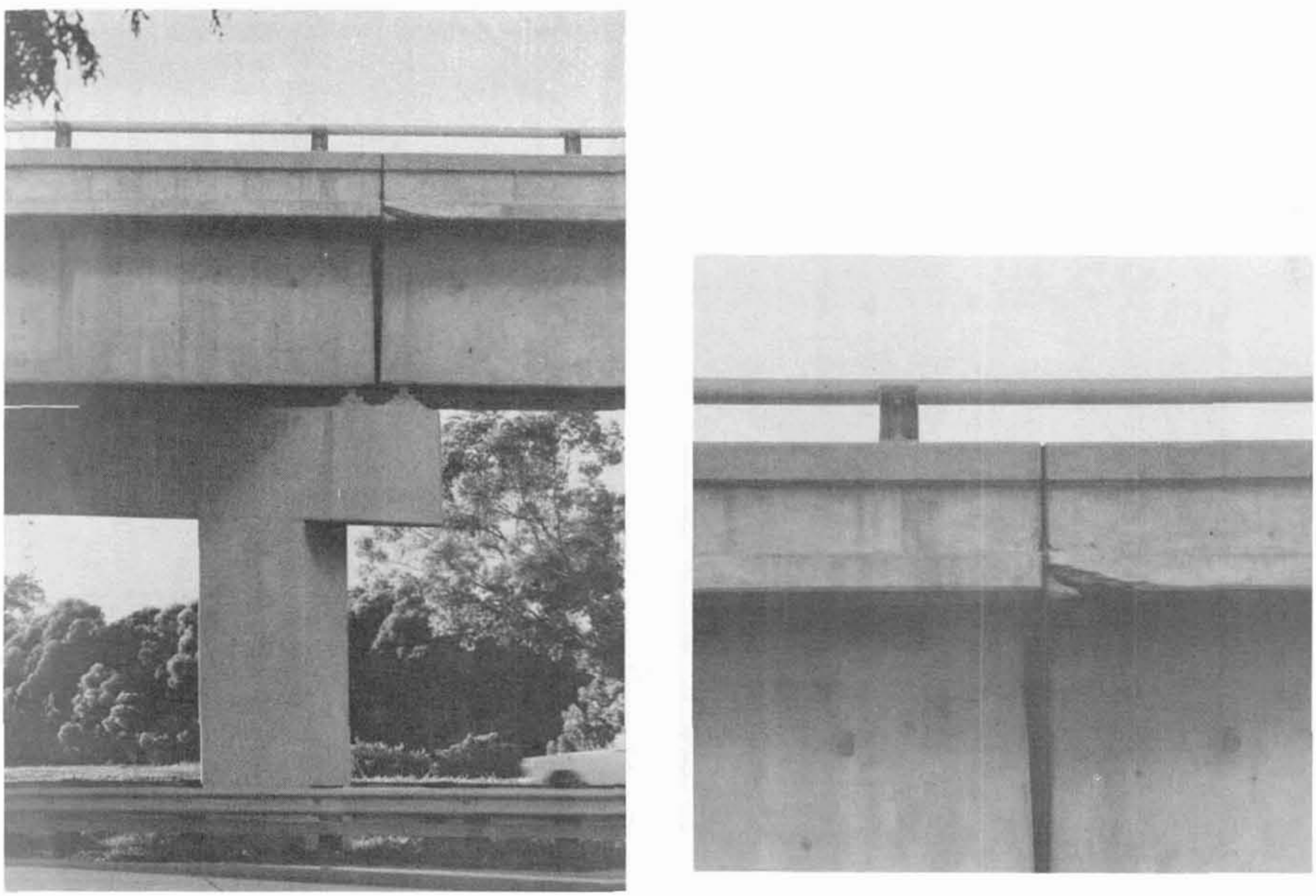


Fig. 5.13 Joint damage on Ward Memorial Boulevard bridge deck. View looking west at bridge on left in Fig. 5.4.

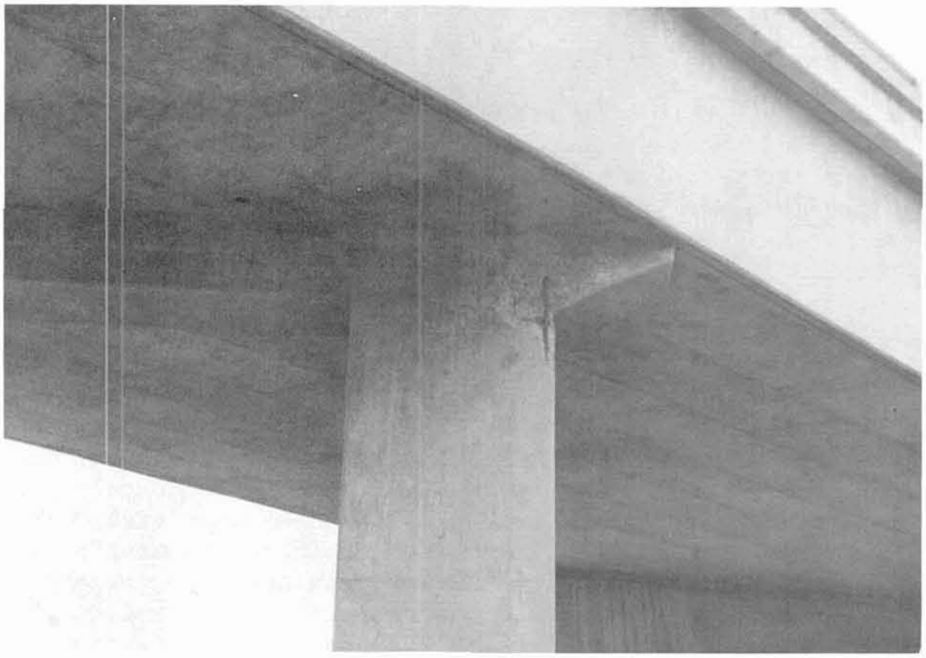
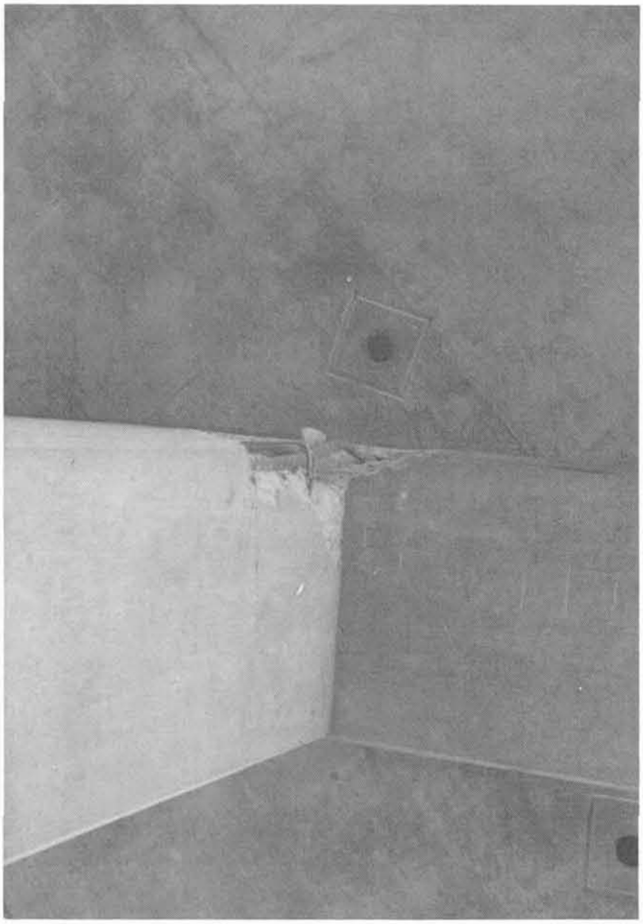


Fig. 5.14 Damaged bent supporting Ward Memorial Boulevard bridge deck, view looking west at bridge on left in Fig. 5.4.

Fig. 5.15 Damaged column supporting Ward Memorial Boulevard bridge deck, back-side view of column in Fig. 5.13. Buckled bar is #10.



There was also evidence from the contour of the ground surface in the vicinity of the Ward Memorial bridges' southern abutment footings, and nearby column footings, that the soil had undergone large displacements. Apparently, the footings were subjected to considerable movement. However, because the surface soil was a loose and sandy silt material, no clearly defined earth edges were created. It was also found that the approach fills at the southern abutment had settled causing the pavement to sag. A settlement of 2" was noted near the paving notch, and 5" against the wingwalls.

The Hollister Avenue bridge is 241 feet long with two single precast-prestressed concrete girder spans and two simple cast-in-place concrete T-beam spans. The bridge deck rests on rocker bearings at the abutments and on two-column bents at mid-span. The earthquake damages to this bridge were similar to the Ward Memorial bridge damages, but they were less severe. Keeper plate bolts were sheard at the southern abutment in a manner indicating a clockwise motion of the deck when viewed from above. The bridge deck pushed against the southern abutment backwall and wingwall, widening the expansion joint gaps and cracking the wingwall. Shifting of the bridge deck caused adjacent sections to impact which damaged joint sealants and cracked and spalled the deck rails. Lateral motion of the bridge deck displaced the soil around some column footings. The columns themselves suffered no damage, only the bent caps and some deck girders incurred light cracking and incipient spalling. There was also some settlement at the approaches.

Damage to the Glenn Annie bridge consisted of some sheared keeper plate bolts at the southern abutment. A number of other bridges in the area showed signs of movement but no significant damage. Bridge approaches as far away as 23 miles west of Santa Barbara needed leveling following the earthquake. The Ward Memorial bridges were closed to traffic for more than 24 hours to ascertain their structural integrity. The total damage to all bridges was estimated to be one-half million dollars.

A survey of roads, walks, and bikeways in the Goleta area revealed that the most significant damage to concrete and asphalt surfaces was cracking at earth-fill locations, but that the cracking was only minor. The most severe and also spectacular damage occurred along a sidewalk which parallels Los Carneros Road, where compression of the concrete sidewalk slab caused large pieces of it to literally buckle up and overturn as can be seen from Figs. 9.7 and 9.8.

5.3 Effects on Airport Facilities

Just north of the UCSB campus lies the Santa Barbara Municipal Airport which is operated by the City of Santa Barbara and covers nearly 1000 acres. There are nearly 100 buildings on the airport property, scattered along the northern and eastern perimeters. The buildings comprise a mixture of hangars, and single story office and service buildings. The majority of the buildings are wooden and of World War II vintage and are left over from a former military air base. Most of the damage to the airport buildings was confined to architectural damage. The most notable structural damage was limited to two hangars and the airport control tower. These damages are described in Chapter 7. With these exceptions, the remaining structural damage consisted of cracked concrete floor slabs in two buildings and shifted wood columns and walls in one of them. The shifting was in a north-south direction. Except for a brief period of evacuation of the control tower, operations at the airport went undisrupted. The power failure in the Goleta area left the passenger terminal and the runways without lights. The tower continued operation with a backup power system.

5.4 Acknowledgments

The authors wish to thank Mr. C. Klassen of the Department of Transportation, State of California, for making possible an inspection tour of the Ward Memorial Boulevard bridges after the earthquake. The authors also thank Messrs. O. Degenkolb and P. Kim, of the Department of Transportation, for making available their written reports on the damaged highway overpasses.

6. EARTHQUAKE EFFECTS ON UTILITIES

6.1 Effects on Water Services

Two separate water distribution systems serve the greater Santa Barbara area. One is operated by the Goleta County Water District, which serves the area roughly west of Ontare Road, and the other by the Water Resources Division of the City of Santa Barbara Public Works Department, which serves the adjoining area east of Ontare Road. Of the two systems, the Goleta County Water District suffered the most serious loss of about two million gallons of filtered water as a result of two separate incidents triggered by the earthquake. At the district's Corona del Mar water purification plant, operators noticed something was wrong downstream when the water level in a five-million gallon reservoir began dropping rapidly. It was determined that a bypass regulating valve had malfunctioned causing a downstream storage reservoir to overflow. Another leak was caused by a break in an 8" meter line serving the UCSB area (Fig. 6.1). A leak not related to the filtered water loss occurred when a 6" pipe tapping the 33" so-called Goleta West Conduit broke at the Double C Ranch and caused a water loss of about 500 to 800 gallons per minute before the leak was shut off. The total cost of repairs to the Goleta water system was set at $5,000.

Sheffield Reservoir of the City of Santa Barbara, which failed in the 1925 earthquake, had to be drained of half of its water to repair an earthquake-caused leaky valve. The city also experienced several water main breaks, two near the western edge of the downtown area and four along the northern perimeter of the airport.

The sewer system of the greater Santa Barbara area came through the earthquake relatively unscathed. There was one report of a backed up sewer in the city. West of the city, inspection and die tests of the Goleta Sanitary District's mile-long, 36" outfall, lying on the ocean floor east of Goleta Point, revealed no leaks. The die was added to the ocean discharge and the pipeline was then checked for leaks by overflying it. A crack, however, was found in the reinforced concrete wall of the outfall junction box, where the land and marine reaches come together. The crack allowed subsurface water to flow into the structure.

Caretakers at three dams on the Santa Ynez River reported that the earthquake was felt only mildly at the dams. The tunnels through the Santa Ynez Mountains which bring water to the coastal regions from Juncal, Gibraltar and Cachuma reservoirs were undamaged. One indication of this was the lack of debris and cloudiness of the tunnel discharge following the earthquake. Further discussion on the performance of dams may be found in Chapter 9.

6.2 Effects on Natural Gas Service

The Southern California Gas Company, which supplies natural gas to the Santa Barbara area, reported that all three of its major supply lines into the area suffered no damage. Damage to the distribution pipeline network was minor. Only two leaks of any significance were detected, one at a rusty connection which was shaken loose by the quake,

Fig. 6.1 Broken eight inch diameter water line along Los Carneros Road.
(Goleta Today photo. Reproduced by permission.)

and another at a welded joint in a 2" main which parted about 1/4". The only service line suffering damage was an abandoned line which broke beyond a shutoff valve. Recapping of the line was required. Total damage was estimated to be $1,000. Gas leaks reported by residents turned out, in most cases, to be from extinguished pilot lights.

The earthquake raised again the controversial question of the acceptability of a proposed liquified natural gas (LNG) tanker terminal site at Cojo Bay, near Point Concepcion, located approximately 80 kilometers west of the epicenter of the earthquake. At least one minor active fault is known to cut across the eastern portion of the site. According to a company spokesman for the operators of the proposed terminal, on-site inspections following the earthquake by company geologists and by geologic consultants to the California Public Utilities Commission revealed no signs of earth movement along the on-site fault, nor at the walls of investigative seismic trenches. The only observable effect was some soil slippage along the coastal bluffs.

6.3 Effects on Electric Power Service

Electrical service is provided by the Southern California Edison Company. The company reported that following the earthquake, about 10,000 customers in the Goleta and western Santa Barbara area were without power for up to five hours before service was restored. The interruption in service occurred when about a third of the company's 16,000 volt distribution circuits became inoperative as a result of swaying and subsequent touching of powerlines. In some instances, the wires were damaged by the resulting electrical discharge. The total damage was set at $35,000. Several fires were started by downed wires. However, the fires were quickly contained by county firemen.

6.4 Effects on Telephone Service

The General Telephone Company of California, which serves the Santa Barbara area, reported no equipment failure or significant disruption in service within the earthquake stricken area. The only noticeable change in service was a temporary increase in the number of local and out-of-town calls which taxed the local switching system and operators, and resulted in some delays.

6.5 Acknowledgments

The authors wish to thank the following people who provided earthquake damage information used in this section: Mr. Gutshall, of the Southern California Edison Company, Mr. L. Lane, of the Goleta County Water District, and Mr. Pisano, of the Southern California Gas Company.

7. EARTHQUAKE EFFECTS ON BUILDINGS

7.1 General Features and Summary

There were no deaths or serious injuries as a result of structural failures in the earthquake. The structural integrity of the majority of the buildings in the area of strong shaking was not seriously impaired, although significant damage was sustained by a variety of structures. Had the duration of strong shaking lasted a few seconds longer it is likely that a number of structures would have sustained serious damage. As in other recent earthquakes, wood or steel structures generally sustained less severe damage than concrete or masonry structures, although some well designed reinforced concrete structures survived with no apparent damage.

As noted in previous sections of this report, the most intense ground motion apparently occurred west of Santa Barbara near Goleta. Consequently, structures in the Goleta area generally suffered more damage than those in Santa Barbara. Many of the major structures in Goleta are located on or near the UCSB campus. These structures include a number of reinforced concrete shear wall buildings up to 8 stories in height located on the UCSB campus itself (see Fig. 3.2), several large steel frame hangars and a control tower at the adjacent municipal airport (Fig. 1.2), a pair of high rise (10 and 11 story) reinforced concrete shear wall dormitories west of the UCSB campus, and a number of long low rise (1-3 story) commercial buildings north of the campus. The majority of the remaining buildings in the Goleta area consist of conventional 1 and 2 story wood frame and commercial buildings. A considerable number of 1-3 story wood frame apartment buildings and duplexes are located in the area, notably in the community of Isla Vista which borders the UCSB campus on the west side (see Fig. 1.2). Finally, there are several mobile home parks in the area located east, north and west of the campus.

Except for a few old wood frame and adobe structures (mostly farm houses), the buildings in Goleta are relatively modern. The majority of these buildings have been constructed within the last 20 to 30 years. Since 1955, building code requirements for earthquake resistance in the Goleta area have been provided by the contemporary edition of the Uniform Building Code.

The total earthquake damage to structures and buildings on the UCSB campus is currently estimated at $3.44 million. Of this total approximately $300,000 in structural damage was sustained. An additional $2.36 million in mostly minor damage is estimated to have been incurred by other structures in the Goleta area, including some 25,000 housing units. Most of the damage to privately owned structures was sustained by mobile homes ($1.62 million) and businesses ($740,000). Of the 148 businesses which were damaged, 68 are apartment buildings with approximately 6 units each. Very little structural damage was sustained by single family dwellings.

The most common structural damage suffered by large buildings consisted of diagonal cracking of concrete shear walls, particularly those aligned along the north-south direction. The most common damage to residential and small commercial buildings consisted of cracking of plaster walls (particularly in multistory buildings), differential settlement of foundations, the failure of a few unreinforced chimneys, fallen hot water heaters, and broken glass. Approximately 25% of the mobile homes in the area were damaged by the earthquake. Many were knocked from their foundation piers and fell mostly toward the south, rupturing utility connections in the process. Over one-third of the mobile homes in a few parks were damaged in this way. Most mobile homes in the area are mounted on piers without adequate lateral reinforcement. Selected examples of the type of damage sustained by the various structures in the Goleta area will be discussed in more detail later in this chapter.

Structures in the Santa Barbara area display a wider variation of age, architecture, and construction than those in Goleta. However, damage to structures of all types was comparatively minor in Santa Barbara.

There are only 4 buildings in Santa Barbara which are 5 or more stories high, and each is more than 25 years old. (Local city zoning ordinances have prevented the construction of additional buildings over 4 stories or 60 feet in height since 1972.) These buildings vary in height up to 8 stories, and the majority are of reinforced concrete shear wall construction. Several of these major buildings were damaged in previous earthquakes (Steinbrugge and Moran, 1954) and were subsequently repaired. In the present earthquake a number of these buildings received minor diagonal cracks in the reinforced concrete shear walls, particularly in the lower stories. In most cases repairs, when needed, will consist of epoxy injection to rebond the cracked surfaces. An example of a building which suffered slight damage of this type is the Freitas Building at 200 E. Carrillo Street (see Fig. 3.6). This building is well instrumented, as noted in Chapter 3, and 9 strong motion records were obtained from different locations within the building. Another large building which suffered minor damage is the Santa Barbara County Administration Building (see Fig. 7.1) located at the corner of Anacapa and Anapamu Streets, in Santa Barbara. This structure is a nonductile reinforced concrete rigid frame with no shear walls. Minor diagonal tension cracks forming an X pattern were developed in some of the columns on the north side of the building, as shown in Fig. 7.2. The Santa Barbara County Court House (Fig. 3.12), across the street from the Santa Barbara County Administration Building, suffered only minor cracking. Total structural and nonstructural earthquake damage to all public buildings in Santa Barbara was estimated at $500,000 to $600,000.

The many smaller old buildings in Santa Barbara, mostly residences, survived the earthquake essentially undamaged. For example, the old Santa Barbara Mission sustained no apparent damage. It is noteworthy that building codes enforced by the City of Santa Barbara have included provisions for earthquake resistance since 1926 as a consequence of the major damage suffered in the earthquake of 1925 (an account of the 1925 Santa Barbara Earthquake is given in Volume XV, No. 4, December 1925, Bulletin of Seismological Society of America). In the present earthquake it has been reported that architectural damage (cracked plaster, broken glass, etc.) to the smaller old buildings in Santa Barbara may have been less severe than that incurred by similar new buildings in this area, which are often more flexible.

Fig. 7.1 Santa Barbara County Administration Building, a reinforced concrete rigid frame structure.

Fig. 7.2 Shear crack forming an X pattern in column in second story of Santa Barbara County Administration Building.

A few very old adobe or wood frame buildings in the Goleta area received serious earthquake damage. For example, a large unreinforced adobe residence located near Coal Oil Point on the West Campus of UCSB received serious damage to several bearing walls in localized areas on the second floor. The building was constructed around 1920. The oldest American-built structure in the Goleta Valley, a large multi-story wood frame building known as the "Stow House", sustained significant cracking of plaster walls in many rooms, but did not sustain serious structural damage. The building is mounted on a high foundation with long redwood joists and supporting piers, and was built in 1872.

7.2 Effects on Structures at the University of California, Santa Barbara

There are approximately 50 permanent buildings and a number of temporary buildings on the UCSB campus. Significant structural damage was sustained by at least 10 of the permanent buildings. It is likely that more serious structural damage was partly prevented as a result of a seismic review program recently instituted by the University. As part of this program, a review of the seismic integrity of all buildings on campus was performed by a consulting structural engineer (Mendes, 1973). Several deficiencies were identified in this review, the most serious of which were fortunately corrected before the earthquake. One such rehabilitated structure which received less than serious earthquake damage is North Hall. Following a brief description of soil conditions, construction history and overall structural damage on the campus, a description of the structural damage sustained by North Hall and several other buildings will be presented.

Soil Conditions

The following description of the underlying soils and foundation material at the campus site was given by Mendes (1973):

> The underlying natural soils consist of silty sand to depths of 10 to 17 feet, underlain by shale to depths in excess of 100 feet. The upper soils are moderately firm at (normally dry) moisture content but would become somewhat weaker and more compressible when wet. Water seepage is usually found in most borings at depths ranging from 6 to 17 feet depending on particular location, past fainfall, etc. In almost all instances, seepage occurs in the silty sand (and sea shell layer) immediately above the shale stratum. This results in a perched watertable against the shale formation. Generally, only one and two story buildings are supported on the silty sand.
>
> The underlying shale is firm to very firm, and usually no difficulty is experienced in penetrating the shale with conventional bucket-type drilling equipment. Some hard, cemented silicious layers are occasionally encountered which require jack-hammers or similar equipment to penetrate through them. Generally, buildings three stories and higher are founded in

the shale formation. Depending on the depth to the shale and foundation loads, conventional spread footings, drilled-and-belled caissons or straight drilled cast in place friction piles are used.

There has been very little heavy site grading except during the period of development at this general location of a U.S. Naval Facility in 1942. All permanent campus buildings have usually been sited within about two feet of existing natural grade.

Construction History

The permanent buildings on the UCSB campus were constructed during the 26 year period between 1952 and 1978. The design of each was governed by the earthquake safety requirements of the then contemporary edition of the Uniform Building Code. Buildings of the University of California are not required to conform to the earthquake resistance standards of public schools in California (Field Act, 1933).

The buildings are generally of Type I (fire resistive) construction, one to eight stories in height, wherein the floor and roof framing system are of reinforced concrete. Columns and bearing walls are usually of reinforced concrete, but some reinforced concrete block construction was utilized in a number of buildings constructed prior to 1962. The lateral force resiting system of almost every building is reinforced concrete or concrete block shear walls (Mendes, 1978).

Overall Structural Damage

The most common form of structural damage to permanent buildings consisted of moderate cracking of shear walls in the lower stories. The pattern of cracking was predominantly diagonal, with walls aligned along the north-south direction usually sustaining more severe damage than east-west walls. Such damage to reinforced concrete shear walls occurred most extensively in the Biological Sciences II, Engineering, Library III, University Center and North Hall buildings (see Fig. 3.2). In most cases repairs will consist of epoxy injection to rebond the cracked surfaces in the shear walls.

Among those buildings with concrete block shear walls, the most severe cracking occurred in Anacapa, Santa Cruz and Santa Rosa residence halls. Epoxy injection repairs are required in each hall. Sixteen shear walls in Anacapa and another sixteen in Santa Cruz were so badly damaged that replacement was necessary. However, the severity of damage sustained in these walls apparently resulted in part from the absence of grout around the steel reinforcement in some parts of the shear walls, and such other occasional deficiencies as missing or mislocated steel reinforcement, and inadequate laps and splices.

North Hall

North Hall is located at the south-east corner of Ocean and Campus Roads (see Fig. 3.2). The building is a three story reinforced concrete shear wall structure with plan dimensions of 240 feet by 34 feet. Photographs of the structure are shown in Figs. 3.4 and 7.3. A seismic joint isolates the structure from an adjoining building complex at the east end.

North Hall is of particular engineering significance for several reasons. First, as previously noted, a review of the seismic safety of the structure as originally designed and constructed (Mendes, 1973) revealed a serious deficiency in lateral load resistance which was corrected by the later construction of additional shear walls. These added shear walls conform to the earthquake resistance provisions of the 1976 edition of the Uniform Building Code. Rehabilitation of the structure was completed on May 13, 1976. Secondly, an extensive series of pre- and post-rehabilitation forced vibration tests were performed on the structure before the earthquake (Hart and others, 1978). The natural frequencies, mode shapes, and damping ratios in the fundamental mode were measured for translation in the north-south and east-west directions, and for torsion. The pattern of soil motion near the structure was also measured. Lastly, a very good collection of 9 strong motion accelerograms were recorded in North Hall during the earthquake, and are presented in Chapter 3 of this report. The peak structural acceleration of 0.94g recorded on the roof is among the largest ever recorded anywhere, as of this date.

Shown in Fig. 7.4 is the typical floor plan locating the shear walls in the structure in its rehabilitated form and also the interior and exterior columns. Details of the reinforcement of these shear walls are provided in Table 7.1. Shown in Figs. 7.5 and 7.6 are the east-west and north-south elevations, respectively. The new 24 foot long east-west shear walls are easily seen in the photographs of Fig. 7.3.

The building is founded on drilled and belled caissons. Allowable bearing pressure of the underlying soil is about 10,000 psf. The floor slab is 4 inches thick at ground level. The reinforced concrete floor and roof framing in the remainder of the building consists of a 2½" slab supported by concrete pan joists (Fig. 7.8) running the length of the building in the east-west direction. The joists are supported at about 24 foot intervals by the girders shown in Fig. 7.7 which run in the north-south direction between exterior columns. Full scale tests of this structure revealed that the floor slabs do not vibrate as rigid bodies, but rather they sustain significant in-plane deformation.

The structure has twenty interior and twenty exterior columns. A section through a typical interior column is shown in Fig. 7.9, and a typical exterior column in Fig. 7.10. The pattern of reinforcement is noted in the figures.

The construction of the roof is similar to that of the floor slabs, except that it slopes up from each edge at an angle of 32.2 degrees with respect to the horizontal.

Fig. 7.3 East-west elevation of North Hall, UCSB, showing the east-west shear walls constructed during rehabilitation in 1976.

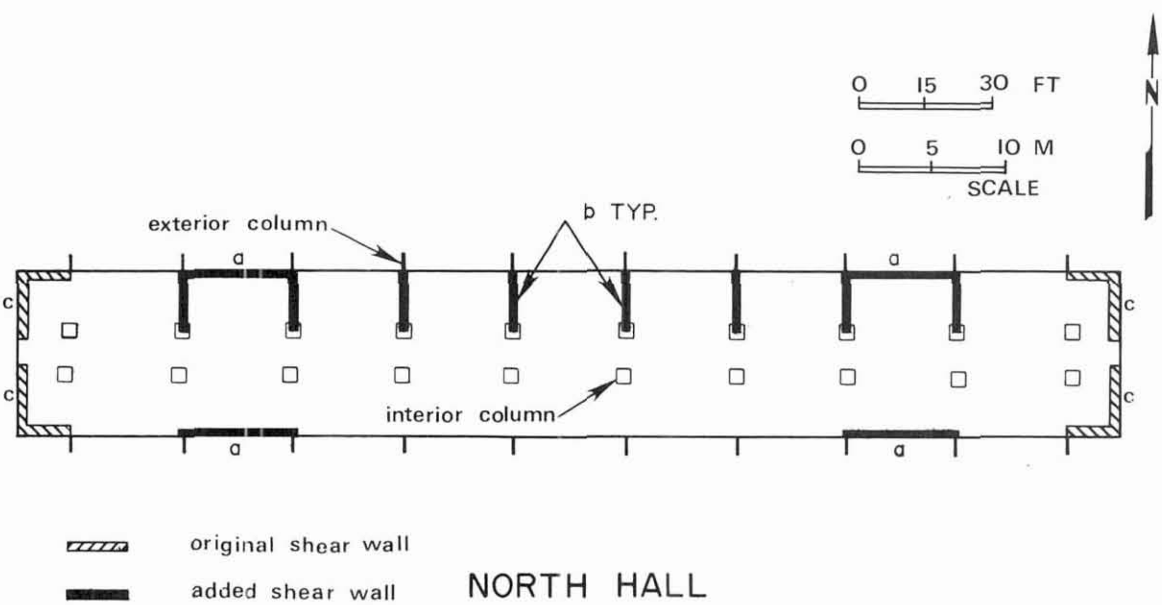


Fig. 7.4 Floor plan of North Hall, UCSB.

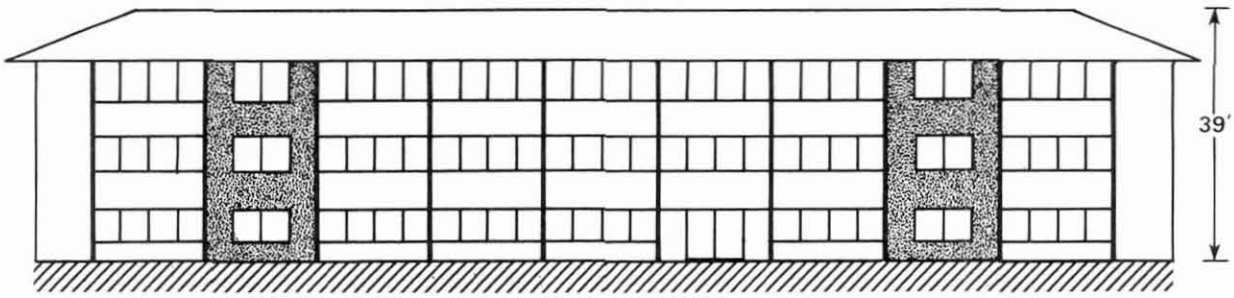


Fig. 7.5 East-vest elevation of North Hall, UCSB.

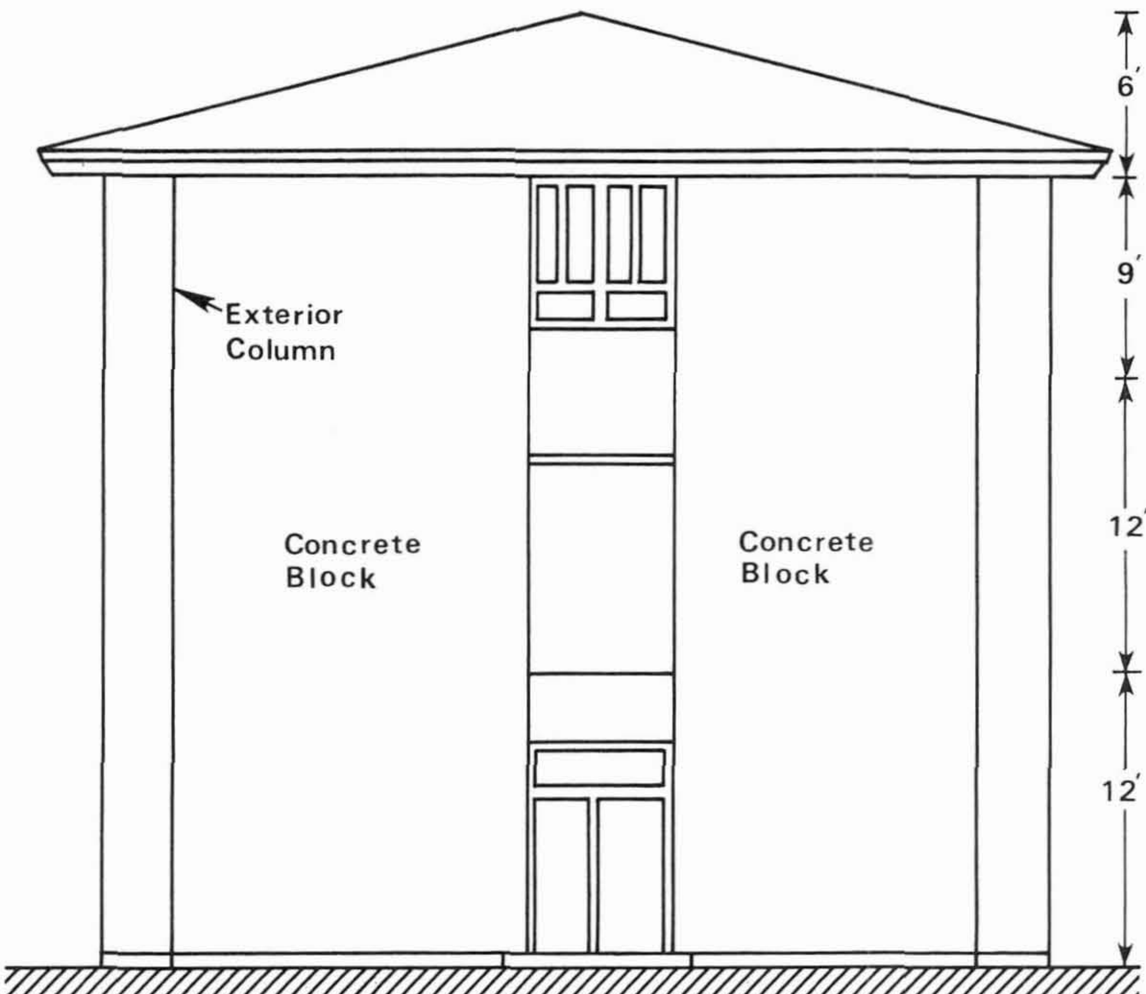
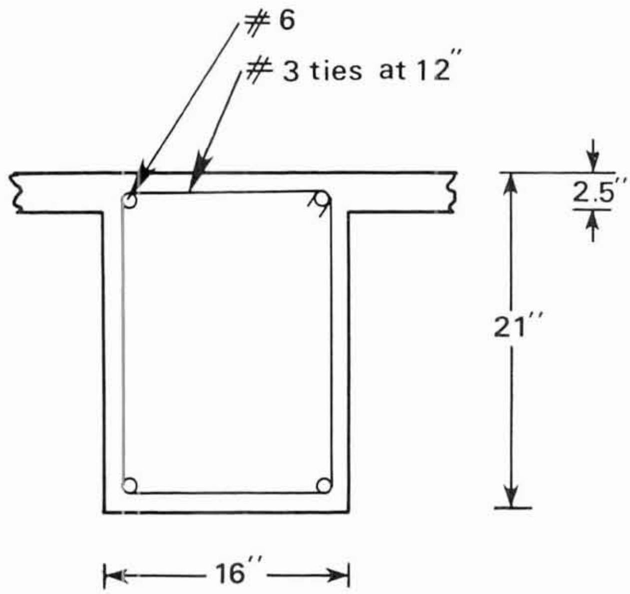
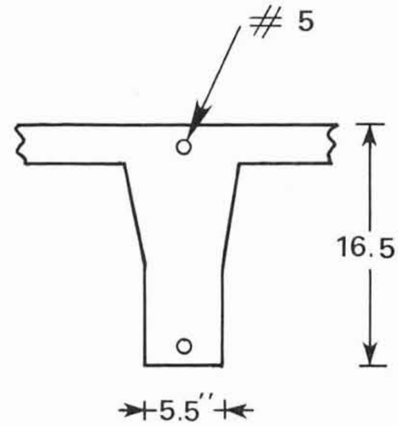


Fig. 7.6 North-south elevation of North Hall, UCSB.



NOTE: Reinforcement varies with loading

Fig. 7.7 Floor girder



NOTE: Reinforcement varies with loading

NOTE: Joists 3'-0" on center

Fig. 7.8 Pan joist

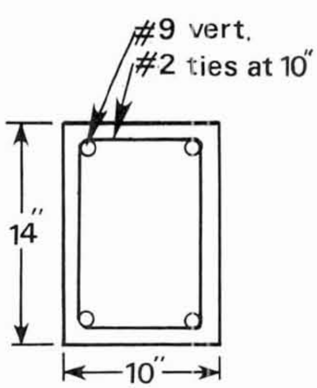


Fig. 7.9 Interior column

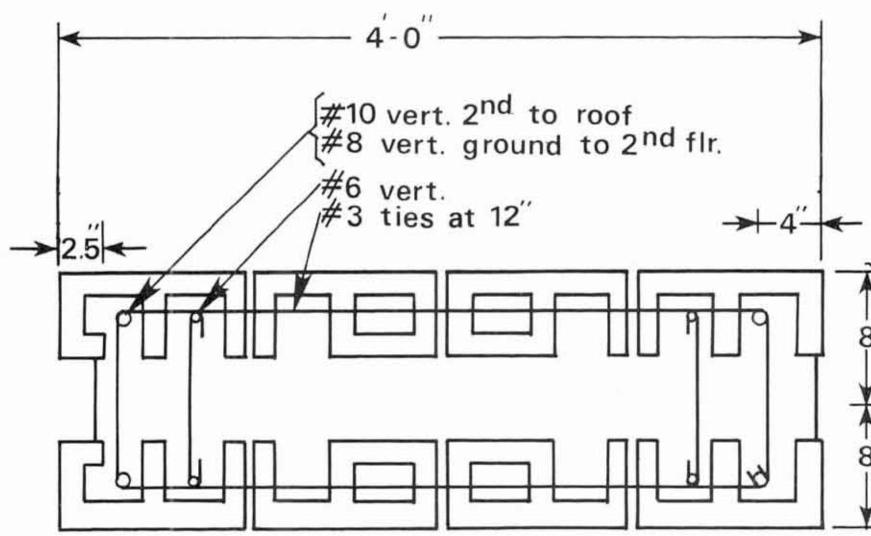


Fig. 7.10 Exterior column

North Hall, UCSB.

TABLE 7.1

DETAILS OF REINFORCEMENT IN SHEAR WALLS, NORTH HALL, UCSB

Wall (Fig. 7.4)	Specified Reinforcement
a	12 inch reinforced concrete wall vertical: #4 bars at 13 inches on centers, each face horizontal: #4 bars at 13 inches on centers, each face (additional horizontal and vertical reinforcement around window openings.)
b	6 inch reinforced concrete wall vertical: #4 bars at 13 inches on centers horizontal: #4 bars at 13 inches on centers
c	8 inch concrete block wall, stacked bond vertical: #4 bars at 24 inches on centers horizontal: #4 bars at 24 inches on centers

The minimum 28 day compressive strengths of the concrete mix are as follows: 3000 psi for the columns, floor beams, roof framing, and the new shear walls, and 1500 psi for the floor slab. In the new shear walls the reinforcing steel is grade 60 for #4 bars and larger, grade 40 for #3 bars and smaller, and is A36. Reinforcing steel in all other parts of the building is intermediate grade deformed bars meeting the requirements of A.S.T.M. A-15 and A-305, with an allowable stress of 20,000 psi (Hart and others, 1978; Mendes, 1973).

Structural damage to North Hall caused by the earthquake consisted of moderate cracking of the shear walls. Significant cracking occurred in all three stories of the newly constructed shear walls, with the most severe cracking occurring in the north-south walls in the first story. Very little cracking occurred in the original shear walls. The typical pattern of cracking to north-south shear walls consisted of primarily diagonal trending cracks of several feet in length, with some apparent X patterns as shown in Figs. 7.11-7.16. In the lower stories these cracks could often be identified on each side of the wall, indicating that the cracks extended through the entire thickness of these 6 inch shear walls. Some vertical cracks were occasionally observed parallel with the connection to the exterior columns.

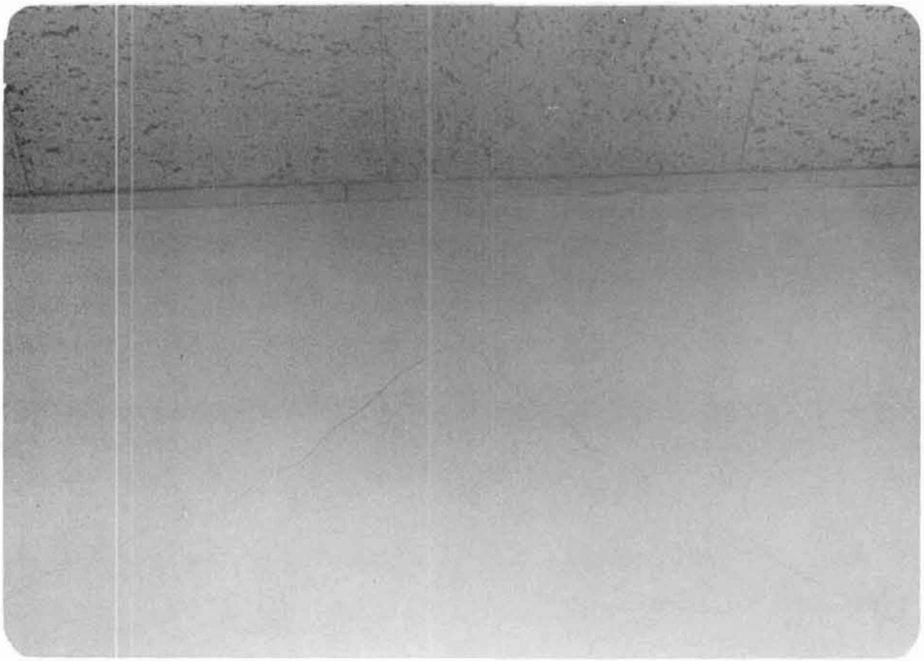


Fig. 7.11 Typical pattern of X cracking of north-south shear walls in first story of North Hall.

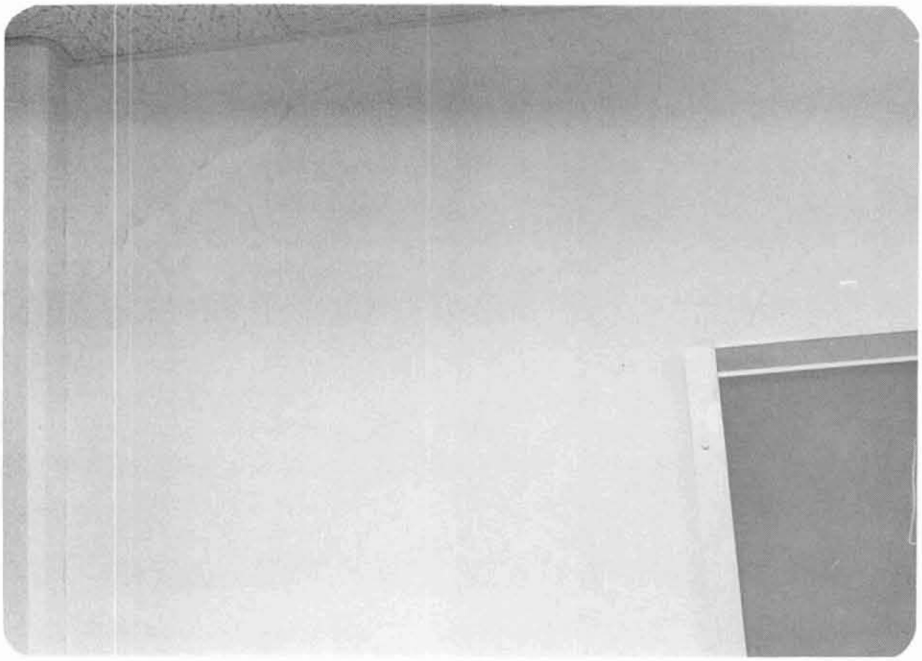


Fig. 7.12 Diagonal cracking of north-south shear wall in first story of North Hall. Vertical member at left is an interior column.

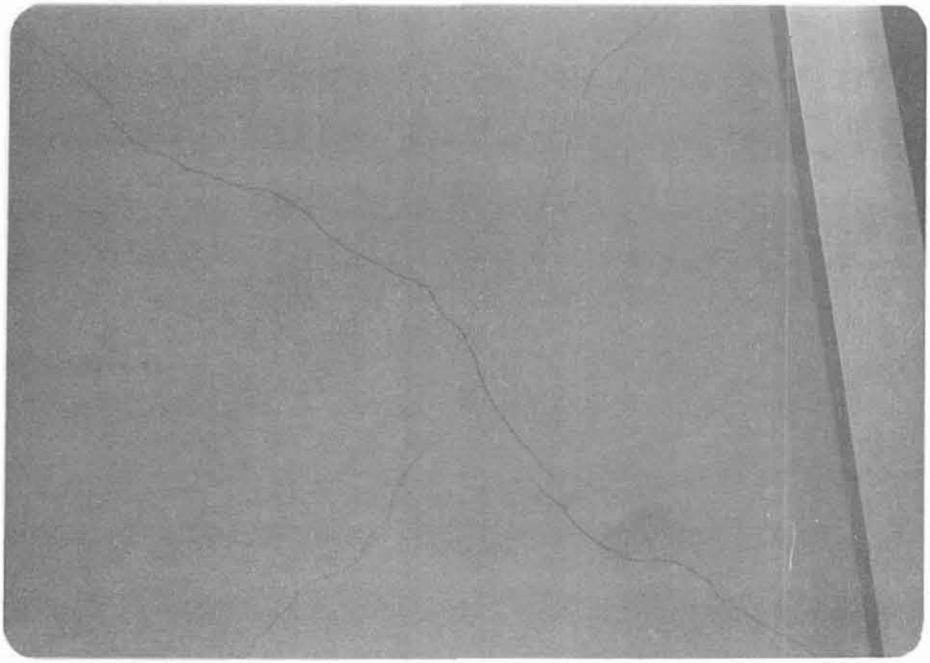


Fig. 7.13 Close up of cracking of shear wall in Fig. 7.12. Orientation is provided by the vertical blackboard frame at right.

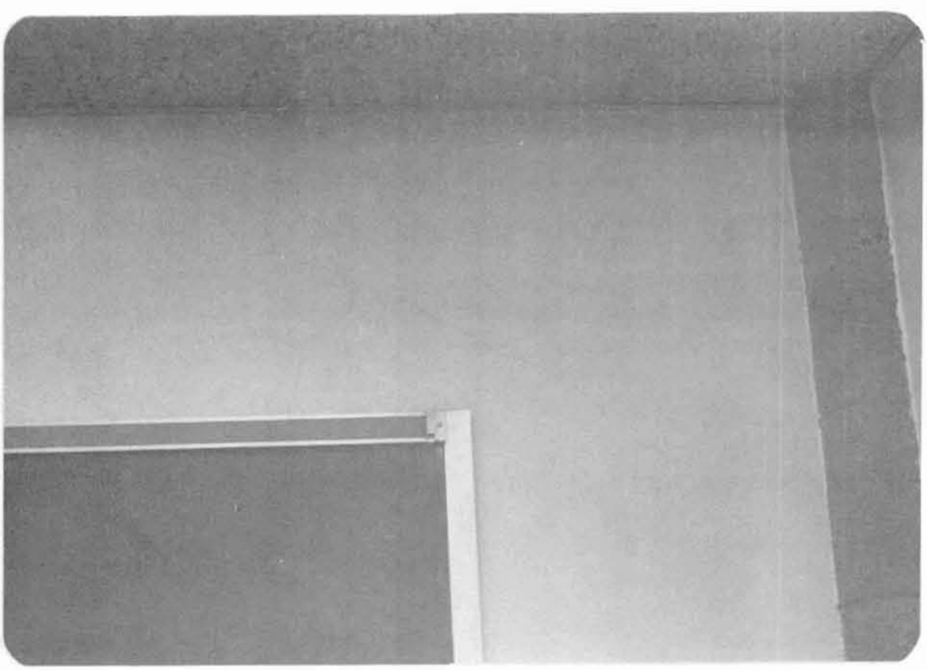


Fig. 7.14 More diagonal cracking of the same shear wall shown in Figs. 7.12 and 7.13.

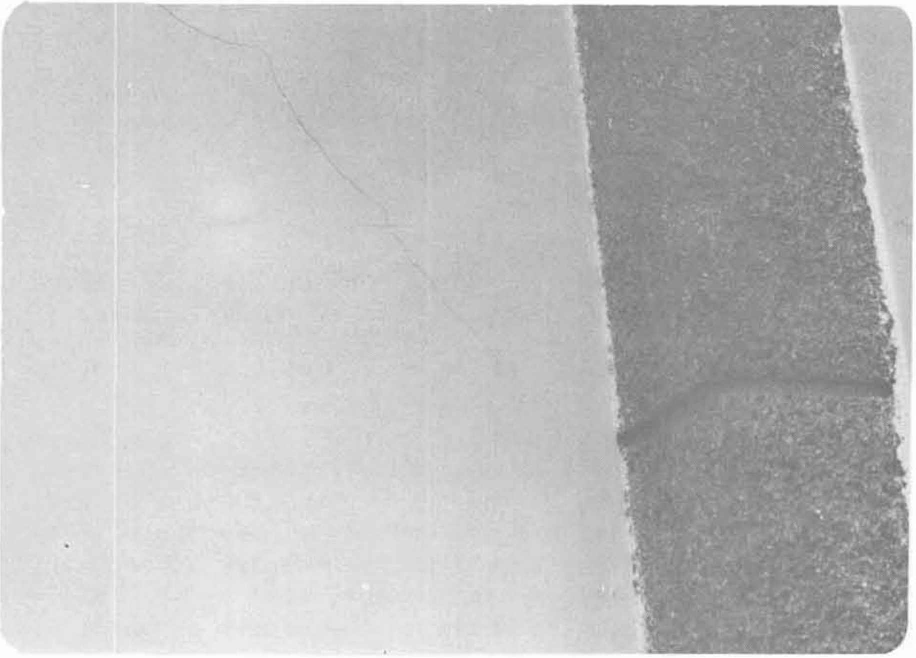


Fig. 7.15 Close up of right edge of diagonal crack in shear wall shown in Fig. 7.14. Vertical member is an exterior column.

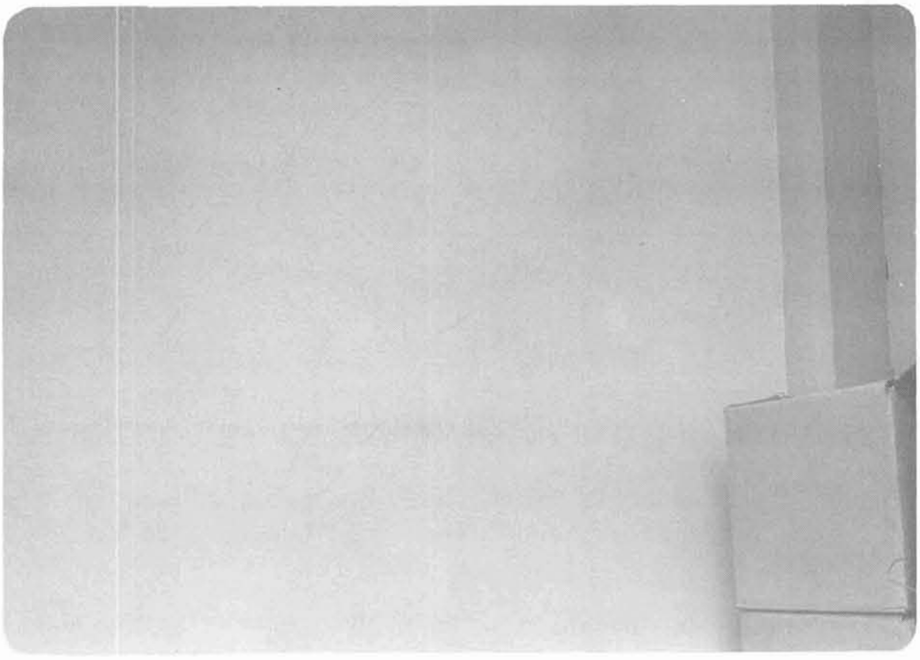


Fig. 7.16 Diagonal crack in north-south shear wall, North Hall.

The east-west shear walls typically sustained less severe cracking. The pattern of cracking consisted of diagonal trending cracks beginning at the corners of the windows and extending for several feet. Some occasional vertical cracks were observed below the windows, and a few horizontal cracks were observed at about mid-height of the windows.

No evidence of excessive soil motion or foundation damage was observed. The exterior columns did not appear to be damaged, nor did the seismic joint with the adjacent building to the east.

Anacapa Residence Hall

Anacapa Residence Hall and Santa Cruz Residence Hall received the most severe structural damage on campus. The two halls are structurally identical and were constructed almost simultaneously from the same set of plans and specifications. Each building consists of four "L" shaped 2 story reinforced concrete block residential units connected to a central one story rectangular shaped reinforced concrete block lounge-recreation unit. In plan view each building resembles a swastika, as shown in Fig. 7.17. Also shown in this plan view are the locations of the concrete block shear walls in a typical wing. Structural detail for the shear walls is specified in Table 7.2. The design of each building was governed by the earthquake resistance provisions of the 1955 edition of the Uniform Building Code. The minimum compressive strength of the concrete mix is 3000 psi, and of the concrete block, it is 1000 psi. The reinforcing steel meets the requirements of A.S.T.M. A-7.

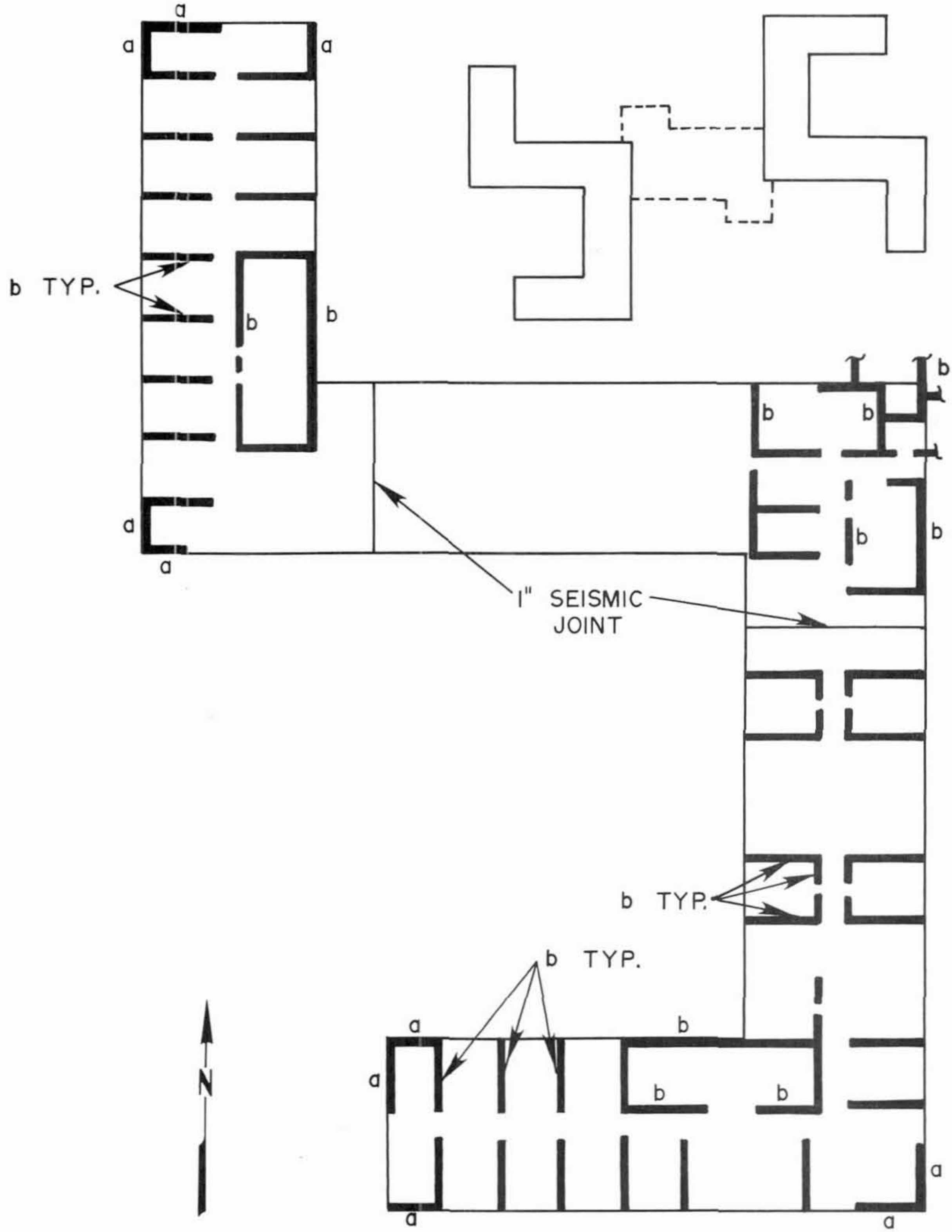
TABLE 7.2

DETAILS OF REINFORCEMENT IN SHEAR WALLS, ANACAPA RESIDENCE HALL, UCSB

Wall (Fig. 7.17)	Specified Reinforcement
a	12 inch concrete block wall vertical: #5 bars at 24 inches on centers horizontal: #5 bars at 24 inches on centers
b	8 inch concrete block wall vertical: #4 bars at 24 inches on centers horizontal: #4 bars at 24 inches on center

Photographs of a typical 2 story residential wing are shown in Figs. 7.18 and 7.19. These units are 37 feet wide with a 1 inch seismic separation located across their width near the corner closest to the central unit. The rectangular shaped sections thus created are 78 feet and 112 feet long.

Structural damage to Anacapa Residence Hall caused by the earthquake consisted of extensive cracking of the concrete block shear walls in several wings. The most severe cracking occurred in the north-south



RESIDENCE HALL # 2

SCALE 1/32" = 1'- 0"

Fig. 7.17 Floor plan of Anacapa Residence Hall, UCSB.

Fig. 7.18 Anacapa Residence Hall, UCSB.

Fig. 7.19 Anacapa Residence Hall, UCSB.

shear walls on the first floor. The cracks were mostly diagonal trending, as shown in Figs. 7.20 and 7.21. The cracks often followed the mortar lines, but occasionally passed through the concrete blocks themselves. Most of the cracks extended through the entire thickness of the wall. Extensive cracking of the headers of many doorways was also observed.

The cracking was noticeably more severe in some places than in others. In one such severely damaged portion, several damaged concrete blocks were chipped away with a hammer to expose the internal reinforcement. It was found in some cases that no grout was in place to bond the reinforcing steel to the concrete blocks, as shown in Figs. 7.22 and 7.23, resulting in an unexpectedly weak shear wall. Further investigation occasionally revealed such additional deficiencies as missing or misplaced steel, and inadequate laps and splices. In these severely damaged areas repairs consisted of complete removal of the concrete block shear walls, and replacement with new reinforced concrete shear walls. Sixteen walls required replacement. In other locations repairs will be accomplished by epoxy injection.

The damage to shear walls in Santa Cruz Residence Hall was very similar to that in Anacapa Residence Hall.

Engineering Building

The engineering building consists of a five story unit which is connected to several one story units on three sides. Plan dimensions of the five story unit are 70 feet by 250 feet, and it is a reinforced concrete shear wall structure. A basic floor plan of the structure is shown in Fig. 7.24 where the broken lines indicate the single story units and the solid lines indicate the five story unit. Also shown on the floor plan are the locations of the shear walls, and of the exterior and interior columns. The structural details of the shear walls are given in Table 7.3.

Photographs of the structure are shown in Figs. 7.25 and 7.26. The one story units are not symmetrically located with respect to the five story unit, and the concrete roof of the one story units is two feet below the second floor of the five story unit. The one story units are also reinforced concrete shear wall structures.

The design of the Engineering building was governed by the 1961 edition of the Uniform Building Code. The minimum compressive strength of the concrete mix is 2500 psi in the footings and one story units, 3000 psi for the walls, beams, columns, slabs, piles and caps, etc., for the five story unit, and 5000 psi for certain columns in the five story unit. The exterior columns and some exterior shear walls contain concrete blocks which have minimum compressive strength of 1200 psi. The structura steel meets the requirements of A.S.T.M. A-36.

The earthquake caused significant structural damage to the interior shear walls in both the north-south and east-west directions. Very little cracking occurred in the exterior shear walls at the ends and center stair tower. Although the cracking was more extensive in the lower stories, the north-south interior shear wall sustained significant

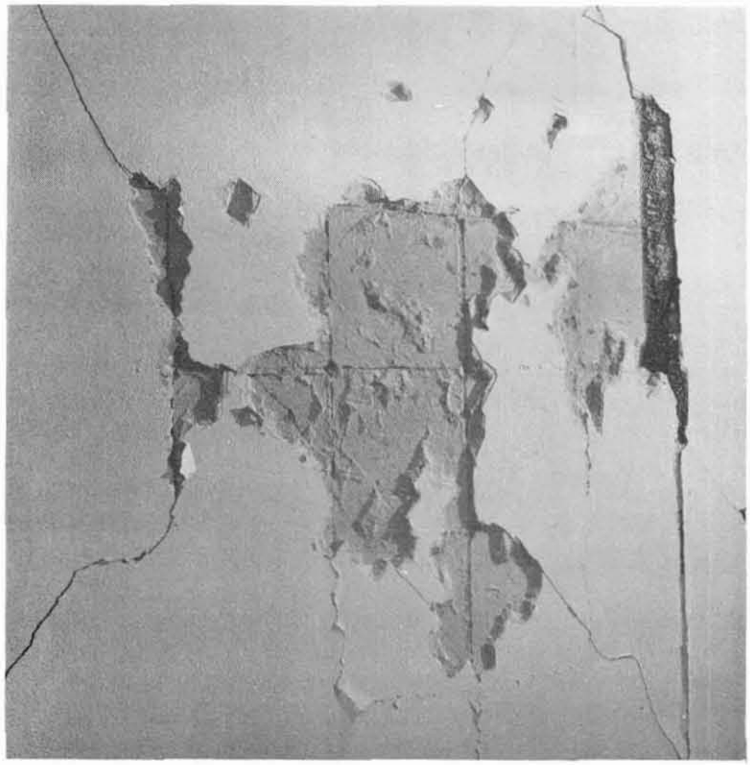


Fig. 7.20 Diagonal cracks in north-south shear wall in first story of Anacapa Residence Hall.

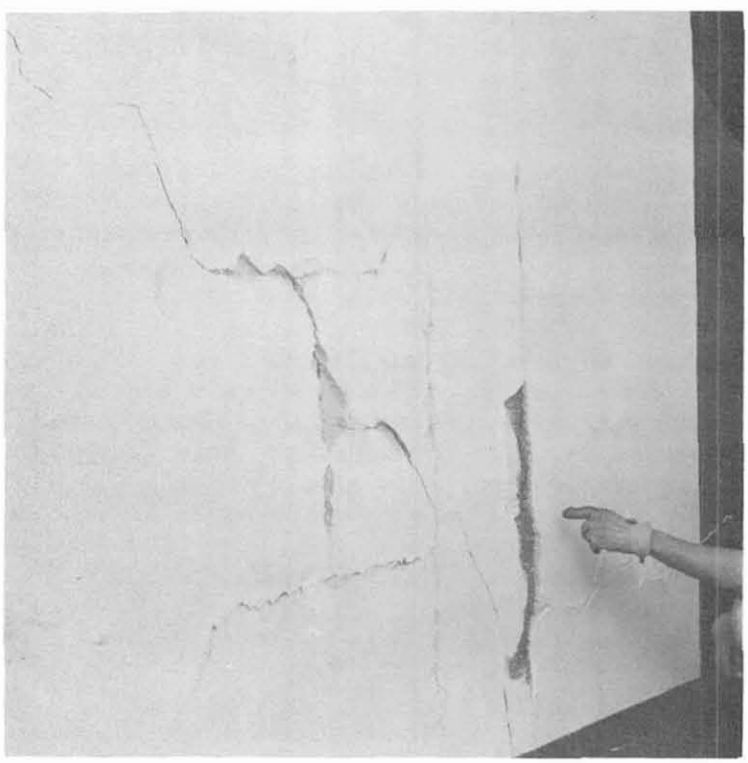


Fig. 7.21 More diagonal cracks in north-south shear walls in first story of Anacapa Residence Hall.

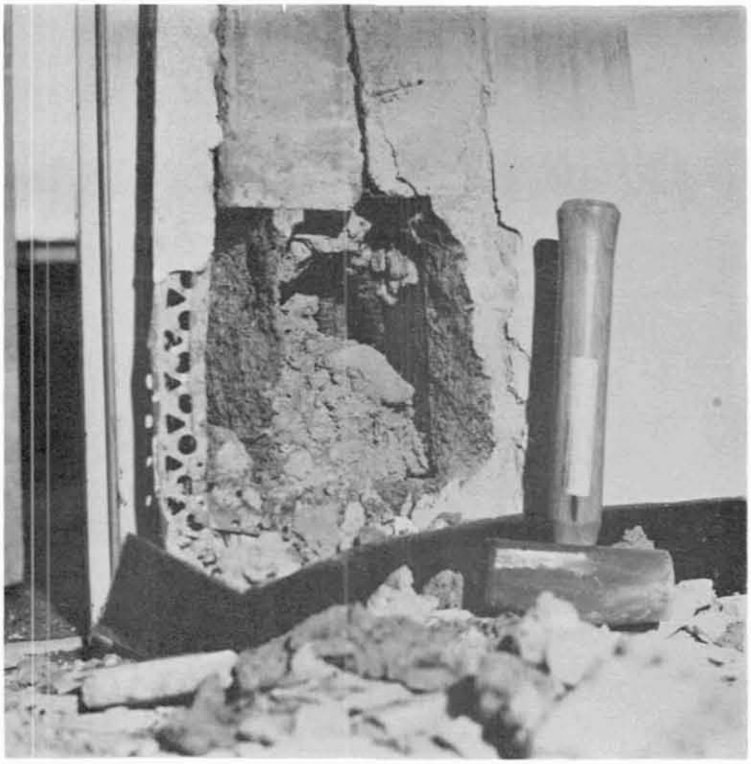


Fig. 7.22 Face of concrete block removed to expose ungrouted reinforcing steel, shear wall in Anacapa Residence Hall.

Fig. 7.23 Another example of ungrouted reinforcing steel, shear wall in Anacapa Residence Hall.

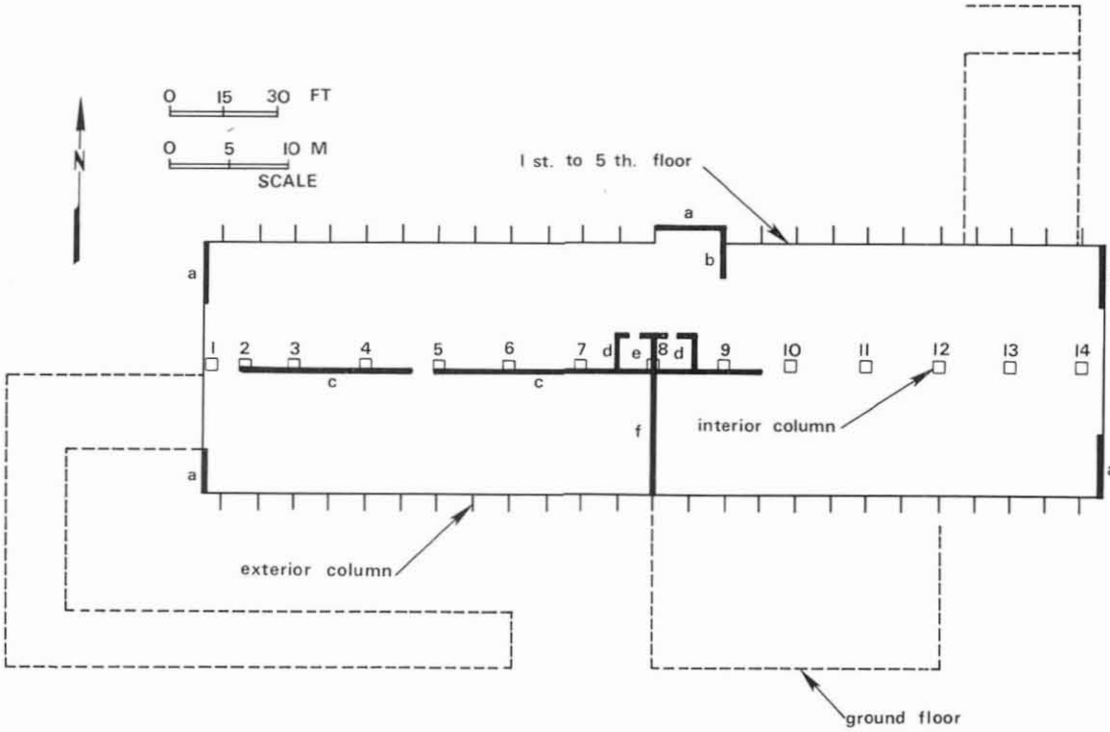


Fig. 7.24 **Floor plan of Engineering Building, UCSB.**

TABLE 7.3

DETAILS OF REINFORCEMENT IN SHEAR WALLS, ENGINEERING BUILDING, UCSB

Wall (Fig. 7.24)	Specified Reinforcement
a	12 inch reinforced concrete wall vertical: #4 bars at 24 inches each face, staggered horizontal: #7 bars at 1/3 story height each face
b	10 inch reinforced concrete wall vertical: #4 bars at 16 inches each face horizontal: #4 bars at 16 inches each face
c	8 inch reinforced concrete wall vertical: #4 bars at 16 inches on centers horizontal: #4 bars at 10 inches on centers
d	8 inch reinforced concrete wall vertical: #3 bars at 18 inches on centers, each face horizontal: #3 bars at 11 inches on centers, each face
e	10 inch reinforced concrete wall vertical: #3 bars at 16 inches on centers, each face horizontal: #4 bars at 16 inches on centers, each face
f	10 inch reinforced concrete wall vertical: #3 bars at 16 inches on centers, each face horizontal: #4 bars at 16 inches on centers, each face

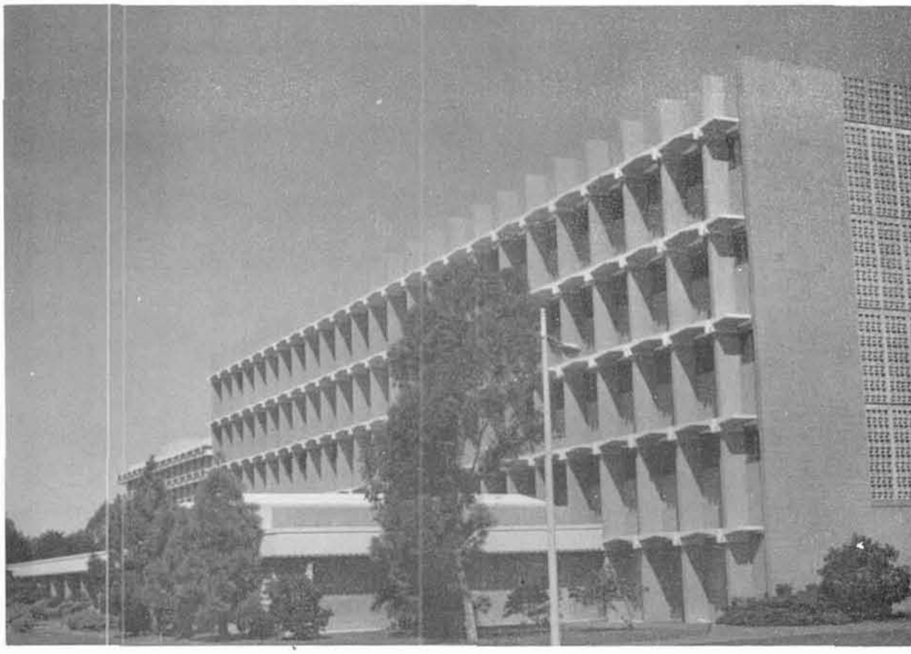


Fig. 7.25 Engineering Building, UCSB. (View from south-east).

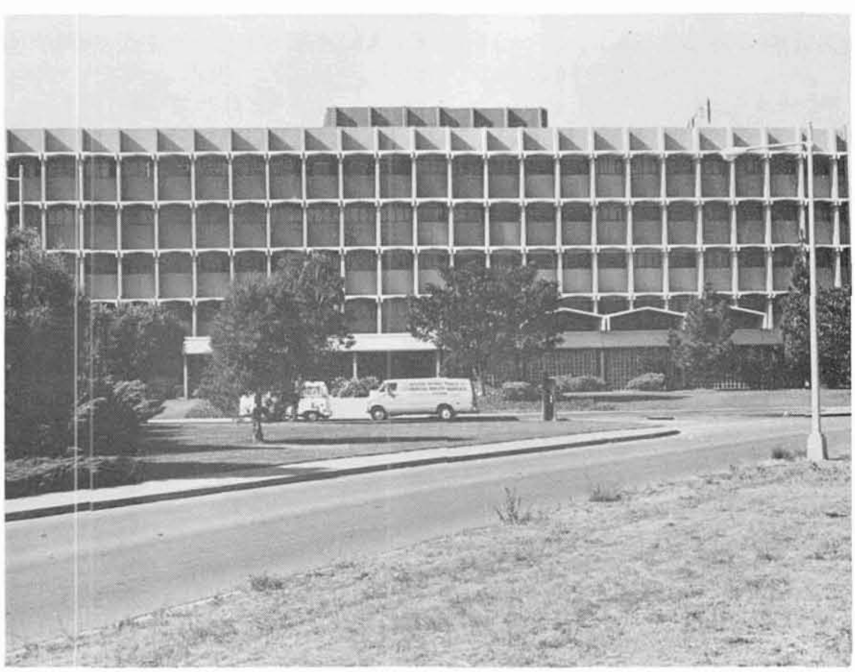


Fig. 7.26 Engineering Building UCSB. (View from south).

cracking in all five stories. The cracks were often found to extend through the entire thickness of the walls. Shown in Figs. 7.27, 7.28 and 7.30 are some of the cracks in the north-south shear wall in the first story and in Fig. 7.29 in the east-west shear wall. Several parallel cracks extending diagonally from floor to ceiling occurred in each wall in the first story. On the third story considerable cracking also occurred in the header over a doorway in the north-south interior shear wall, as shown in Fig. 7.31. The cracks extended through the wall as indicated by the mirror image crack pattern on the other side of the doorway, shown in Fig. 7.32. Diagonal cracks also occurred in other portions of the north-south shear wall in the third story, as shown in Fig. 7.33. Similar cracks occurred in the second, fourth and fifth stories of the same north-south shear wall. Repairs by epoxy injection are planned.

Biological Sciences II

The Biological Sciences II building is a six story reinforced concrete structure which is relatively symmetric. The plan dimensions are 120 feet by 120 feet. A photograph of the structure is shown in Fig. 7.34. Resistance to earthquake forces is provided by concrete shear walls which enclose stairs, utility shafts and elevators. Most of these elements are located at the perimeter of the building. The stair and elevator towers function as a closed box and are considerably more rigid than isolated shear walls. The stair towers at the ends of the building are 50 feet long in the east-west direction. However, the north-south length of the north tower is 28 feet, while that of the south tower is 10 feet. Thus, it is possible that a significant torsional response was induced by the earthquake.

The design of the building was governed by the earthquake resistance provisions of the 1964 edition of the Uniform Building Code. The minimum compressive strength of the concrete mix is 3750 psi for beams, columns, walls, footings, caissons, etc., and 5000 psi for certain columns. The reinforcing steel meets the requirements of A.S.T.M. A-36.

The earthquake caused structural damage to shear walls in the stair towers at the ends of the building. Diagonal and horizontal cracks formed in the exterior walls in each tower in the lower stories. Some typical examples of these cracks are shown in Figs. 7.35-7.37. Again repair by epoxy injection is planned.

Library III and University Center

These and other multistory reinforced concrete buildings on campus received damage to shear walls which was similar to that just described in other buildings. The cracking, however, occurred mostly in the lower stories. A photograph of the eight story Library III building is shown in Fig. 7.38.

7.3 Effects on Commercial and Residential Buildings

Within a five mile radius of the UCSB campus there are a number of commercial buildings which received significant earthquake damage.

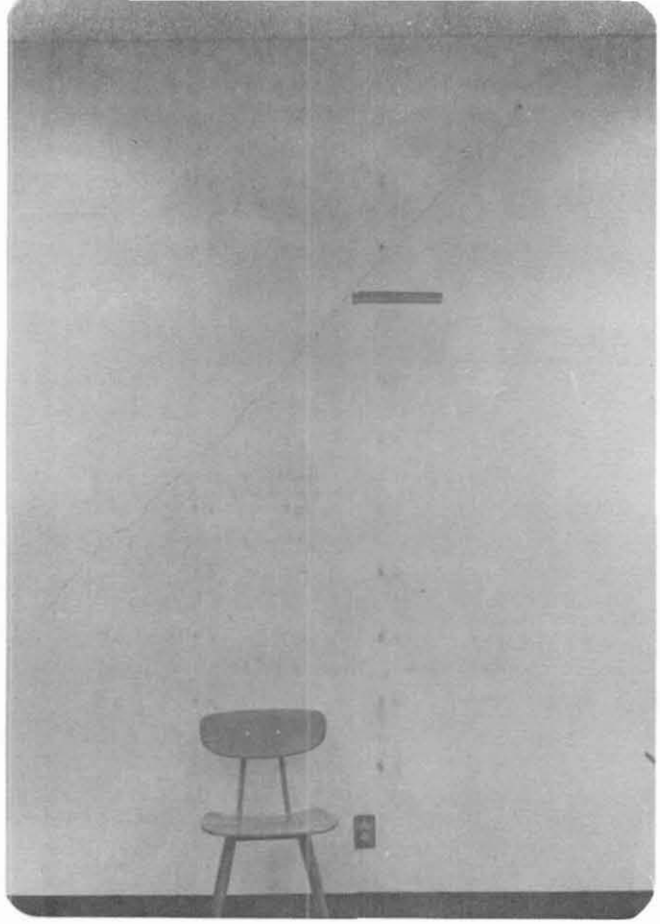


Fig. 7.27 Diagonal crack in north-south shear wall in first story of Engineering Building, UCSB. This crack extends through the thickness of the wall and is visible from the other side.

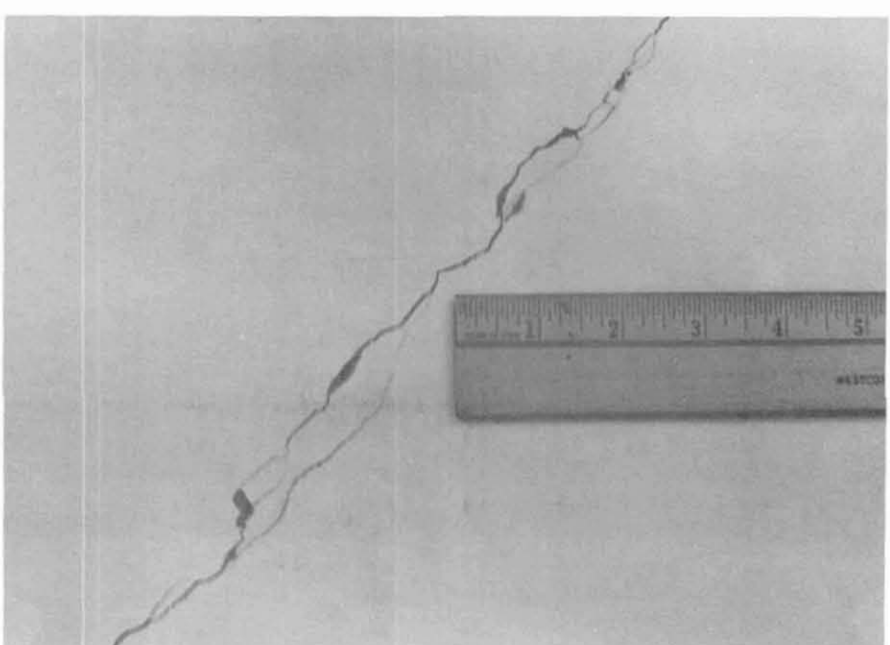


Fig. 7.28 Close up view of crack shown in Fig. 7.27.

Fig. 7.29 Diagonal cracks in east-west shear wall in first story of Engineering Building, UCSB.

Fig. 7.30 Cracks in another portion of the north-south shear wall in the first story of Engineering Building, UCSB.

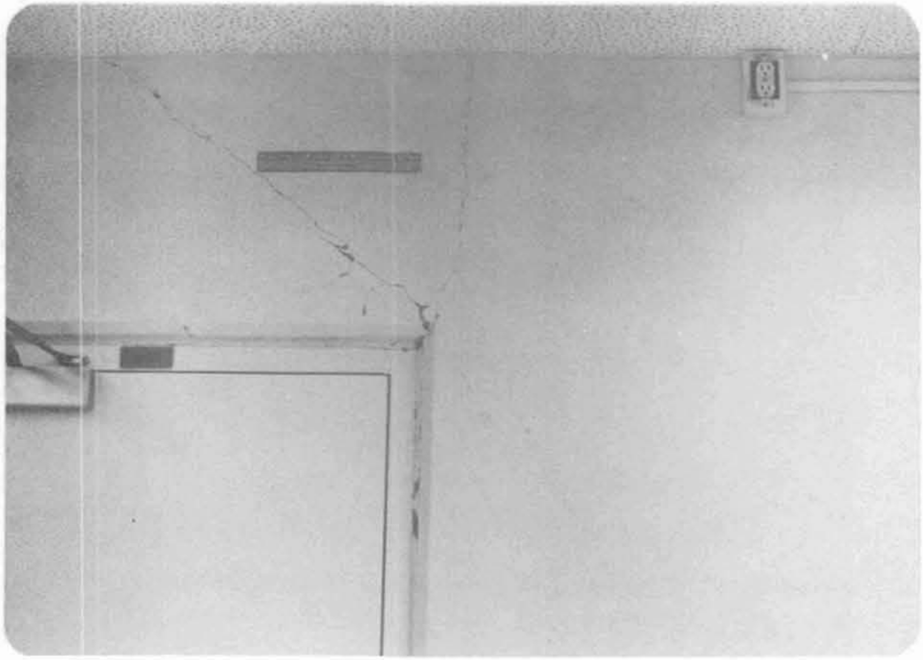


Fig. 7.31 Cracks in header over doorway in north-south shear wall in third story of Engineering Building, UCSB.

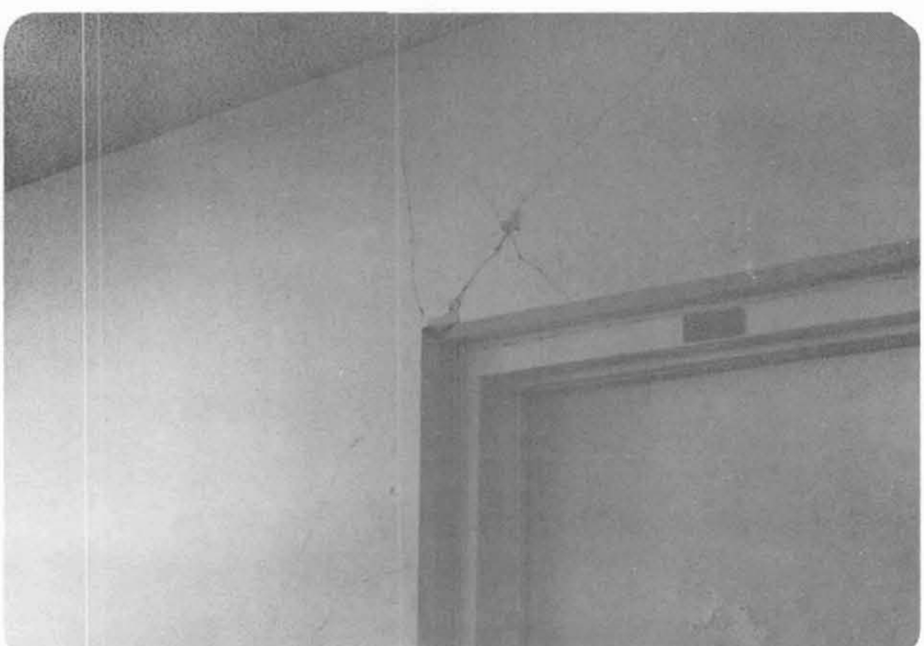


Fig. 7.32 Cracks in reverse side of shear wall shown in Fig. 7.31.

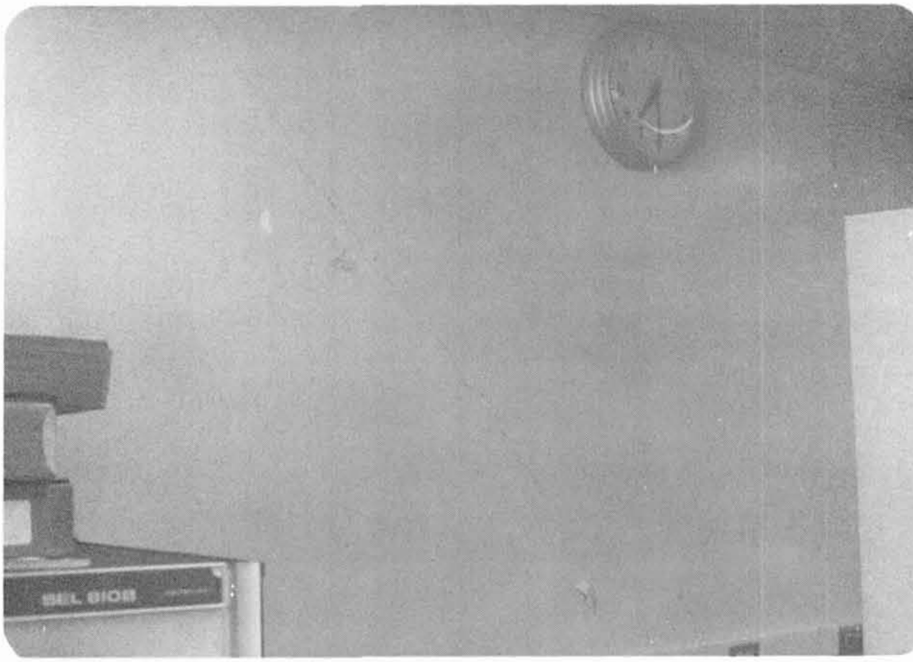


Fig. 7.33 Diagonal crack in north-south shear wall in third story of Engineering Building, UCSB.

Fig. 7.34 Biological Science II Building, UCSB. (View from northeast).

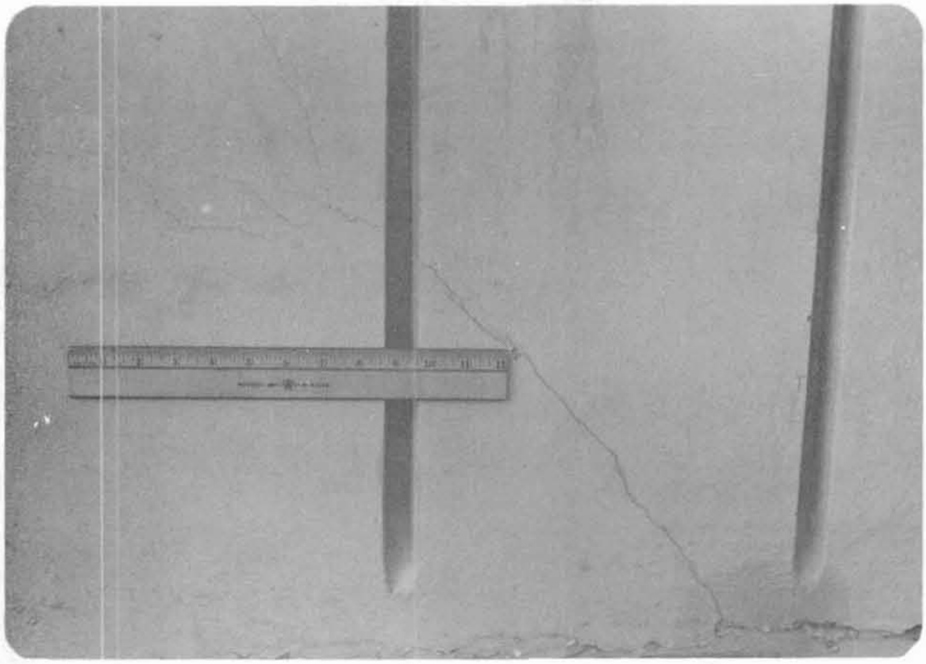


Fig. 7.35 Cracks in exterior of east-west shear wall near base of south stair tower of Biological Science II Building, UCSB.

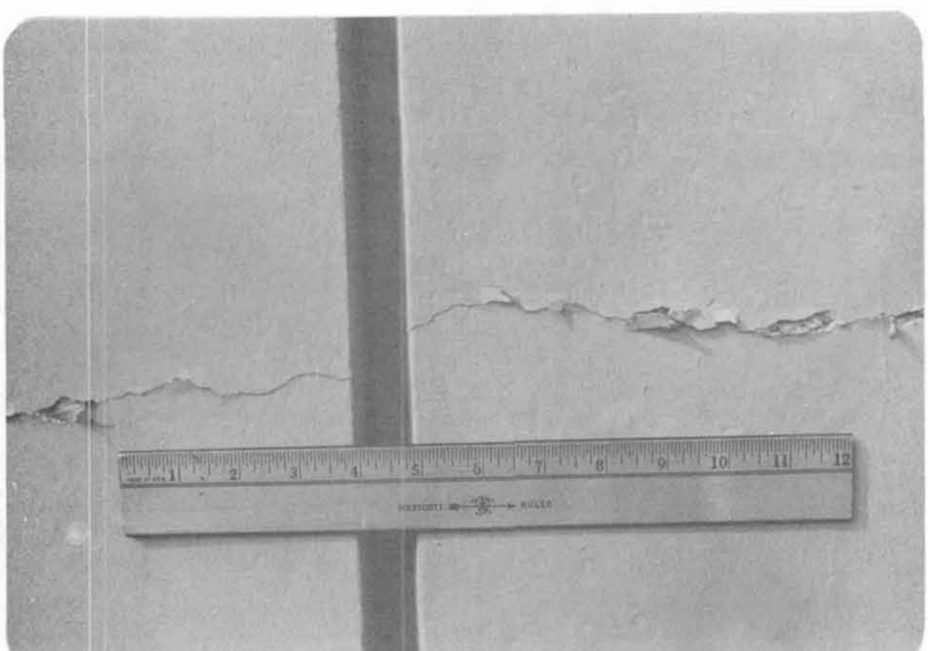


Fig. 7.36 Nearly horizontal cracks in east-west shear wall near base of south stair tower of Biological Science II Building, UCSB.

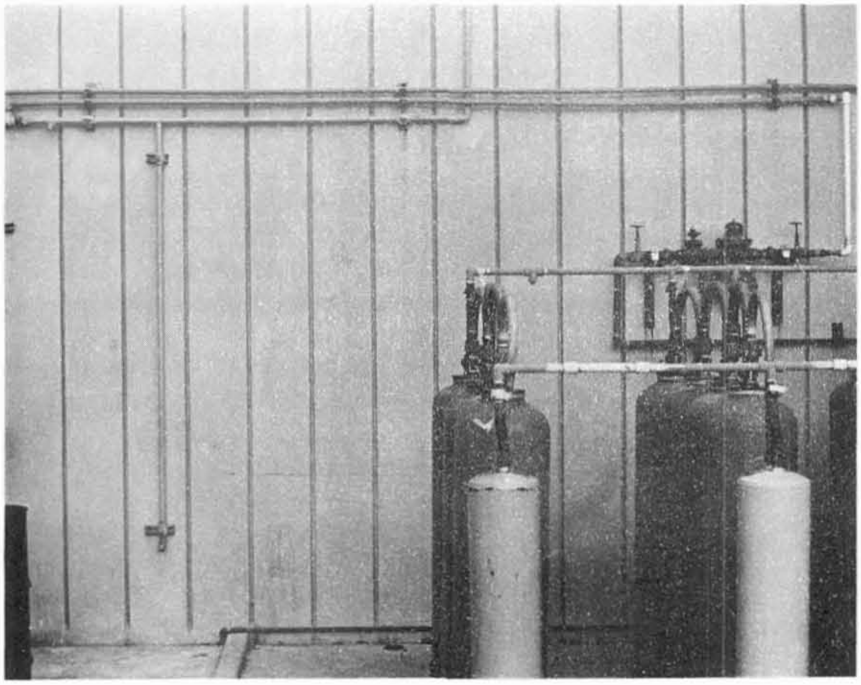


Fig. 7.37 Diagonal crack in north-south shear wall near base of north stair tower of Biological Science II Building, UCSB. (View from west).

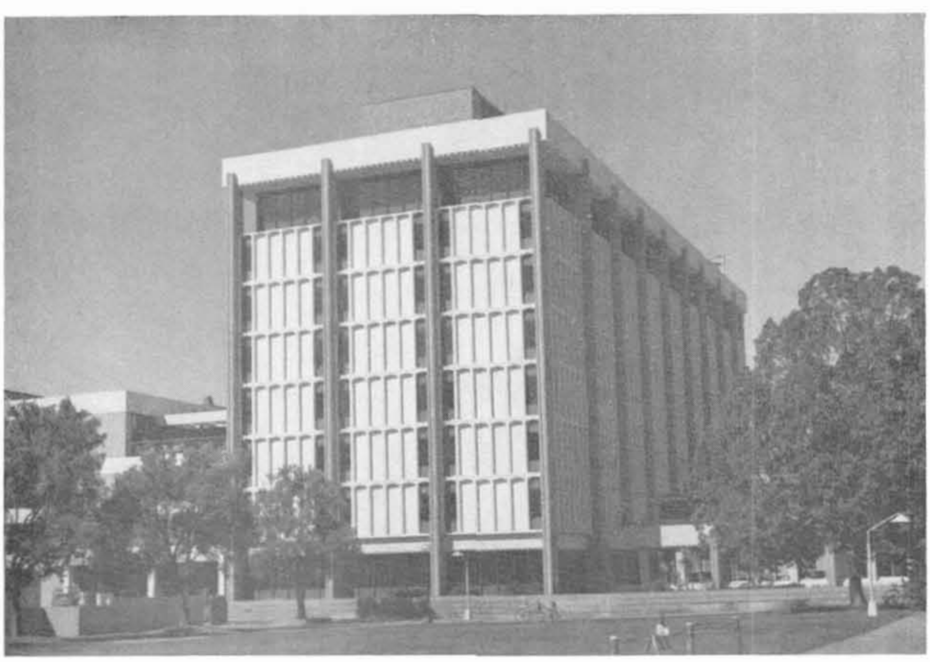


Fig. 7.38 Eight story Library III Building, UCSB. This building also sustained cracks in shear walls in lower stories.

These buildings typically have long plan dimensions in the east-west direction, and are reinforced concrete shear wall structures of one or two stories in height. Examples of such buildings are those at the Delco Electronics facilities of the General Motors Corporation at 6767 Hollister Avenue in Goleta (see Fig. 1.2). At this facility there are two nearly identical long two story office buildings (Administration and Engineering Buildings) with reinforced concrete shear walls at the ends and near the center stairway. Each of these buildings received moderate cracking of the shear walls in an X pattern, with most extensive cracking in the north-south shear walls in the first and second stories as shown in Figs. 7.39 through 7.41. It appears that the west end of the buildings sustained significantly more damage than the east end. The north-south shear wall at the west end of the Administration Building received severe cracking near the header over the doorway, as shown in Figs. 7.42 and 7.43.

Also located at the Delco Electronics facilities is a precast concrete panel tilt-up structure with longest plan dimensions in the north-south direction. The structure is one story high, has a flat roof, houses several laboratories, and is known as the Research and Development Building. Earthquake damage to this structure consisted primarily of working loose of the joints between panels, as shown in Figs. 7.44 and 7.45. The reinforced concrete column which forms the south-west corner of the building suffered considerable cracking and spalling, as shown in Fig. 7.46. The panels aligned along the north-south direction, which form the long east and west exterior walls, apparently rocked back and forth with sufficient amplitude to open a ¼ inch gap between the roof beam and panels. The damage was more apparent along the western edge of the building.

A large one story steel frame and sheet metal building which houses the Flight Physics Laboratory is also located at the Delco facility. The longest plan dimension of this building is in the east-west direction. Relatively minor earthquake damage was sustained by this building. A steel column near the large sliding doors at the west end was not properly anchored to the concrete floor slab and consequently slipped toward the west causing misalignment of the doors. Some of the sheet metal panels which form the exterior walls in the longitudinal direction are designed to break loose during an explosion within the building. A few of these panels had broken loose at the corners after the earthquake as shown in Fig. 7.47. Other damage to this building consisted of many fallen light fixtures.

At the Santa Barbara Municipal Airport which forms the northern boundary of the UCSB campus (see Fig. 1.2), several large one story wood frame commercial buildings received minor damage. Damage to these buildings, which are founded on soft alluvium, included some minor differential settlement of foundations which caused cracks in the concrete floor slabs. Some wall panels in the north-south direction were torn loose from the wood studs, as shown in Fig. 7.48. These buildings often have large spans without interior walls. The wood columns in such open span areas were occasionally shifted along the north-south direction, as shown in Fig. 7.49. Many of the commercial buildings at the airport were built in the 1940's.

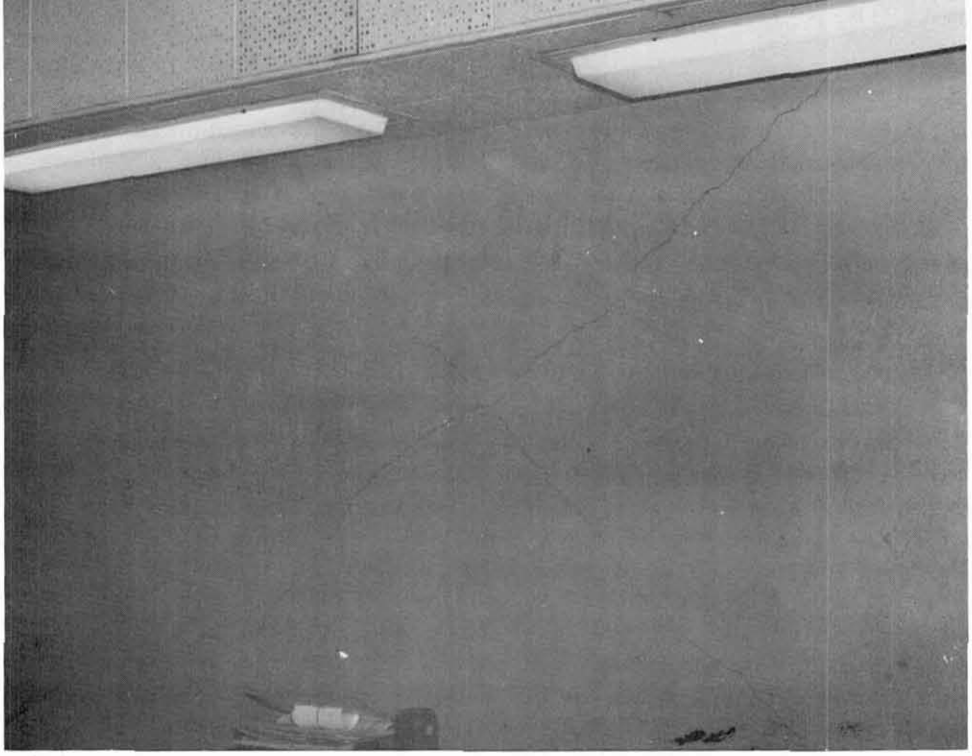


Fig. 7.39 Pattern of X cracks in 10 inch thick R/C shear wall at east end of first story of Administration Building, Delco Electronics facilities.

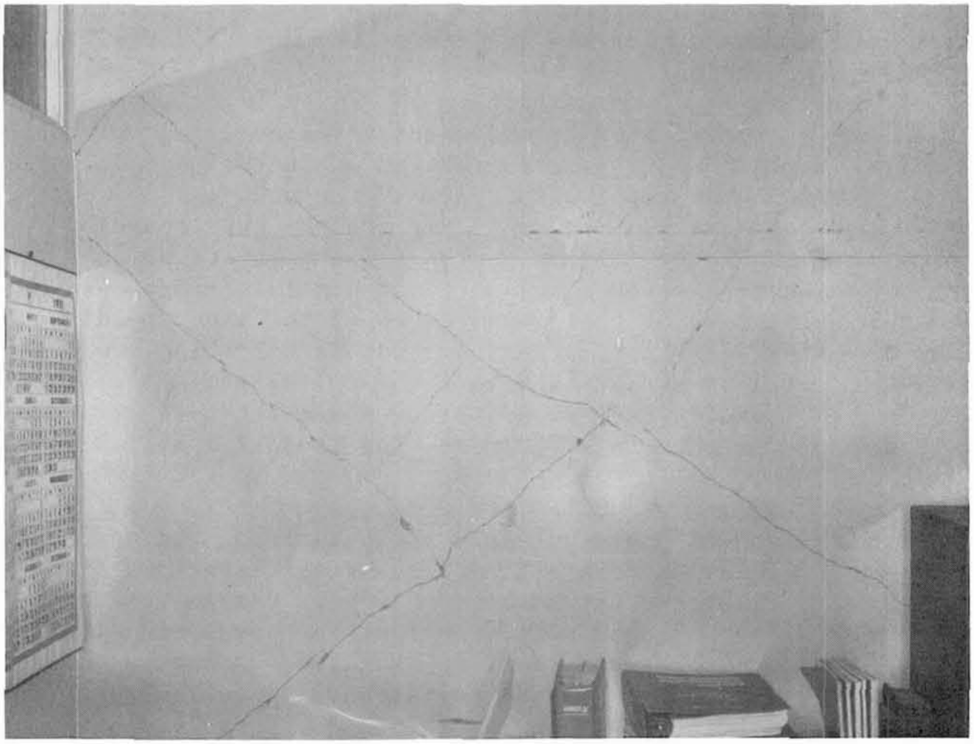


Fig. 7.40 Pattern of X cracks in shear wall at west end in first story of Administration Building, Delco Electronics facilities.

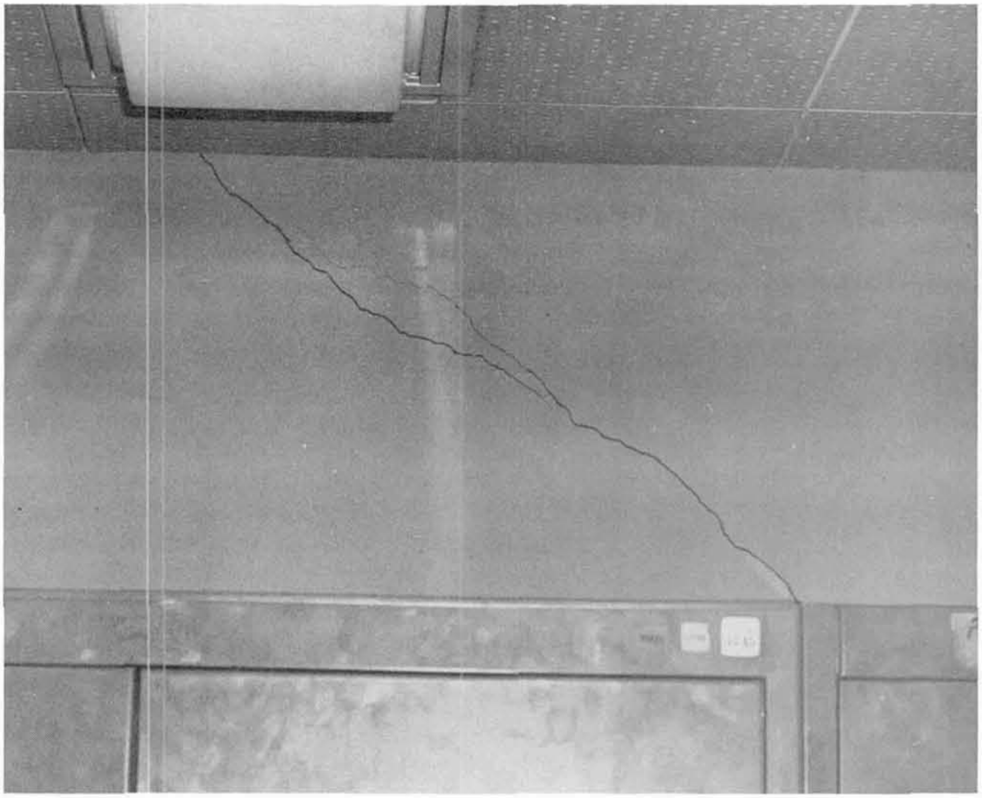


Fig. 7.41 Diagonal crack in shear wall near center stair tower in second story of Administration Building, Delco Electronics facilities.

Fig. 7.42 Cracks in shear wall over doorway at west end in first story of Administration Building, Delco Electronics facilities.

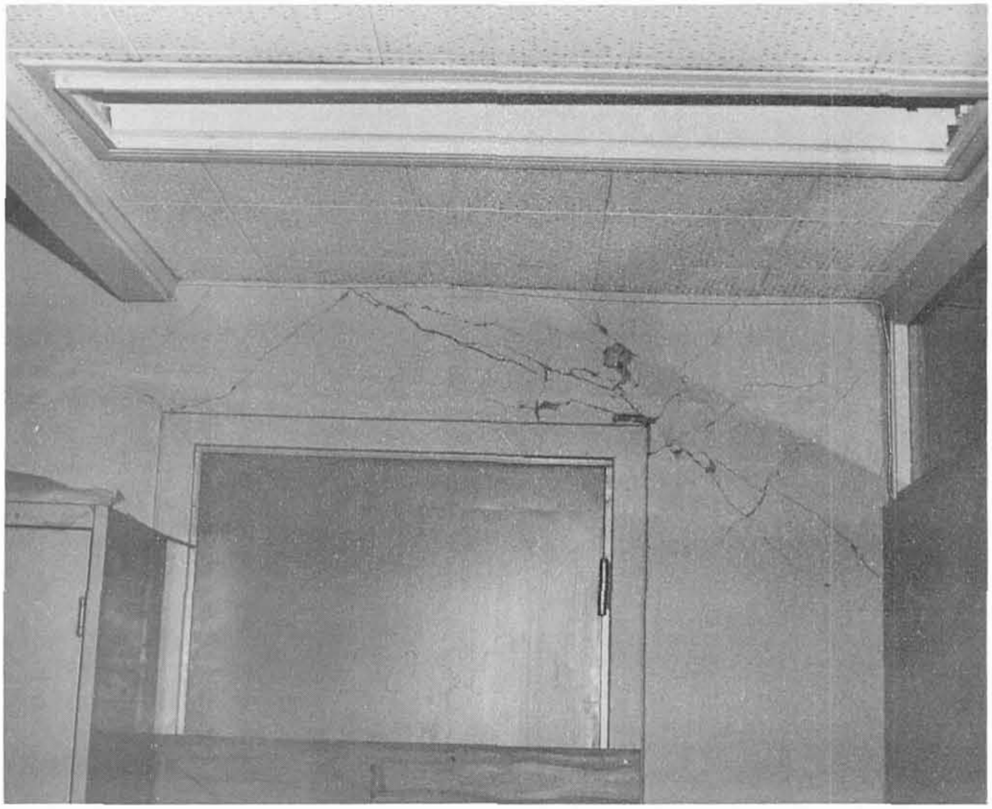


Fig. 7.43 Cracks in reverse side of shear wall shown in Fig. 7.42.

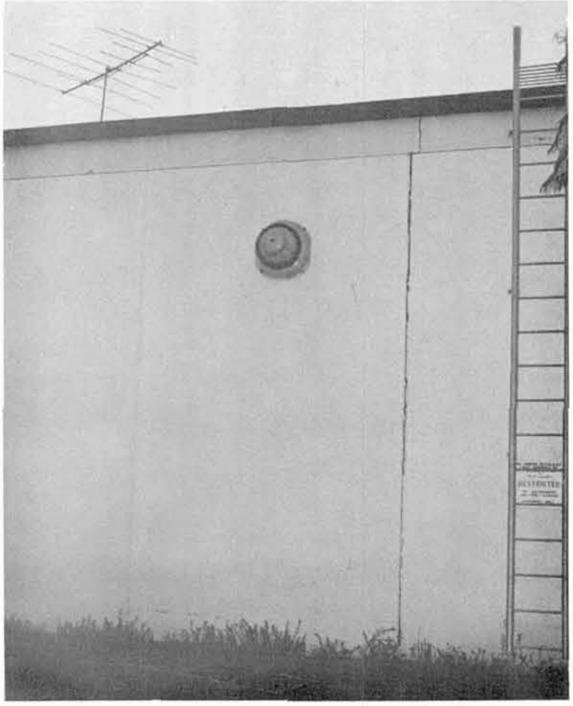


Fig. 7.44 Cracks at joints between precast concrete tilt-up panels, Research and Development Building, Delco Electronics facilities.

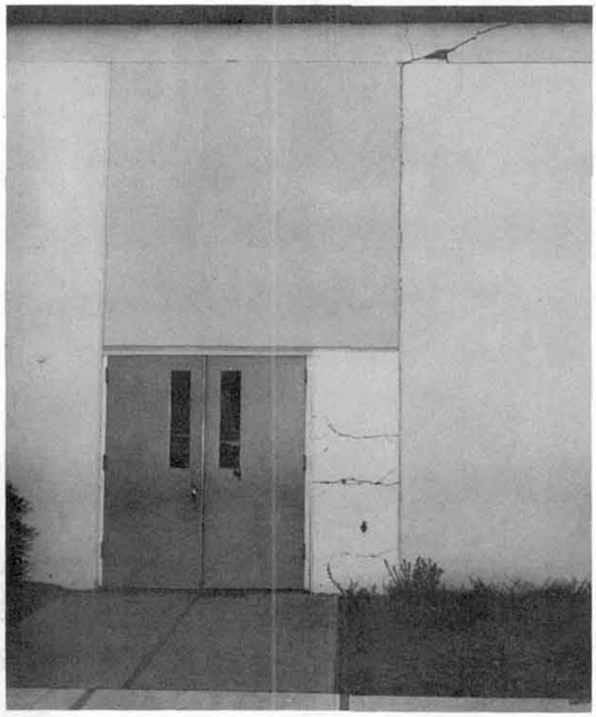


Fig. 7.45 Cracks at joints between panels and doors, Research and Development Building, Delco Electronics facilities.

Fig. 7.46 Cracking and spalling of columns at southwest corner of Research and Development Building, Delco Electronics facilities.

Fig. 7.47 Explosion panel which broke loose at the corner during the earthquake, Flight Physics Laboratory, Delco Electronics facilities.

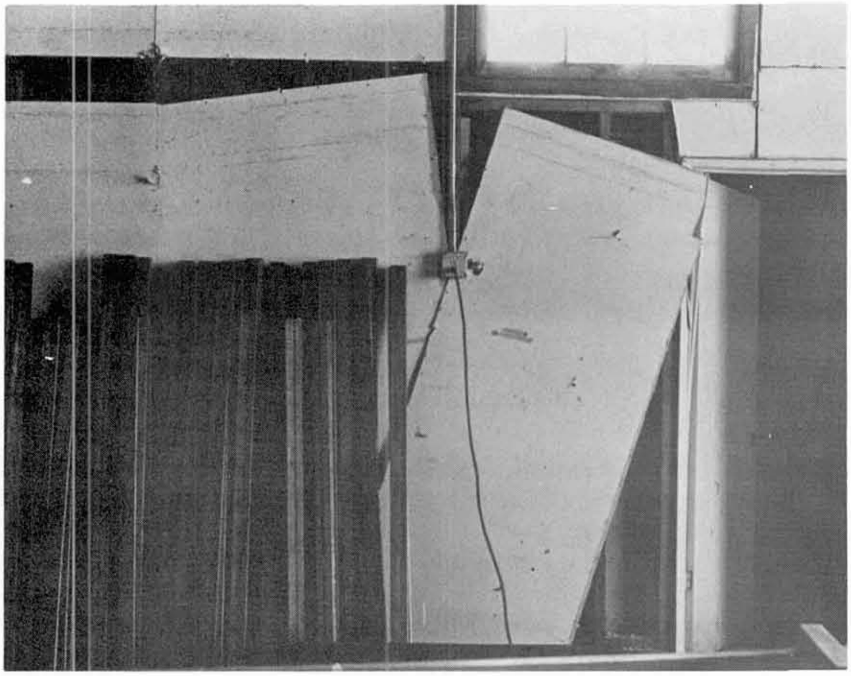


Fig. 7.48 Wall panels were torn loose from wood studs in single story commercial building at the Santa Barbara Municipal Airport.

Fig. 7.49 Wood column shifted north in single story commercial building at the Santa Barbara Municipal Airport.

Similar damage was reported at other commercial buildings in the area.

Earthquake damage to wood frame residential buildings in the area consisted mostly of cracked plaster, particularly in multistory units, as shown in Figs. 7.50 and 7.51. Some differential settlement of foundations occurred which caused cracking of concrete floor slabs, and additional cracking of plaster and misalignment of door jambs. Unreinforced chimneys toppled at several locations, and even a few rein-forced chimneys were damaged, as shown in Fig. 7.52. Glass breakage was common in many areas, and unbraced hot water heaters rocked with sufficient amplitude to damage plumbing connections. Although relatively little structural damage was sustained by residential buildings, a substantial number sustained the type of architectural damage just described.

7.4 Effects on Mobile Homes

A total of 324 mobile homes were damaged during the earthquake. It was reported that more than 35% of the 147 mobile homes in the Santa Barbara West Mobile Home Park on Winchester Canyon Road (Fig. 1.2) were shaken off their pedestal foundations, and a similar high proportion were damaged at the San Vicente Mobile Home Park on Old Mill Road (Fig. 1.3). Examples of this type of damage are shown in Figs. 7.53 through 7.59. Although relatively minor structural damage was sustained in most cases by the mobile homes themselves, considerable damage to plumbing, utilities, porches, awnings, stairways, skirts, etc., resulted from the earthquake.

Current state law does not allow mobile homes, which are considered as vehicles for tax purposes, to be permanently attached to foundations. Consequently, such homes are usually mounted on a large number of small concrete or steel pedestals as shown in Figs. 7.56 through 7.58. These pedestals are not anchored to the ground so that a minimum of lateral force resistance is available to prevent homes from falling off their foundations. Most of the homes at the Santa Barbara West Mobile Home Park fell to the south. The total resulting horizontal shift was on the order of 1 to 2 feet in many cases, as shown in Fig. 7.59.

A total of four mobile homes were damaged so badly that they were uninhabitable after the earthquake. One such home was completely destroyed when it burned to the ground as the result of a broken gas line. The situation clearly represents a dangerous hazard to life and property for a segment of society, notably senior citizens, who are often particularly ill-prepared to cope with such problems.

7.5 Effects on Special Structures

Reported in this section are the effects of the earthquake on two special structures at the Santa Barbara Municipal Airport: the air traffic control tower and the very large hangars of nearby Aero Spacelines, Inc.

Fig. 7.50 Cracks in exterior plaster walls of two story residential building in Isla Vista.

Fig. 7.51 Cracks in exterior plaster walls of two story residential building in Isla Vista.

Fig. 7.52 Damage to chimney on modern residence in Isla Vista.

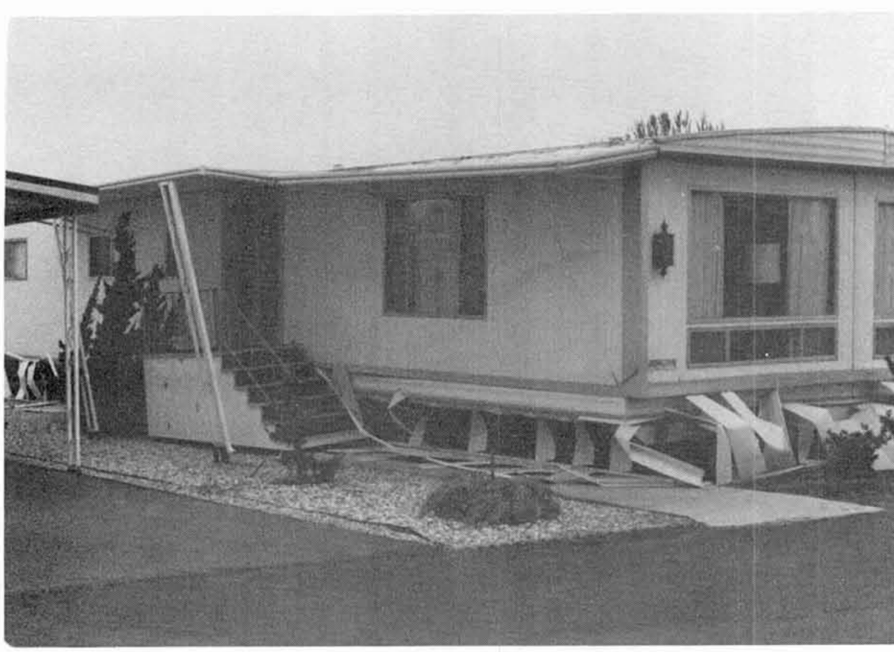


Fig. 7.53 Mobile home which was shaken off its foundation at Santa Barbara West Mobile Home Park on Winchester Canyon Road.

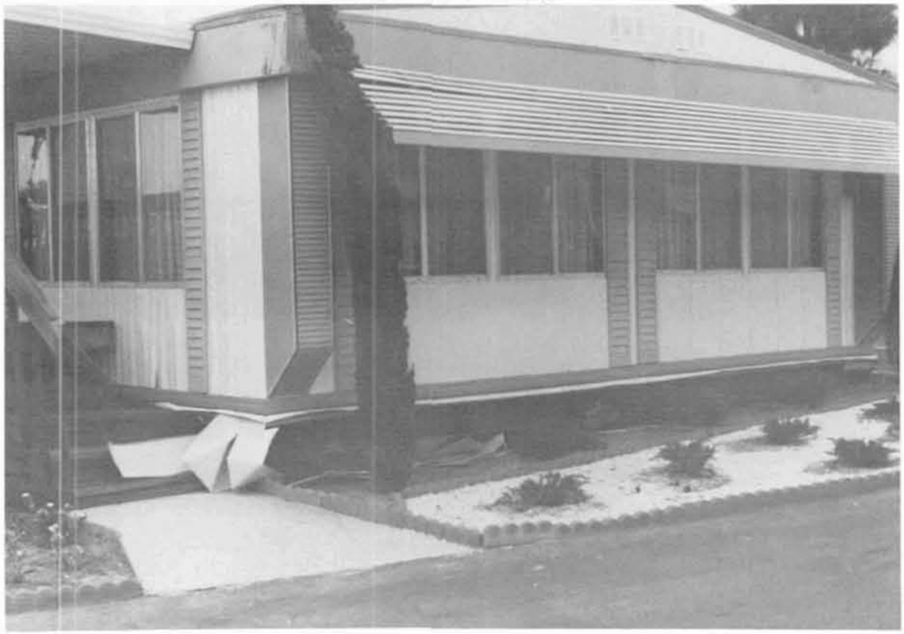


Fig. 7.54 Another view of a mobile home which was shaken off of its foundation at Santa Barbara West Mobile Home Park.

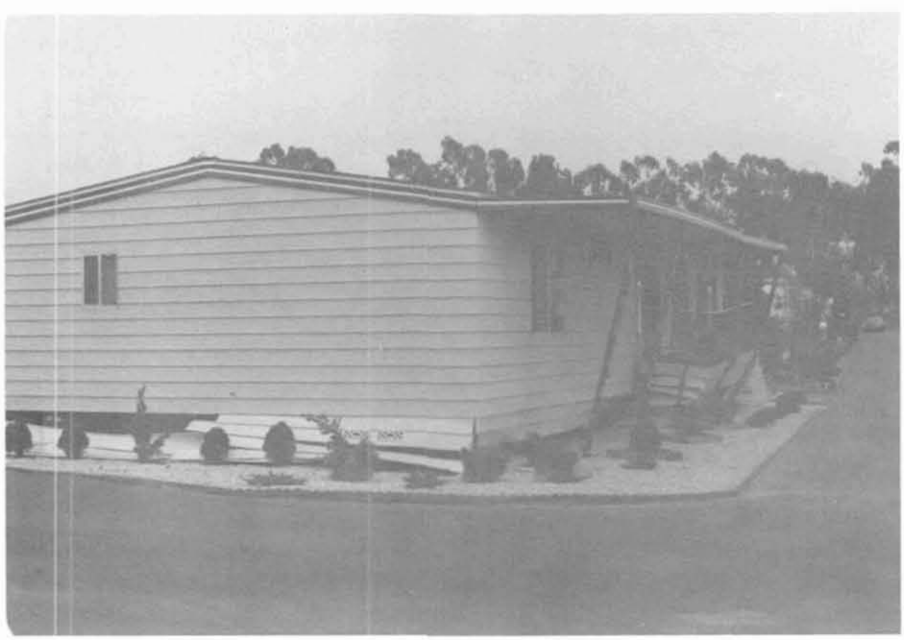


Fig. 7.55 View of damaged porch, awning, and skirt of mobile home which fell from its foundation at Santa Barbara West Mobile Home Park.

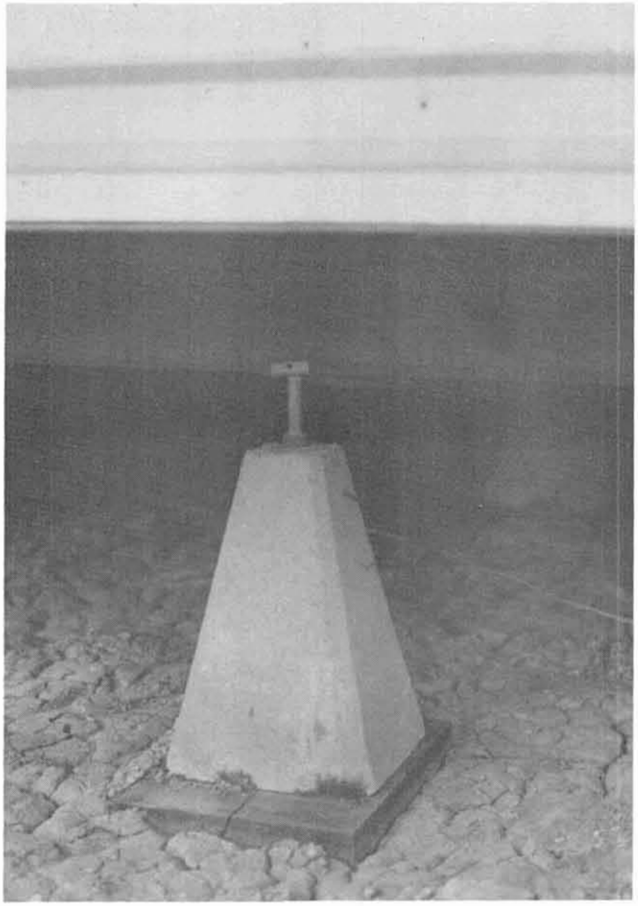


Fig. 7.56 Typical concrete pier upon which some mobile homes are mounted.

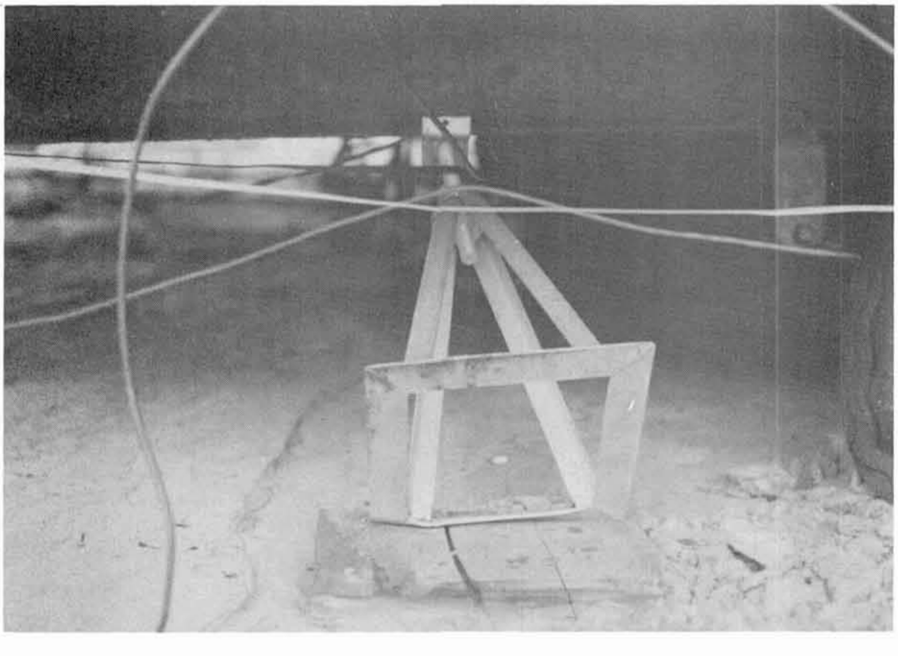


Fig. 7.57 Typical metal pier upon which other mobile homes are mounted.

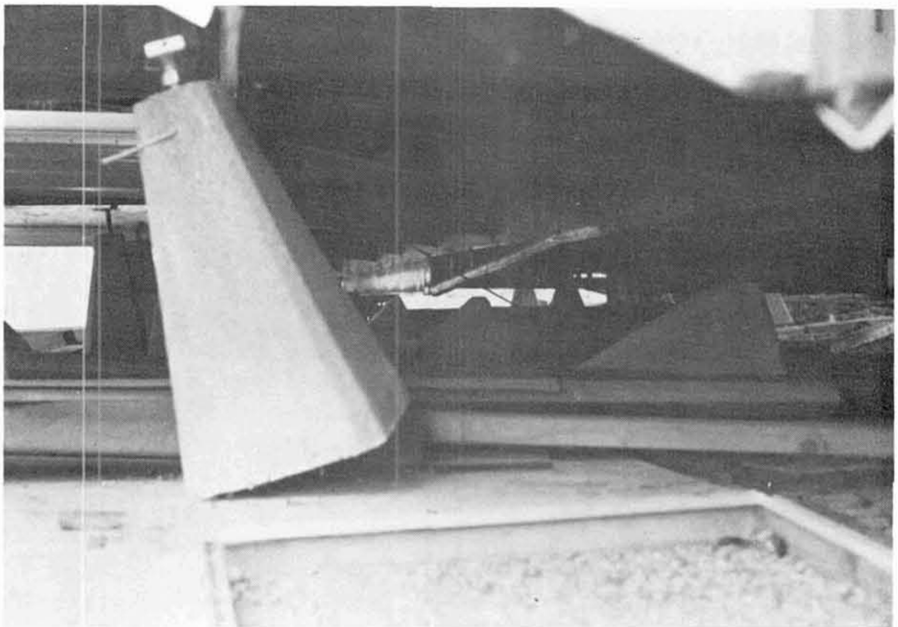


Fig. 7.58 View of overturned concrete piers under a mobile home which fell from its foundation.

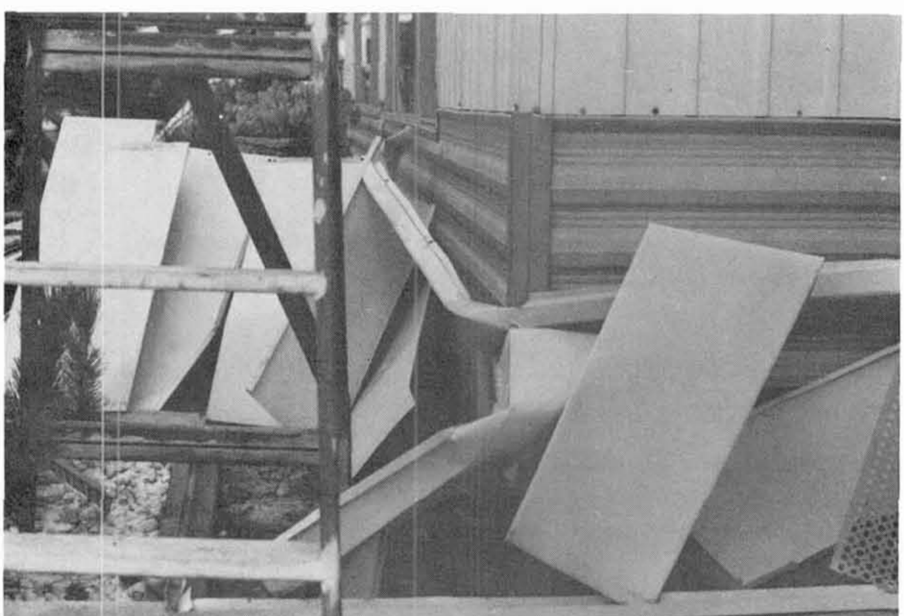


Fig. 7.59 Close up of fallen mobile home showing total horizontal shift of approximately 1 to 2 feet.

Air Traffic Control Tower

The air traffic control tower received significant structural damage as a result of the earthquake. The tower is a steel frame structure with lateral reinforcement provided by rectangular steel tube bracing. The bracing tubes are attached so that they make an angle of 18½ degrees with respect to the horizontal, and are attached to the wide flange steel columns. A photograph of the structure is shown in Fig. 7.60.

Earthquake induced stresses in the bracing tubes were sufficiently large that nonlinear response and permanent deformation was sustained at the joints. As a result, it is estimated that the top of the tower may have sustained a permanent deflection on the order of ½ to 1 inch.

Nonlinear joint behavior occurred in the first and second stories, and is shown in Figs. 7.61 through 7.63. Each bracing tube is welded to a ¼ inch steel connection plate which is then bolted to a wide flange steel column. The amplitude of motion was sufficiently large that the connection plate was permanently pried away from the column leaving a gap of approximately 1/8 inch at the bottom edge. Possible initiation of cracks in the weld between the plates and tubes was noted, and minor buckling of the tubes occurred in the first story.

Hangars of Aero Spacelines, Inc.

Earthquake damage was sustained by the structural supports for the large sliding doors on two of the large hangars owned by Aero Spacelines, Inc. These hangars are steel frame structures with sheet metal covering and a substantial concrete floor slab. The steel columns and girders in each building form a series of bents aligned along the north-south direction. Shear forces in the north-south direction are resisted by steel rigid frames. In the east-west direction, shear resistance is provided at lower levels by diagonal tension braces made of angle section steel. The hangars, which have no interior columns or walls, have plan dimensions of 180 feet by 220 feet, and a roof height of approximately 51 feet.

Structural damage to these buildings consisted of plastic deformation and mild buckling of the diagonal tension bracing steel in the east-west direction (as shown in Figs. 7.64 and 7.65), and failure of some of the structural connections at the supports for the large sliding doors along the west edge of the buildings. It is noteworthy that an identical third hangar which had no doors sustained damage only to the diagonal bracing steel. Damage to the structural supports for the doors is shown in Figs. 7.66 and 7.67. Several of the steel bracing members, which angle up from the rail at the top of the doors to the roof, were torn loose from the railing. One such member nearly fell off and was left dangling by a single bolt. These bracing members, which are steel C sections approximately 18 feet long, were not well attached, as they typically sheared off the bolts at the railing.

Fig. 7.60 Air traffic control tower, Santa Barbara Municipal Airport (view from south).

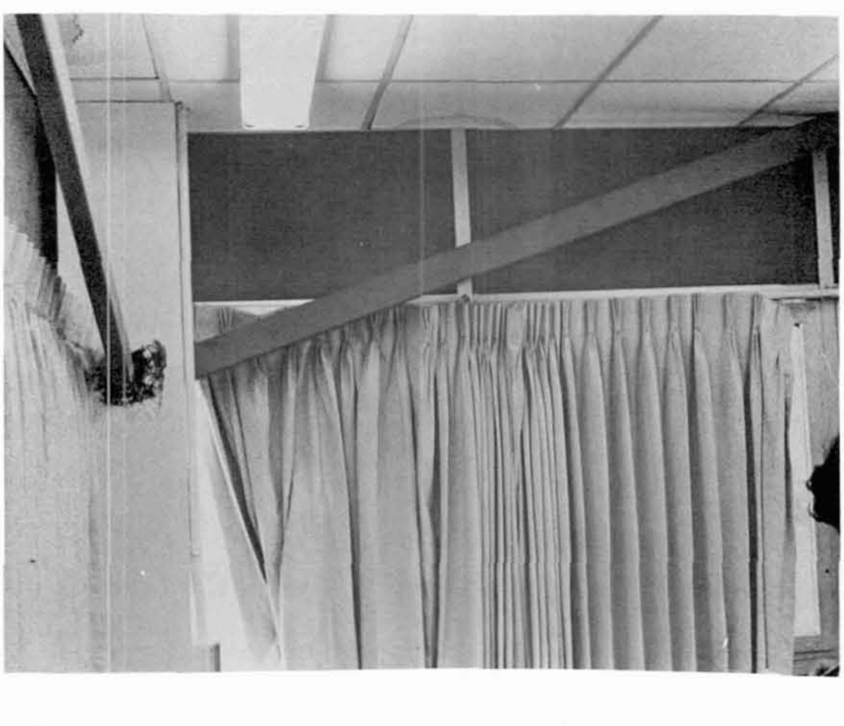


Fig. 7.61 Damage to joint between steel bracing tube and column in southeast corner, second story, air traffic control tower. Damaged tube runs north and south.

Figure 7.62 Close up of damaged joint shown in Fig. 7.61

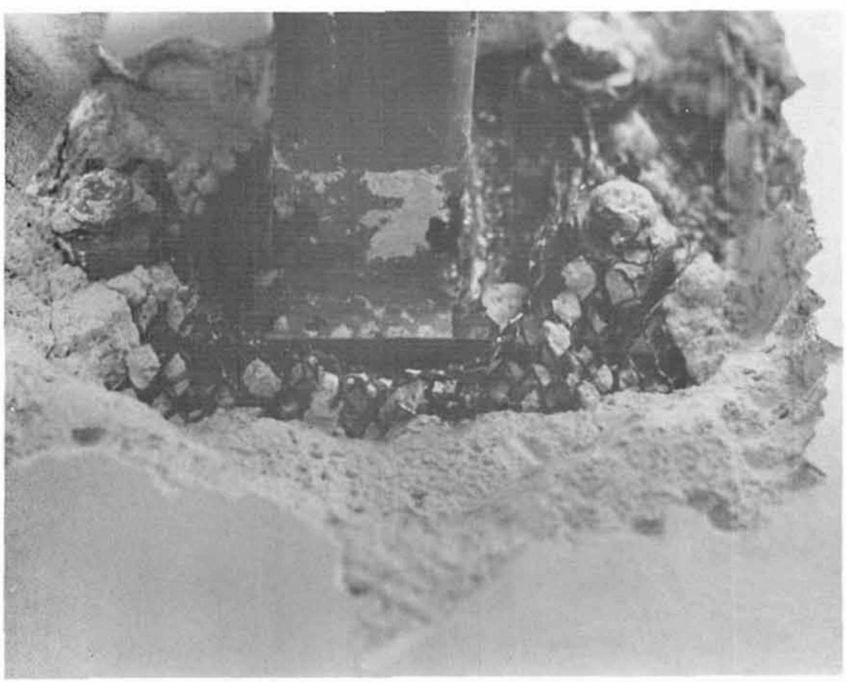


Figure 7.63 View from under bracing tube of damaged joint shown in Fig. 7.62. Note gap between column and bottom edge of connection plate

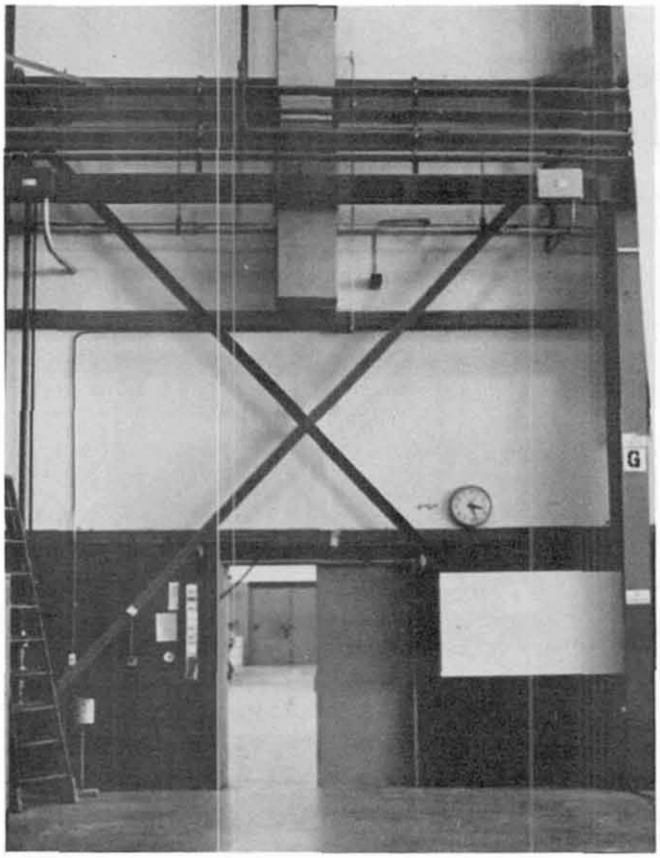


Figure 7.64 Diagonal bracing steel along east-west wall of large hanger at facilities of Aero Spacelines, Inc.

Figure 7.65 Buckling of diagonal bracing steel shown in Fig. 7.64

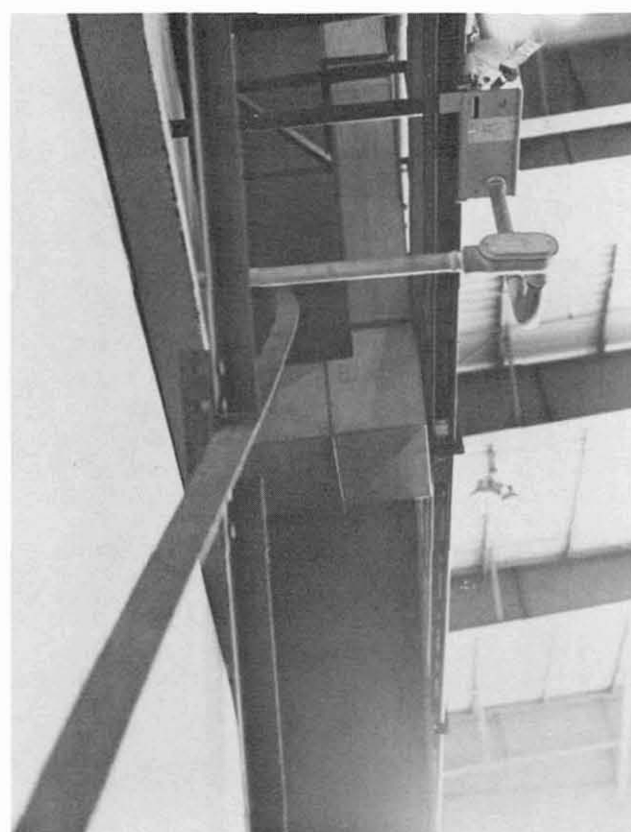


Figure 7.66 Interior of large hangar at facilities of Aero Spacelines, Inc., showing large sliding doors and damaged steel bracing which angles up to the roof from the rail at top of doors

Figure 7.67 Close up from directly under damaged steel bracing of sliding doors shown in Fig. 7.66. Note separation of rail and bracing in center of picture

7.6 Acknowledgments

The willingness of many individuals and organizations to provide tours of damaged facilities, photographs, damage reports, and similar assistance is gratefully acknowledged. The long list of such individuals includes especially Mr. Stanley H. Mendes, consulting structural engineer, Mr. John F. Meehen and Mr. Donald Jephcott and their associates with the Office of the State Architect, Mr. Ray Nokes with the County of Santa Barbara, Mr. Charles Drier and Mrs. Clare Bailey with the City of Santa Barbara, the staffs of the Facilities Management and Environmental Health and Safety Departments at UCSB, Mr. Thomas Steiglitz with Delco Electronics, and Mr. Kirk S. Irwin, President of Aero Spacelines, Inc.

8. ARCHITECTURAL, EQUIPMENT AND PROPERTY DAMAGE

8.1 Property Damage

As is true in most earthquakes in populated areas, the most widespread type of damage was in the form of breakage or damage of household belongings and store merchanidise that toppled from shelves, or sometimes fell with the shelving to the floors. Even cupboards and refrigerators were thrown open spilling their contents. Supermarkets and liquor stores sustained heavy losses of shelved inventory particularly in the Goleta Valley area as can be seen from Fig. 8.1. One of the worst casualties from the standpoint of fallen objects was the UCSB Library where almost one-third of the Library's 1.2 million volumes tumbled to the floor as shown in Fig. 8.2. The book shelves in the Library are all anchored to the building walls, and none fell over. In general, household furnishings and other items that were top heavy and free standing on small bases fell over. In UCSB campus laboratories, hundreds of items crashed to the floors, particularly in storerooms. Wall cabinets were pulled out of their mountings and fell over desks, laboratory tables and equipment. Spilled chemicals and the possible danger of noxious fumes brought county firemen with breathing apparatus to the Chemistry Building shortly after the earthquake. Arrangements had to be made for the removal of chemical wastes. Several rattlesnakes stored in glass cases in the building had escaped, but were soon recaptured and accounted for.

Another widespread type of damage was broken glass in residential, school, and commercial buildings. Many commercial buildings required the replacement of large tempered glass window panes. Because the earthquake had occurred on a Sunday and lumber yards were not open, glaziers were soon running out of plywood for boarding up broken windows following the quake. To resupply the glaziers with plywood, police opened up a lumber yard. After the earthquake, there was also a demand for auto glass because garage doors and other items in garages had fallen on cars breaking their glass.

8.2 Architectural Damage

Most of the architectural damage to residential and commercial buildings was limited to minor cracking and falling of plaster and stucco, dislodgment of air conditioning ducts, and dislodgment of tiles and panels from suspended acoustical ceilings. A potentially hazardous example of falling ceiling panels occurred in a lecture hall of the Chemistry building at UCSB. There, sheet metal panels about 8" x 48" x 18 gauge and weighing several pounds each were dislodged from ceiling strip openings and went sailing down on top of the unoccupied seats below leaving gashes in the backs of the seats. Views of the ceiling and of a dislodged panel are shown in Figs. 8.3 and 8.4. Less frequently, lighting fixtures were loosened or fell outright as shown in Figs. 8.5 and 8.6. The most frequent location of damage to suspended ceilings was found to be near where the ceilings abut against vertical walls. At such locations, the lateral motion of the ceilings against the walls resulting from the pendulum like swinging of the suspended ceilings caused the ceiling frameworks to spread apart and spill their panels. Since 1975, minimum standards for cross-bracing of suspension channels

Fig. 8.1 Toppled merchandise at Smith's Food King supermarket in Goleta. (Santa Barbara News-Press photo. Reproduced by permission).

Fig. 8.2 Fallen books in the 1.2 million volume collection of the UCSB Library. (Santa Barbara News-Press photo. Reproduced by permission).

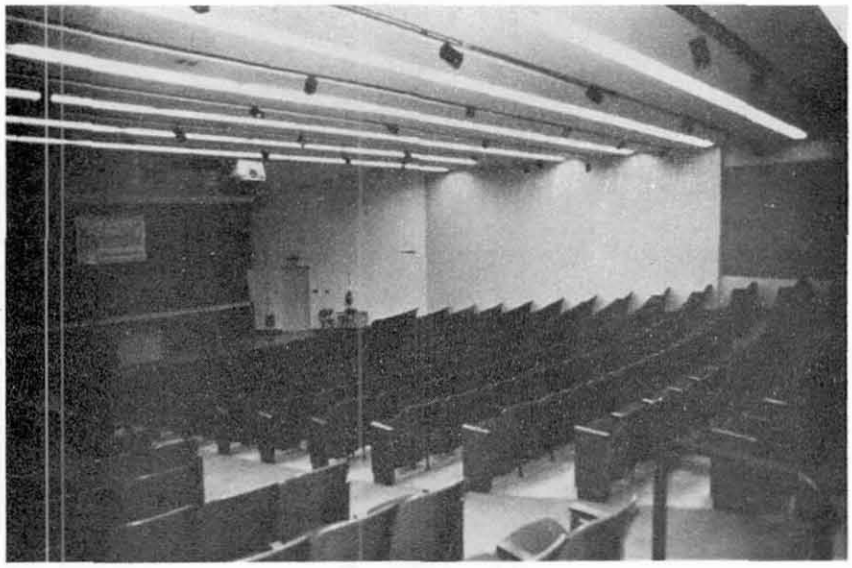


Fig. 8.3 Lecture hall of UCSB Chemistry Building where sheet metal panels fell from the ceiling.

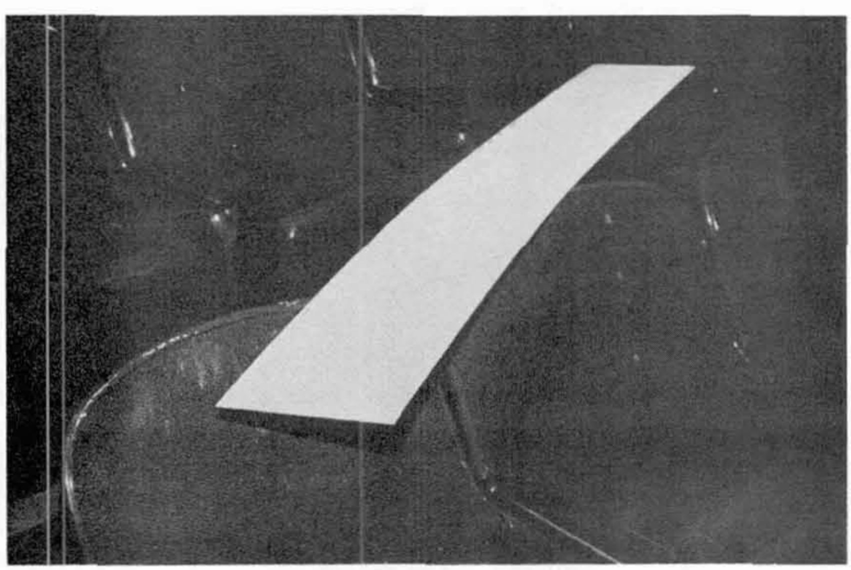


Fig. 8.4 Close up of fallen sheet metal panel, UCSB Chemistry Building (Fig. 8.3).

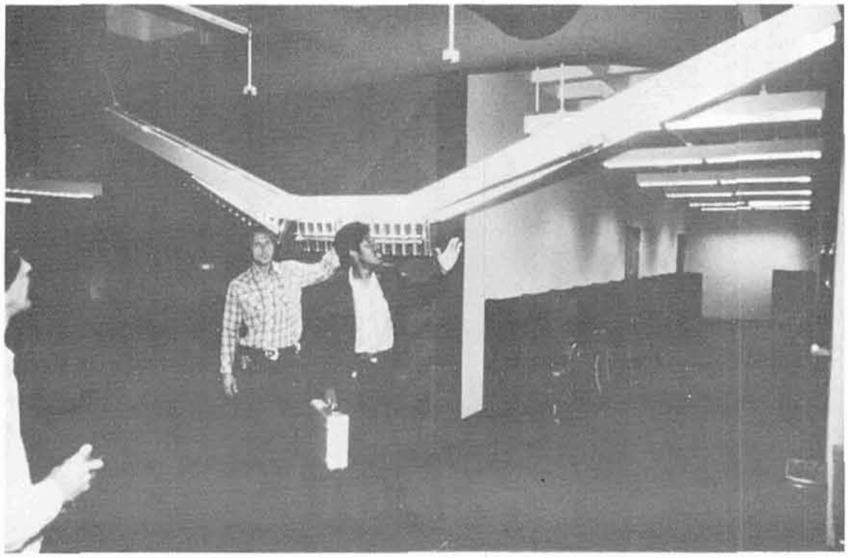


Fig. 8.5 Dislodged fluorescent lighting fixture in UCSB Library.

Fig. 8.7 Cracks in plaster wall of Santa Barbara County Administration Building.

Fig. 8.6 Dislodged and missing fluorescent lighting fixtures from overhead electrical raceways, in Flight Physics Building, Delco Electronics.

have been in force, and ceilings built according to these regulations showed no damage. In building spaces used as offices, wall partitions were moved, some as much as one inch. At one company owned laboratory, the earthquake induced structural motion activated the overhead fire supression sprinkler system. The typical type of interior damage suffered by commercial and governmental buildings is shown in Fig. 8.7, which shows the cracking of the plaster walls in the stairway of the Santa Barbara County Administration Building located in the downtown sector of the city. The total damage to the building was estimated to be $100,000.

8.3 Equipment Damage

Mechanical equipment on or near the roof tops of multistory buildings incurred considerable damage from building motion, particularly on the UCSB campus. In many instances, such equipment is spring mounted for vibration isolation purposes. When these supports did not provide sufficient lateral restraint, swaying motion of the buildings tended to knock the equipment off its supports as was amply evident from a survey of the damages. Figures 8.8 through 8.10 show an overall view and two close-ups of the collapsed supports under a 14,000-lb centrifugal water chiller on the top of the eight-story section of the UCSB campus Library (see Fig. 7.38). At the same location, several hot water pumps were wrenched from their anchor bolts, and in one instance, a pump's mounting base integrally cast with the pump motor case was simply broken off, as seen in Fig. 8.11. On the top of this and more than twenty other UCSB buildings, boilers and fans were shifted from their vibration isolation supports when inadequate lateral restraints were present, bolted down pumps were shorn loose, and the supports under cooling towers and were buckled and bent. In many cases the elevated concrete housekeeping pads on which the equipment rests were chipped and cracked. A typical example is shown in Figs. 8.12 and 8.13 which show an overall view of a boiler installation on top of six-story Ellison Hall, and a close-up of the damaged supports. A similarly sized boiler on top of six-story Phelps Hall, shown in Fig. 8.14, which has seismic restraints that conform with the current code and are of the type shown in the close-up in Fig. 8.15, received no damage. Such seismic restraints were the exception rather than the rule on the UCSB mechanical equipment surveyed. Equipment lighter in weight, such as fans, did not fare better. Figures 8.16 and 8.17 show a series of fans which fell off their supports on the roof of the Biological Science II building. Equipment control cabinets, electrical junction boxes and wiring were also dislodged and moved.

The lack of antisway braces on mechanical equipment piping, combined with the excessive unrestrained motion of the connected machinery, caused pipes and their hangers to bend and break. As a result, large sections of piping networks were shifted from their normal positions. Pipe connections were put under exceptionally high stresses and, in some cases, the pipes sheared in two as visible in Fig. 8.18. Where flexible connections were provided, such as between fans and their outlet ducts, or between pumps and pipes, these were invariably damaged or broken when the attached machinery was displaced. At places where pipes and ducts penetrate walls, the penetrating conduit or the wall tended to be damaged. For example, the piping system supplying sea water to the UCSB Marine Research facility suffered several system disabling breaks at wall

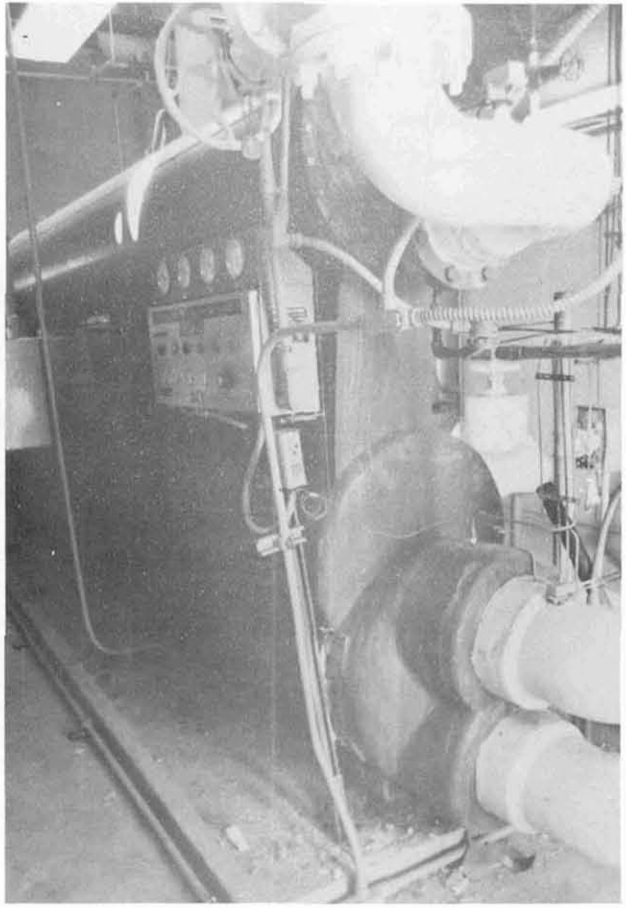


Fig. 8.8 14,000 lb centrifugal water chiller on top of Library III Building at UCSB (see Fig. 7.38). Vibration isolation supports were damaged.

Fig. 8.9 Close up of damaged supports at front of chiller (Fig. 8.8).

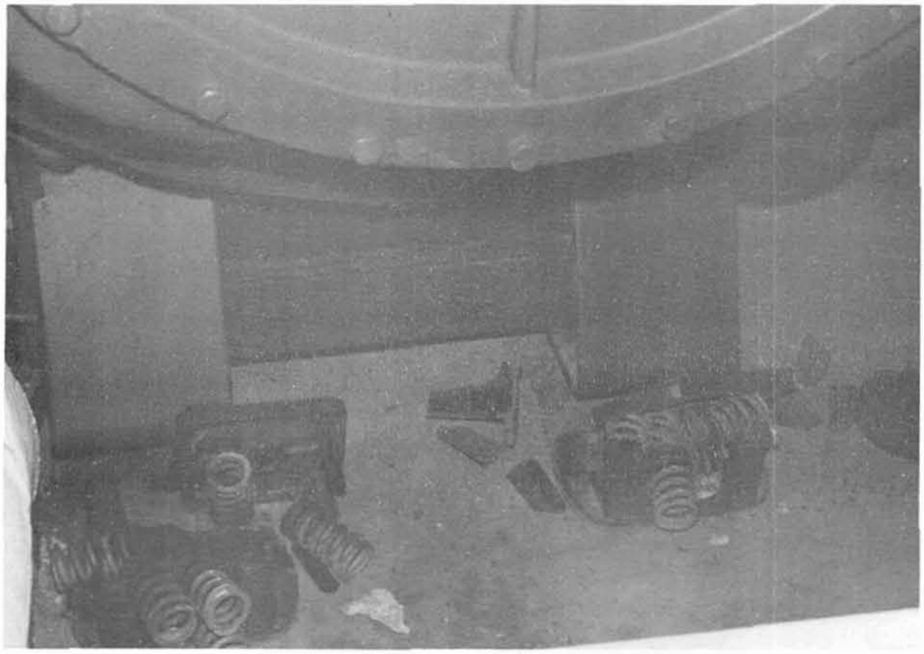


Fig. 8.10 Close up of damaged supports at back of chiller (Fig. 8.8).

Fig. 8.11 Broken mounting base of hot water pump on top of Library III Building, UCSB.

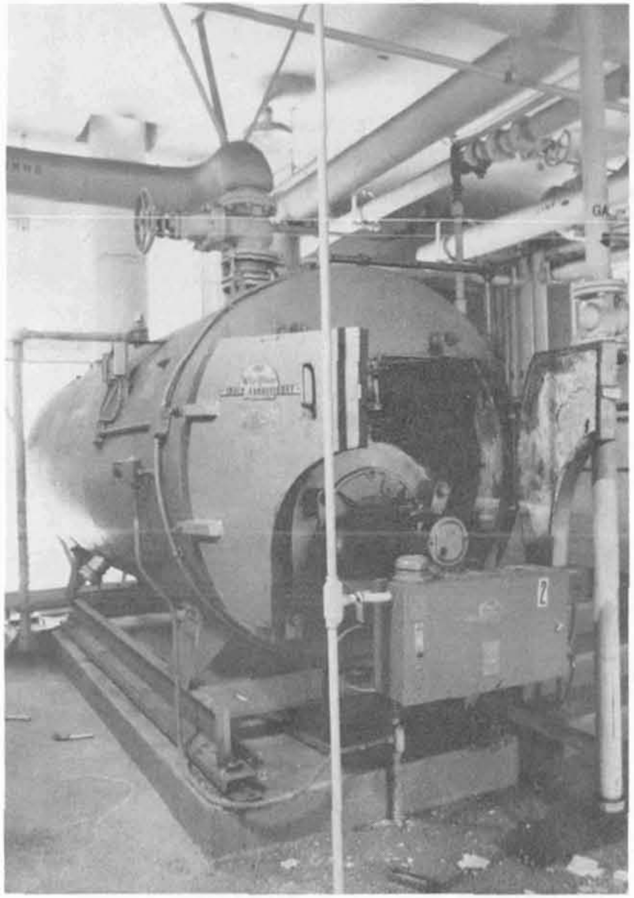


Fig. 8.12 Boiler on top of six-story Ellison Hall, UCSB. Vibration isolation supports were damaged.

Fig. 8.13 Close up of damaged support on left side of boiler (Fig. 8.12).

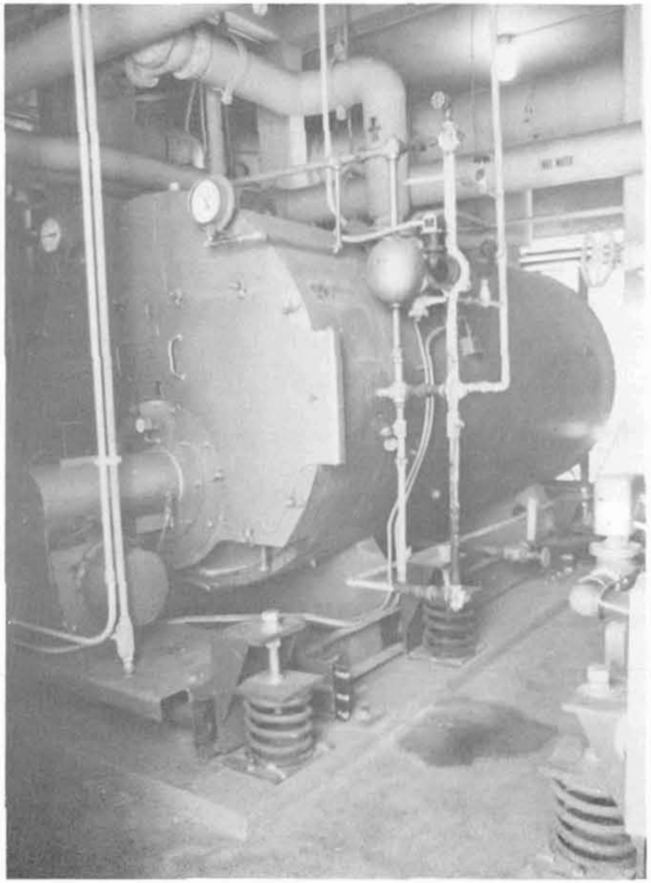


Fig. 8.14 Boiler on top of six-story Phelps Hall, UCSB. Vibration isolation supports were not damaged.

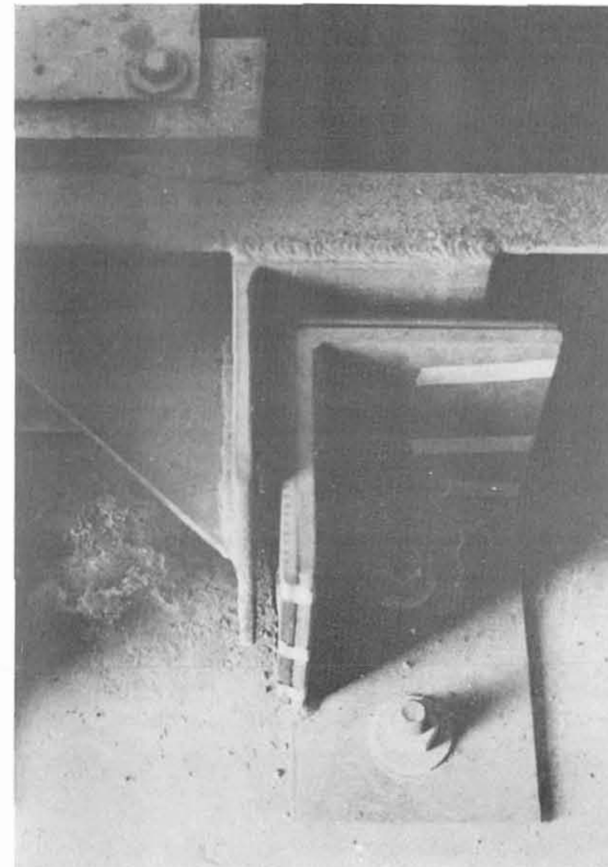


Fig. 8.15 Overhead close up of seismic restraint on boiler (Fig. 8.14).

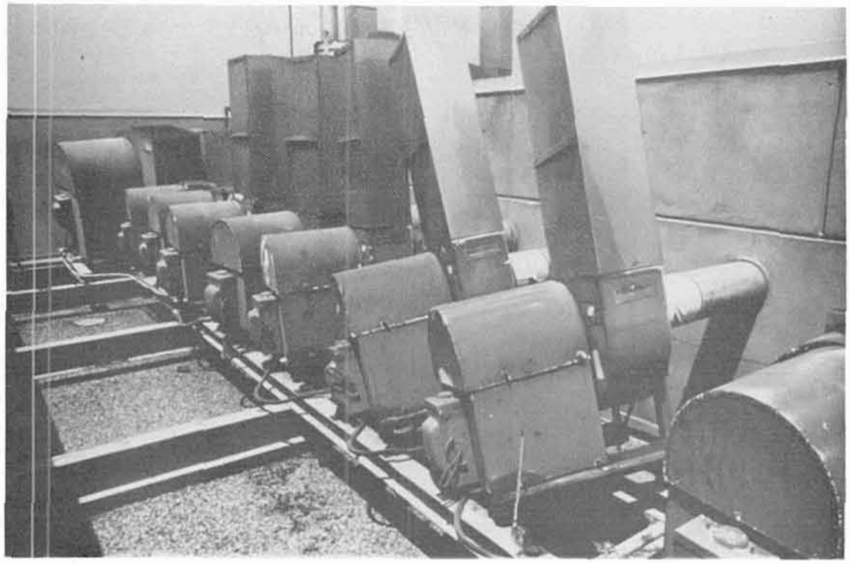


Fig. 8.16 *Fans dislodged from their vibration isolation* supports on top of Biological Sciences II, UCSB (see Fig. 3.14).

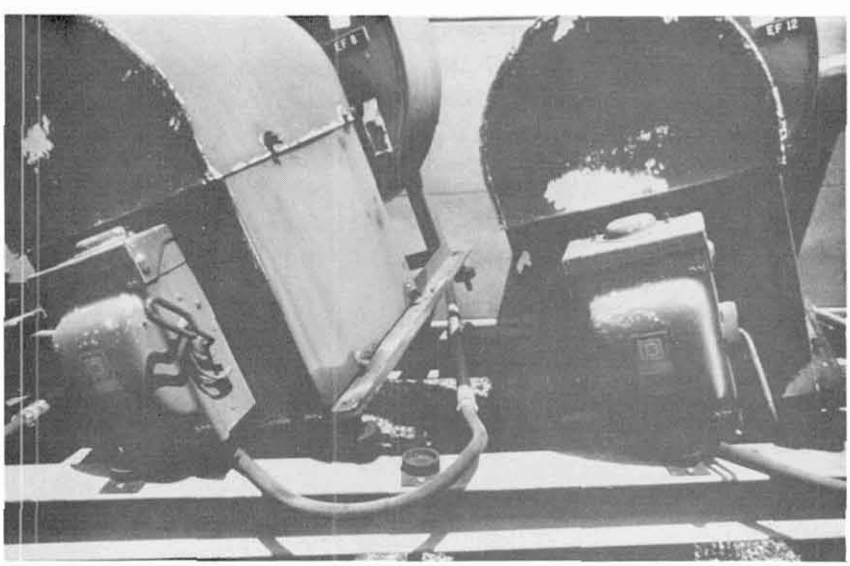


Fig. 8.17 Close up of damaged supports in Fig. 8.16.

penetration locations. One such break, which occurred in an eight-inch diameter discharge line, is shown in Fig. 8.19. In this instance, the soil around the wall of the installation settled several inches.

A noteworthy exception to the mechanical equipment damages just described was the equipment installed in the basement of the new four-story addition of the UCSB Library. This equipment was installed throughout with supports and restraints that conform with current seismic design criteria. Only a minor shift in the piping system in a north-south direction was noted. A typical piece of equipment in this installation is shown in Fig. 8.20, together with a close-up in Fig. 8.21 of its commercially available seismic restraints.

Equipment damage also occurred in homes. For example, in some residences, free standing water heaters came uncoupled from their water lines, and sometimes the tanks toppled over.

A large vibration shaker located in a ground level laboratory of a local company received damage to its supports. The shaker was designed for vertical acceleration only, and received damage to its supporting "O" rings. The shaker could not be floated after the earthquake.

8.4 Elevator Damage

Nearly half of the 49 elevators serving the UCSB campus buildings were incapacitated by the quake. The most frequent type of damage was the dislodgement of counterweights from guide rails of electric traction (cable) elevators. Brackets holding the guide rails were bent or broken, counterweight guide shoes were bent or broken, as seen in Fig. 8.22, and the loose counterweights twisted cables. The pattern of damage showed that elevators that had been high in a building (counterweight low) suffered no damage. However, elevators that had been low (counterweight high) were disabled. Two new elevators installed within the last year with the most up to date earthquake protection features, as required by the Elevator Code, were undamaged. On several of the elevators, power was cut off by earthquake activated inertial switches. Attempts to operate some of the older traction type elevators without such switches, where the counterweights had come loose, resulted in further damage when the loose counterweights collided with the cars and other equipment in the hatchways. On two elevators, the counterweights were snagged by beams and the continuing operation of the driving motor abraded the custom made sheaves against the cables.

Hydraulic elevators fared much better. The most notable damage was spilled oil and some misaligned doors. The door misalignments could be either a result of door frame deformation or guide rail displacement.

All elevators with rooftop machinery rooms suffered some damage to the equipment there. Motor generators and pumps were knocked off their

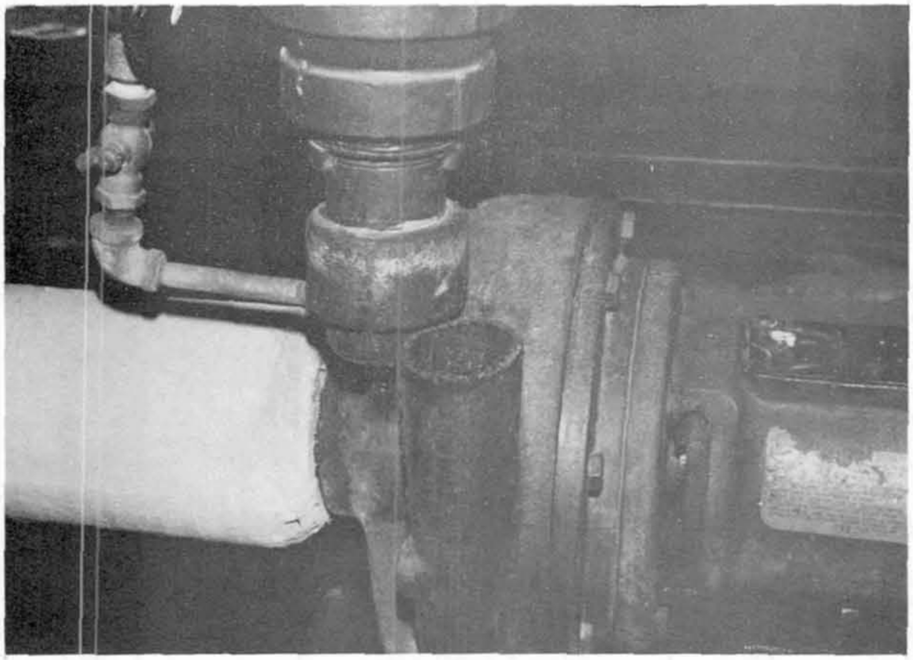


Fig. 8.18 Broken cast-iron valute at discharge connection of pump on top of six-story Ellison Hall, UCSB.

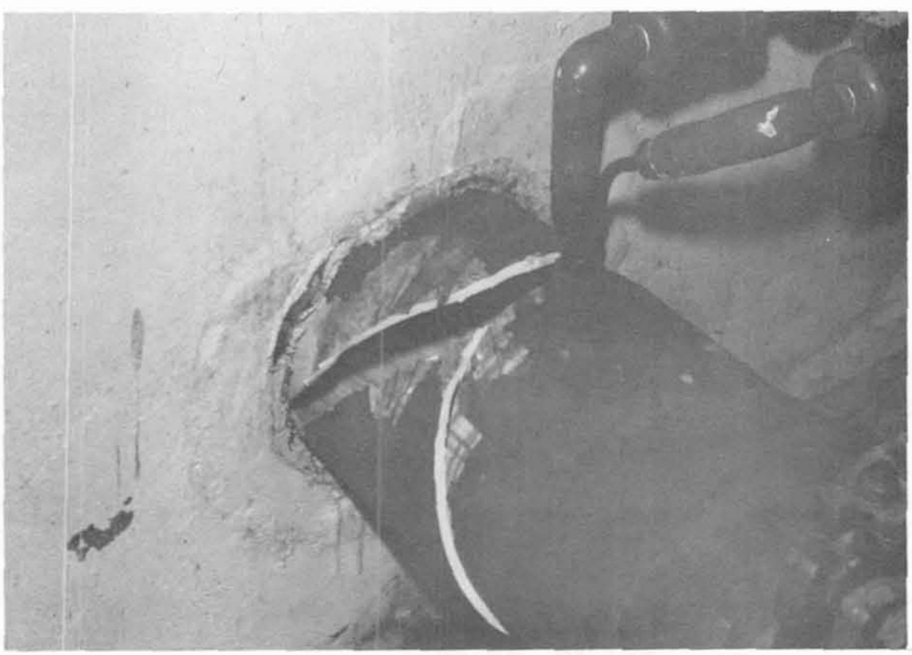


Fig. 8.19 Break in 8 inch sea water discharge pipe at wall penetration, UCSB Marine Research Facility.

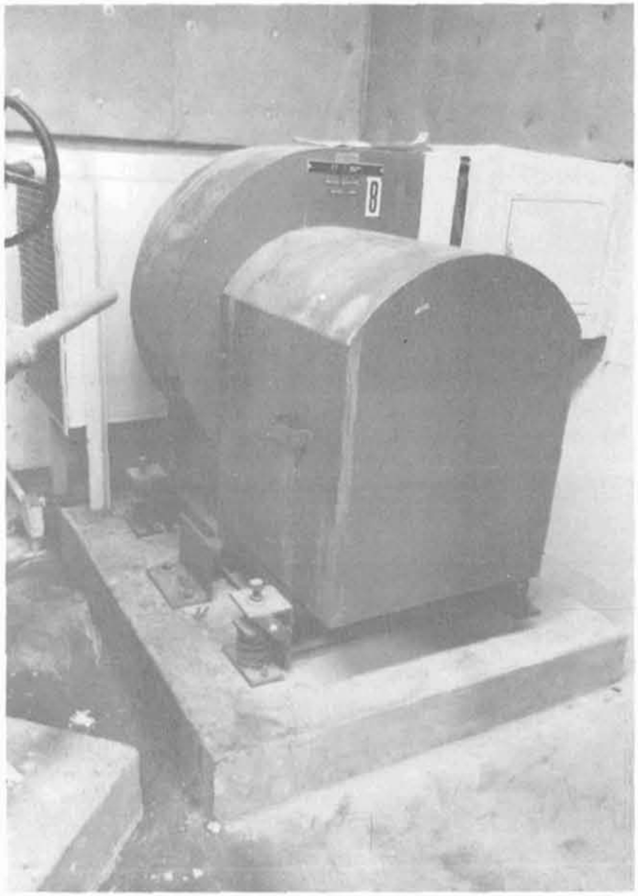


Fig. 8.20 Fan in basement of four-story Library IV Building, UCSB. Vibration supports were not damaged.

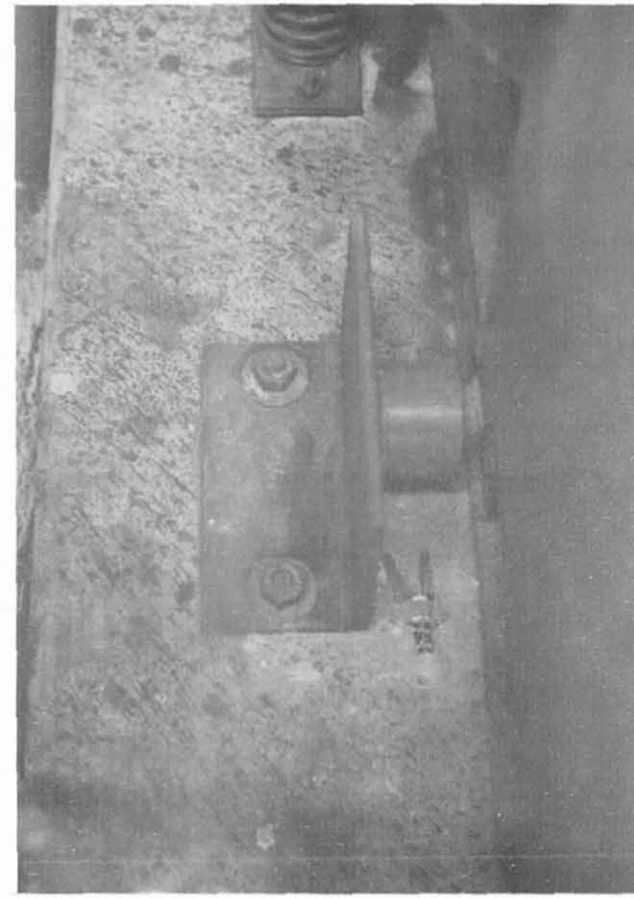


Fig. 8.21 Close up of commercially available seismic restraint on fan (Fig. 8.20).

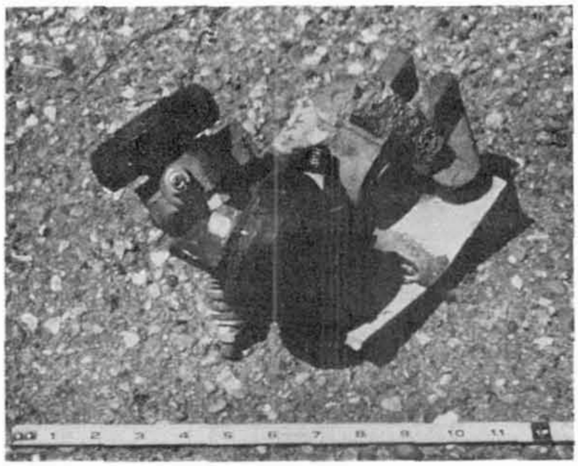


Fig. 8.22 Broken roller guide/shoe from electric traction elevator in five-story Engineering Building, UCSB.

vibration isolation pads and, in some cases, moved several inches. On one hydraulic elevator, sloshing of the oil in its tank apparently caused the tank to rupture. This could possibly be prevented by installing baffles in the tank. The Elevator Code now requires only that pumps and tanks be tied down securely. In some traction elevator machine rooms, plaster had fallen from the walls and into the elevator controllers. It appears that the recently instituted requirements for additional support for guide rails and anchorage of machinery would have prevented most or all of the elevator damage observed in this earthquake. The total cost of elevator damage at UCSB was set at over $70,000.

8.5 Damage to Sliding Doors

Building motion caused numerous sliding doors to come off their tracks in the quake area, mostly at the botton track. Examples include the large sliding doors in the gymnasium on the UCSB campus, and the large sliding doors on the hangars of Aero Spacelines, Inc., at the airport. There appeared to be no pattern to the dislodgment according to size or weight of doors. Many hinged as well as sliding doors will require refitting due to misalignment of door frames caused by shifting of floors and walls.

8.6 Acknowledgments

The authors wish to thank Mr. T.L. Towne, Director of Facilities Management at UCSB, for making available the earthquake damage survey reports by the following individuals and firms: Archer-Spencer Engineering Associates, Hesselberg, Keesee and Associates, Inc., C. Mistretta, L. Stein and Strahl Associates. The authors also thank Mr. W.H. Steinmetz, Manager of Environmental Health and Safety at UCSB, for making available photographic documentation of the earthquake damage at UCSB. Mrs. C. Bailey, Assistant Director of the Santa Barbara Municipal Airport, Mr. K.S. Irwin, of Aero Spacelines, Inc., and Mr. T. Stieglitz, of Delco Electronics, allowed inspection tours of their respective facilities which is gratefully acknowledged.

9. EARTHQUAKE EFFECTS ON SOILS AND DAMS

9.1 Effects on Soils

The earthquake caused several rock slides on San Marcos Pass, the section of State Highway 154 which runs northwesterly through the Santa Ynez Mountains from U.S. Highway 101 between Goleta and Santa Barbara. A photograph of one of the slides is shown in Fig. 5.3. Although no motorists were injured by the slides, the highway was closed throughout the following day or two for removal of loose boulders, and blasting in some areas. Extension fractures also opened in at least one area on a steep slope which forms the shoulder of the highway.

Some minor slides also occurred along the cliffs at the coastline, and some other rock slides occurred off the roads in the Santa Ynez Mountains. However, no major landslides occurred in the Los Padres National Forest areas in the Santa Ynez Mountains.

As previously noted, the major fault motion occurred offshore in the Santa Barbara Channel. Consequently, no surface traces of fault motion have been found onshore in Goleta or elsewhere. However, evidence of some extension fractures resulting from lateral spreading was found near Goleta beach near the northeast entrance to the UCSB campus. As shown in Figs. 9.1 through 9.4, several cracks opened in the bicycle path leading to the University. These cracks indicate a northward sense of slip of an arcuate slab, 200 feet long and 25 feet wide, of the south bank of the flood channel of Goleta slough. The maximum extension is approximately 1½ inches. No vertical relative slip was apparent. The cracks extended a considerable distance into the brush on each side of the path. Soil in this general vicinity is a relatively soft alluvial fill at the mouth of the Goleta slough.

Lateral spreading and differential settlement of from 3 to 6 inches occurred in localized areas of the sand spit near the mouth of the lagoon on the UCSB campus (see Fig. 3.2). Settlement of approximately 6 inches occurred around parts of the sea water pumping facility of the UCSB Marine Science Institute as shown in Figs. 9.5 and 9.6. This large differential settlement contributed to the rupture of large water lines inside the pumping facility. No evidence of liquefacation has yet been reported.

Evidence of lurching was found in some areas near the Married Student Housing facilities of UCSB on Los Carneros Road, and on Los Carneros Road north of Hollister Avenue. Shown in Figs. 9.7 and 9.8 is a north-south section of concrete sidewalk along Los Carneros Road north of Hollister Avenue. As a result of sudden acceleration of the ground beneath it and being constrained at the south end, the sidewalk evidently buckled upward, fractured, and fell upside down as shown in the photograph. An inspection of the surrounding area revealed no evidence of surface ruptures, buckling, or damage of any kind to the adjacent asphalt pavement, concrete curb and gutter, or ground.

An east-west section of the sidewalk at the southern edge of the UCSB Married Student Housing facility is shown in Figs. 9.9 and 9.10.

Fig. 9.1 Extension fracture in the bicycle path northeast of UCSB. Note misalignment of centerline. Building at upper right is Biological Sciences II, UCSB. Cracks runs in a northwesterly direction.

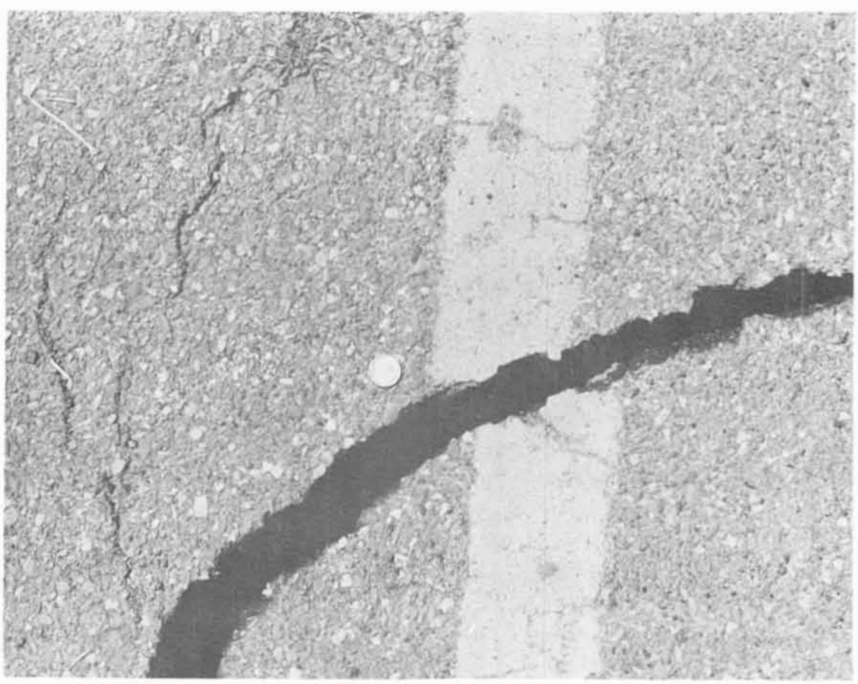


Fig. 9.2 Close up of extension fracture shown in Fig. 9.1. Scale given by the coin (quarter) in the center of the picture.

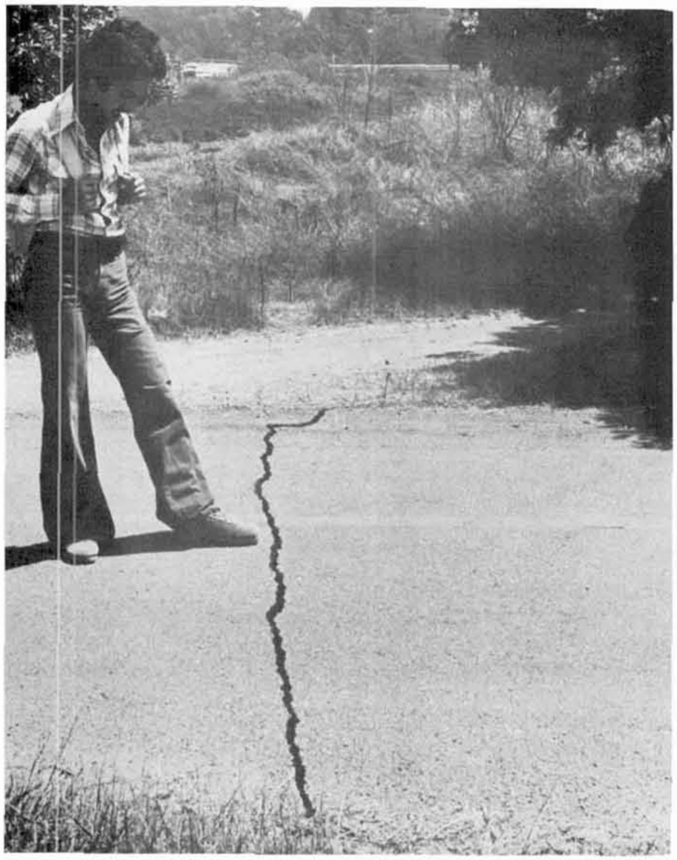


Fig. 9.3 Another extension fracture in the bicycle path shown in Fig. 9.1. This crack also runs in a north-westerly direction.

Fig. 9.4 Close up of the extension fracture shown in Fig. 9.3. Scale given by the coin (quarter) in the center of the picture.

Fig. 9.5 Settlement of soil near pumping facility at sand spit, UCSB. Note previous soil line on concrete.

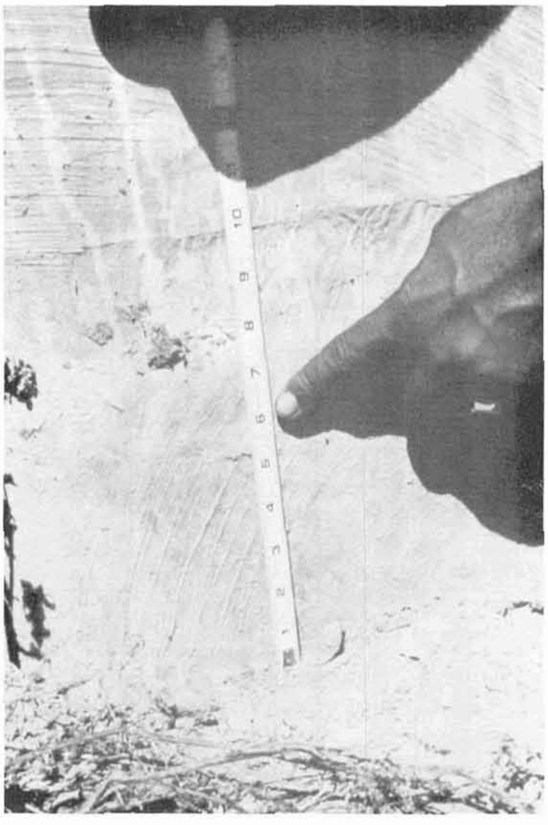


Fig. 9.6 Close up of soil settlement shown in Fig. 9.5.

Fig. 9.7 Concrete sidewalk which buckled and fell upside down on Los Carneros Road north of Hollister Avenue, Adjacent pavement, curb, and gutter were not disturbed.

Fig. 9.8 View of sidewalk in Fig. 9.7 from opposite direction.

Fig. 9.9 East trending concrete sidewalk at UCSB Married Student Housing on Los Carneros Road. (View from east.)

Fig. 9.10 Close up of curb push out shown in Fig. 9.9. (View from south.)

Horizontal lurching evidently thrust this sidewalk toward the pavement, fracturing the curb as shown in Fig. 9.10. An inspection of the surrounding area again revealed no evidence of surface ruptures or other damage to pavement or soil.

It has been reported that the train derailment near Hollister Avenue and U.S. Highway 101 in Goleta resulted from failure of a fill. The amount of lateral spreading was sufficient to cause a kink in the tracks which was noted by the railroad engineer as he approached it at 50 miles per hour.

At the facilities of Delco Electronics near the UCSB Married Student Housing shown in Figs. 9.9 and 9.10, an accurate triangulation was performed to check for relative soil displacements caused by the earthquake. The results of this survey showed that no such displacements occurred in this area.

9.2 Effects on Dams

Several dams are located in the mountains near Santa Barbara (see Fig. 9.11). As noted in Chapter 3, very small accelerations were recorded by strong motion instruments in the valve house and at the crest of Bradbury Dam (Lake Cachuma) and by instruments at Juncal Dam (Jameson Lake) and Gibraltar Dam (Gibraltar Reservoir). The accelerograph at Casitas Dam did not trigger, but was fully operational.

Except for minor damages to a few valves, no significant damage was reported at any of the dams. However, a substantial increase in the rate of ground water inflitration into the Tecelote Tunnel was reported. This tunnel, which runs from Lake Cachuma through the Santa Ynez Mountains to Goleta, is a major artery in the water distribution system for Goleta, Santa Barbara, and Carpinteria. Accurate measurements of the change in the rate of inflow are not yet available. Similar increases in the rate of inflow into the Doulton and Mission Tunnels were also reported. These tunnels supply south coast water from Jameson Lake and Gibraltar Reservoir, respectively.

The water behind earth-fill Sheffield Dam had to be lowered to allow repair of an earthquake-damaged valve. The dam itself was not damaged, although it has received damage in past earthquakes.

9.3 Acknowledgments

The comments of Professor A.G. Sylvester of the Department of Geological Sciences of the University of California, Santa Barbara, are gratefully acknowledged. Also acknowledged is the cooperation of the Cachuma Operation and Maintenance Board and the Montecito County Water District, the City of Santa Barbara and the Goleta County Water District in providing information on the performance of dams and aqueducts during the earthquake.

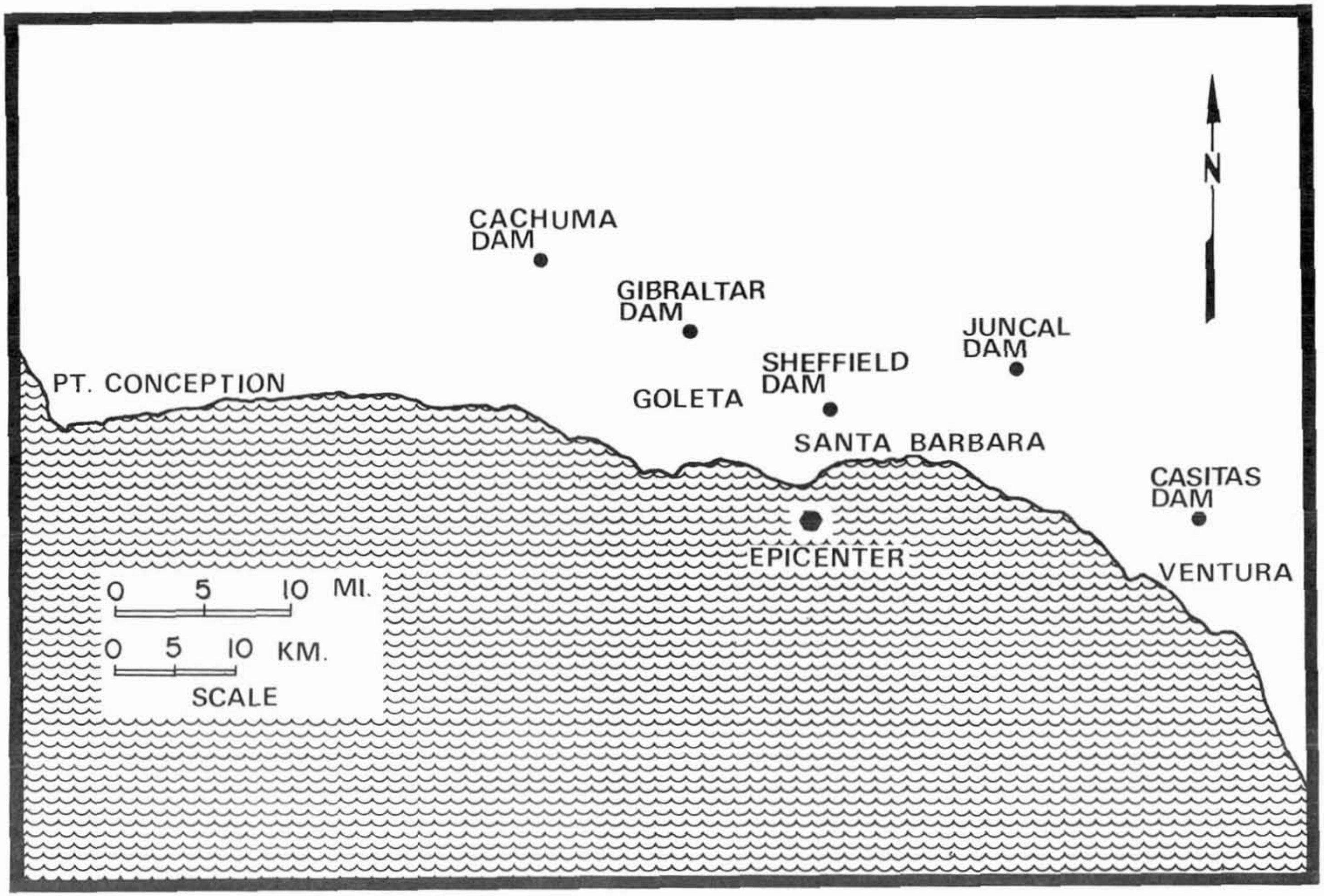


Fig. 9.11 Location of Dams in the Santa Barbara area

10. EARTHQUAKE EFFECTS ON COASTAL FACILITIES AND OFFSHORE STRUCTURES

The earthquake caused almost no damage to the 14 offshore oil platforms in the Santa Barbara Channel, but $30,500 in damage was sustained at Marina #1 in the Santa Barbara Harbor.

10.1 Effects on Coastal Facilities

The most extensive damage to coastal facilities occurred at Marina #1 in the Santa Barbara Harbor (see Fig. 1.3). Within the harbor several marinas are maintained by the City of Santa Barbara for the mooring of small recreational and commercial fishing boats. Marina #1 consists of a floating dock about 1000 feet long and 8 feet wide, running in a northeast direction. A number of floating "fingers" extend from the marina and form walkways to the individual boats. Several such marinas run roughly parallel or perpendicular to the shoreline and to each other within the harbor. Marina #1 is farthest from the shore and is parallel to the shoreline.

The marina is constructed of a number of floats which are styrofoam filled thin concrete shells. Alighment of the floats is maintained by a double row of concrete piles which extend through holes in the floats. This arrangement allows for vertical motion during changes in water level. A plywood gusset plate with a hole and guide rollers is provided for each pile. During the earthquake the piles, which extend a minimum of 12 feet below the mud line, moved with the underlying soil while the floats tended to move differently with the water surface. As a result, 52 of the piles and gusset plates were damaged. Typically, the gusset plates and rollers were torn loose and broken up by the lateral loads while the piles were left tilting away from vertical. Repairs consisted of realigning the piles and providing new gusset plates and roller guides, which cost a total of $30,500.

The amplitude of motion of the nearby pier was sufficiently large that minor damage was sustained by utility connections and some small leaks were developed in water lines. Fortunately no leak occurred when supports tore loose and allowed a large fuel line to sag 3 or 4 feet beneath the Navy pier. There were reports of visible motion of the sandbar at the mouth of the harbor during the earthquake, but permanent soil motion was not sufficient to alter the normal schedule of dredging operations.

No significant damage was reported at the nearby facilities maintained by the U.S. Coast Guard and the U.S. Navy.

On the coast between the UCSB campus and the location of the train derailment (see Fig. 1.2), small onshore oil production and storage facilities are maintained in several locations. In two such locations, at the ARCO facility and the Aminoil facility near Ellwood, minor damage was reported. The damage consisted of minor cracks in some unfinished concrete and concrete block construction, some broken water lines, downed power lines, cracked pipe nipples on small oil lines, a slow leak in a waste water tank, and minor landslides along the bluffs which blocked access roads to some wells. The shaking in this area was sufficiently strong to cause some mechanical equipment to shut down momentarily when the excessive vibration switches were triggered by the earthquake. No damage was sustained by large oil storage tanks.

10.2 Effects on Offshore Structures

Currently there are 14 offshore platforms in the Santa Barbara Channel. These platforms are distributed along the coast from near Point Concepcion in the west to Ventura County in the east, as shown in Fig. 10.1. The name of each numbered platform, and of the oil company which operates it, is listed in Table 10.1.

The earthquake had only minor effects on these platforms. After the earthquake the platforms were inspected by officials from the State Lands Commission or the U.S. Geological Survey, and by the petroleum operators' personnel. There was no reported damage to structures, wells, or oil and gas lines, and no significant changes in well production or oil seeps.

The earthquake caused excessive vibration which automatically shut down compressors on platforms Holly, Hilda, and Heidi. Earthquake induced electric power failures on shore caused temporary interruption of production on platforms Holly, A, B, and C. Production was quickly restored in all cases.

Personnel on platform Holly, which is closet to the UCSB campus, said the earthquake caused the platform to rock north and south noticeably for a few seconds. At platform Hondo to the west, strong motion was reported to have been noticeable for about 20 seconds, although no vibration switches were activated and nothing fell from bookshelves, work benches, and the like. At platform Hilda to the east the shaking was reported to have been strong, and drill pipe rattled noticeably in the derrick. As noted in Chapter 3, no instrumental recordings of the strong motion on platforms were obtained because of a common malfunction of recording systems.

10.3 Acknowledgments

The information reported in this section was provided by Mr. Yamada with the Public Works Department of the City of Santa Barbara, Mr. A.D. Willard of the State Lands Commission, Mr. F. J. Schambeck of the U.S. Geological Survey, Mr. R. Hanscom with the Petroleum Department of the County of Santa Barbara, and numerous officials with various oil companies in the area.

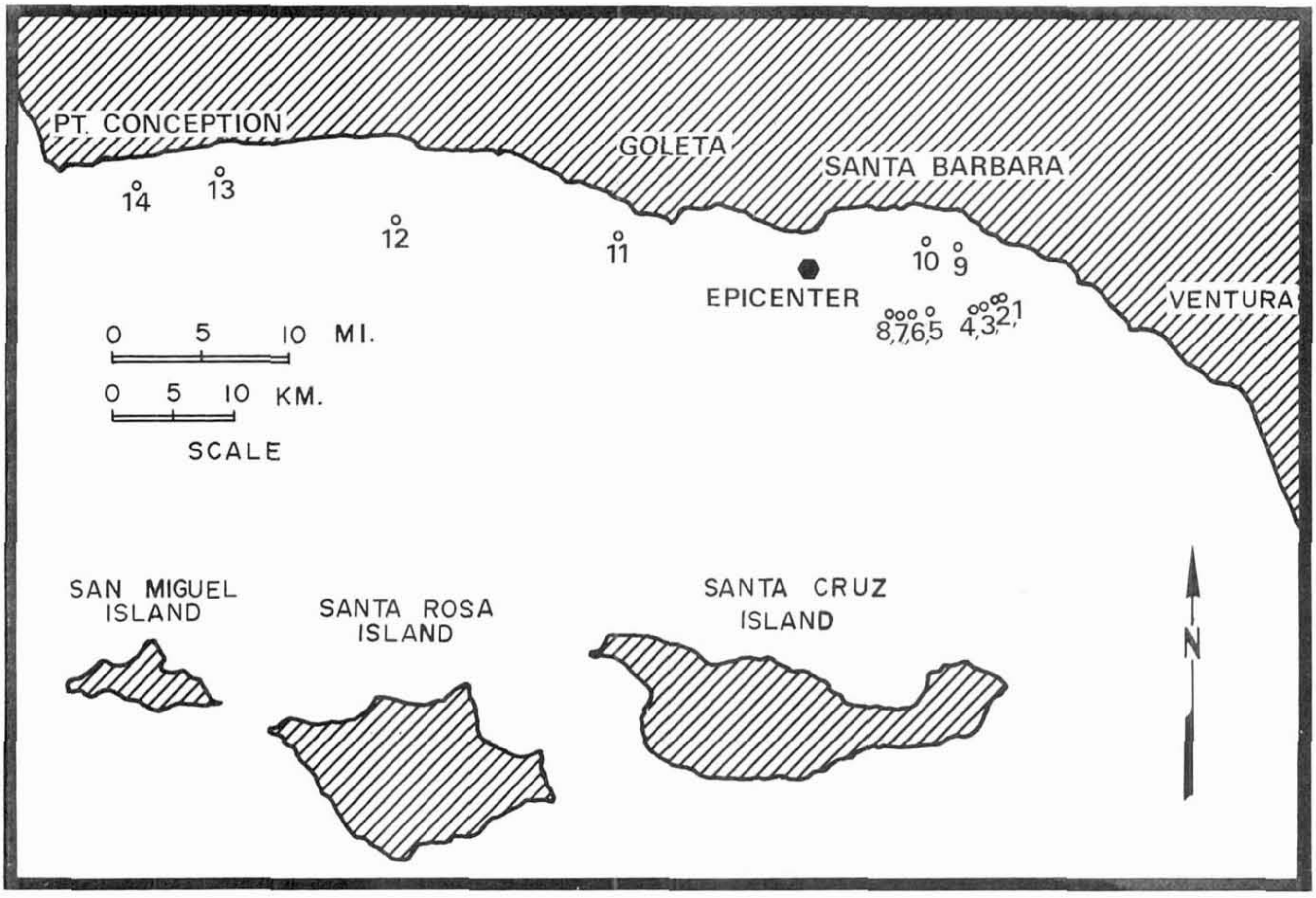


Fig. 10.1 Location of Offshore Platforms in the Santa Barbara Channel

TABLE 10.1

OFFSHORE PLATFORMS IN THE SANTA BARBARA CHANNEL

Number	Name	Petroleum Operator
1	Heidi	Chevron USA
2	Hope	Chevron USA
3	Hogan	Phillips Petroleum
4	Houchin	Phillips Petroleum
5	Hillhouse	Sun Oil
6	A	Union Oil
7	B	Union Oil
8	C	Union Oil
9	Hazel	Chevron USA
10	Hilda	Chevron USA
11	Holly	Atlantic Richfield
12	Hondo	Exxon
13	Helen	Texaco, Inc.
14	Herman	Texaco, Inc.

11. EVIDENCE OF LOCALLY NONLINEAR BEHAVIOR OF STRUCTURES

A variety of structural systems showed evidence of locally nonlinear behavior during the earthquake. Such behavior typically occurred at relatively flexible connections between adjacent structures which tended to move separately under base excitation. Thus, during this moderate earthquake, the nonlinear behavior was often confined to the flexible connections themselves, or to those portions of the structures which interface with such connections.

In some cases nonlinear behavior in flexible connections was intentional and in fact intended to prevent significant structural damage. For example, some of the mechanical equipment on the UCSB campus was mounted on flexible supports which included earthquake restrainers or snubbers. Photographs of such equipment are shown in Figs. 8.14, 8.15, 8.20, and 8.21. The flexible spring mountings are provided to prevent excessive transmission of vibrational forces into the structure. However, when subjected to earthquake base motions such flexible mountings typically result in large relative motion between equipment and foundation unless snubbers are provided. The snubbers prevent excessive amplitudes of relative motion by providing an effective support stiffness which increases with the amplitude of relative motion. The resulting nonlinear behavior is confined to the flexible mountings and damage is prevented.

In other cases the intentionally flexible connections were provided for reasons other than earthquake protection, or they were intended to behave linearly. Such cases typically resulted in localized earthquake damage to the connections themselves. Examples include the many cases of damage to unsnubbed vibration mountings for equipment reported in Chapter 8, and many other cases of damage to seismic joints in buildings and expansion joints in highway bridges. Seismic joints are intentional gaps between adjacent structures to prevent structural interaction during earthquakes. The clearance between adjacent structures is typically assumed to be sufficient to prevent collisions and the associated nonlinear dynamical interaction. Many cases of relative motion at such joints were found in multistory buildings on the UCSB campus. Examples of such effects on seismic joints are shown in Figs. 11.1 to 11.4. In the majority of cases it appears that impact did not occur and that the adjacent structures probably did not interact significantly during the earthquake. It is possible however, that dynamic interaction did occur in some locations, such as the seismic joints between the Graduate Tower and the elevated walkways to the adjacent South Hall on the UCSB campus, as shown in Figs. 11.5 and 11.6. Minor damage to seismic joints was reported in most of the multistory buildings on campus. In one case this minor damage resulted in a safety hazard when a damaged seismic joint prevented the opening of a second floor emergency exit on the north side of the UCSB Library, as shown in Figs 11.7 and 11.8.

Expansion joints in highway bridges are intentional gaps between adjacent bridge sections provided to prevent excessive thermal stresses resulting from thermal expansion and contraction during changes in temperature. Evidence of minor impact at such joints was observed in

Fig. 11.1 Damage to seismic joint in South Hall, UCSB.

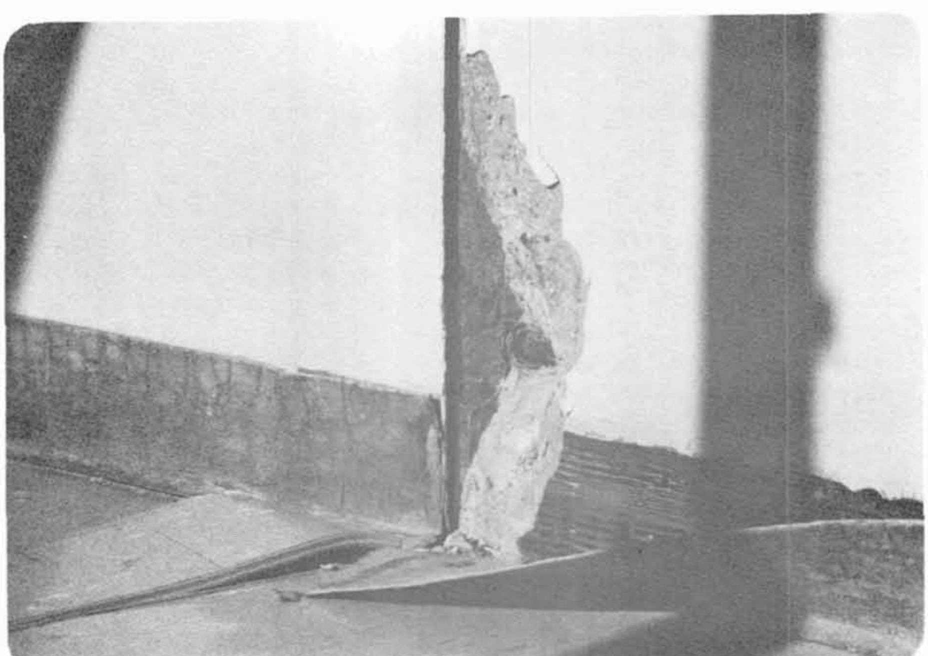


Fig. 11.2 Damage to seismic joint in South Hall, UCSB.

Fig. 11.3 Another damaged seismic joint in South Hall, UCSB.

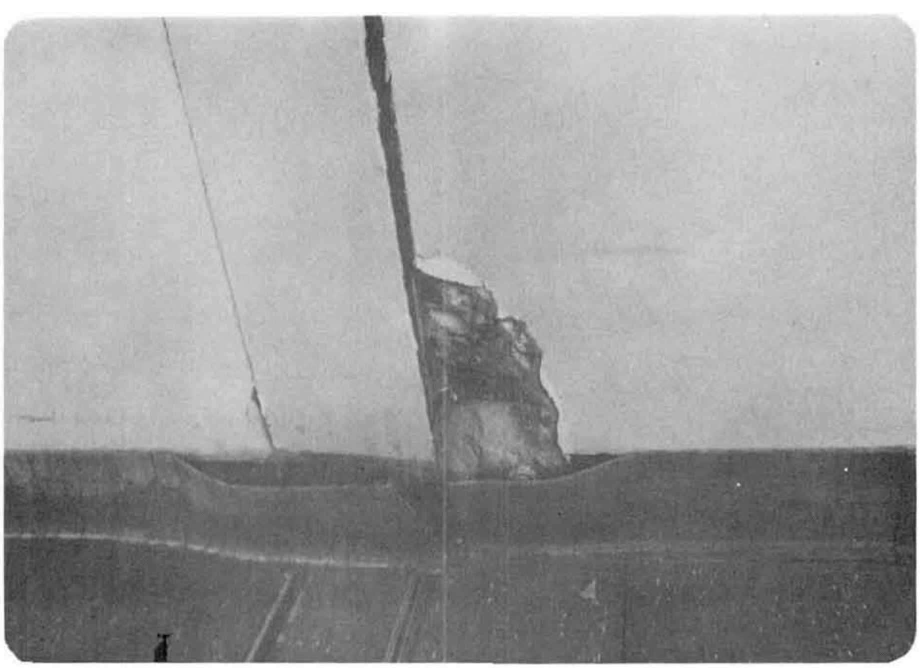
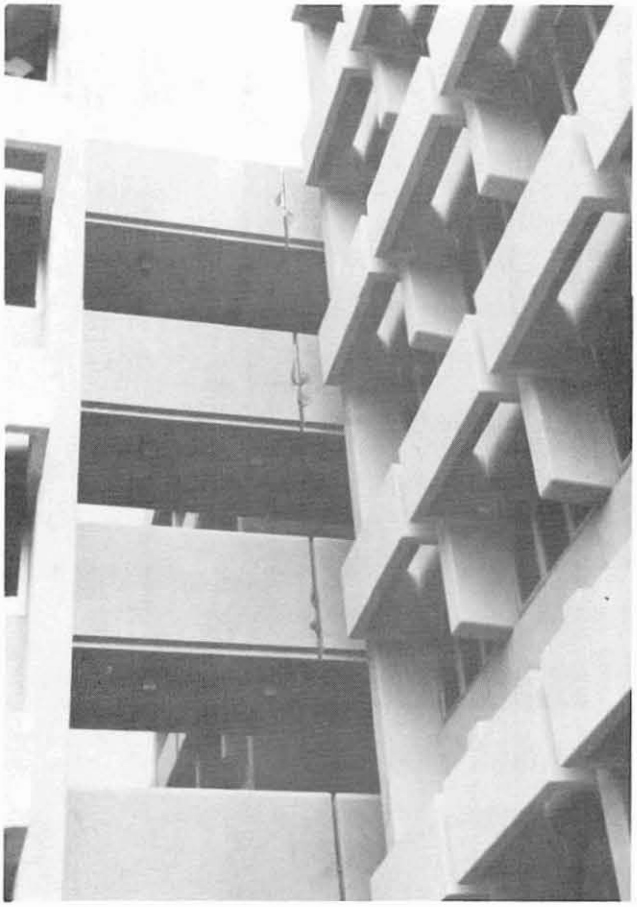


Fig. 11.4 Close up of the damage in the corner at the right in Fig. 11.3.



ig. 11.5 Damage to seismic joints on third through sixth floor walkways between South Hall and the Graduate Tower, UCSB campus.

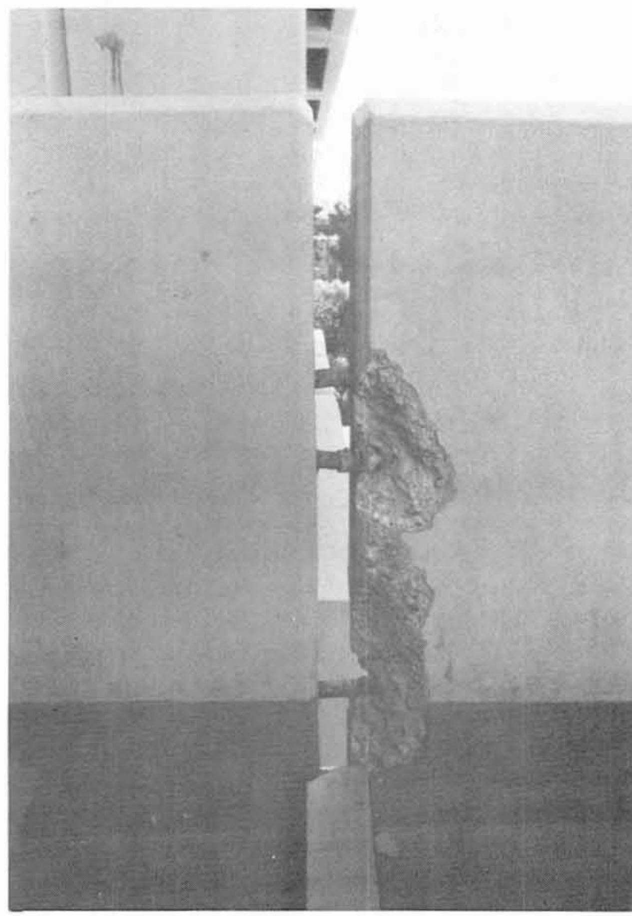


Fig. 11.6 Close up of damage to seismic joints shown in Fig. 11.5. View from inside walkway.

Fig. 11.7 Stairway from emergency exit on north side of UCSB Library I Building. Stairway and building are separated by a seismic joint.

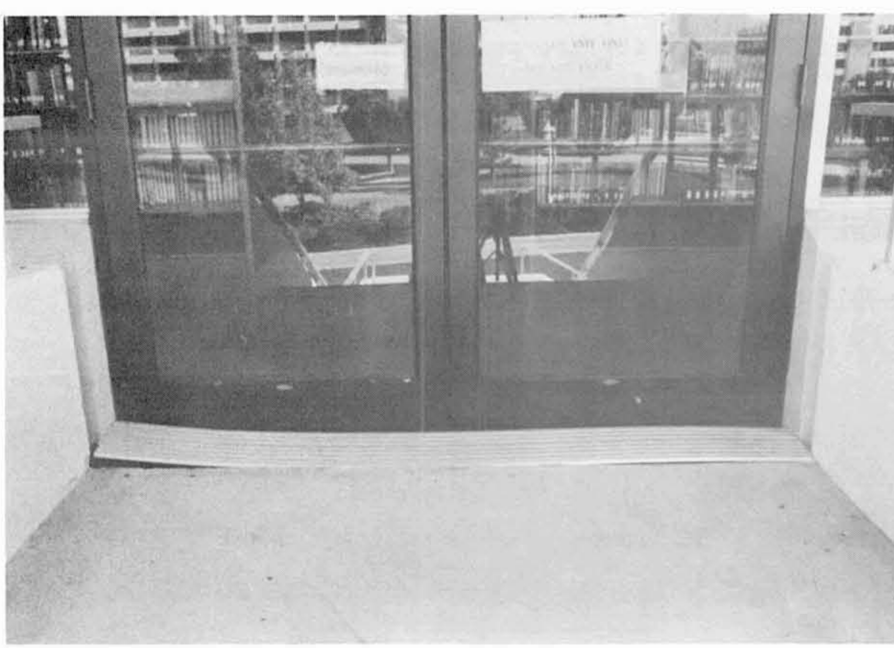


Fig. 11.8 Close-up of damage to seismic joint between stairway and building in Fig. 11.7. Note that damaged cover plate blocks the opening of emergency doors.

the bridge at Ward Memorial Boulevard and U.S. Highway 101, which is described in Chapter 5. Photographs of this evidence are shown in Figs. 5.13.

Another example of intentionally flexible connections which sustained earthquake damage is found at Marina #1 in the Santa Barbara Harbor. As described in Chapter 10, the marina is constructed from concrete floats whose alignment is maintained by rows of concrete piles which extend through holes in the floats to allow for vertical motion resulting from changes in water level. These flexible connections between floats and piles are achieved by providing each pile with a plywood gusset plate with a hole and guide rollers. The design did not provide adequate lateral resistance and extensive damage to the flexible connections resulted from the earthquake.

Locally nonlinear behavior also occurred at joints between reinforced concrete tilt-up panels in some industrial buildings in Goleta. Examples of this type of behavior are shown in Figs. 7.44 and 7.45 which were taken at the facilities of Delco Electronics in Goleta.

In contrast to the locally nonlinear behavior just described, nonlinear behavior distributed throughout many portions of a structural system also occurred in this earthquake. Such distributed nonlinear behavior resulted in many cases from damage to relatively stiff but weak secondary components distributed throughout the structural system. An example of such behavior is the architectural damage to plaster walls in relatively flexible modern multistory buildings. Photographs of this type of damage are shown in Chapters 7 and 8. The plaster walls are evidently not sufficiently flexible to sustain without damage the levels of deformation necessary for the primary structural frame to resist the earthquake forces. Another example of similar distributed nonlinear behavior occurred at the control tower of the Santa Barbara Municipal Airport. As described in Section 7.5, lateral reinforcement of the tower is provided by diagonal steel bracing tubes between columns. These tubes were not strong enough to resist the lateral deformations caused by the earthquake and consequently yielded at many locations. Photographs of structural damage at a typical location within the tower are shown in Figs. 7.60 to 7.63.

12. CONCLUSIONS AND RECOMMENDATIONS

The ground shaking produced by this earthquake constitutes an extreme example of an asymmetrical pattern of radiation of seismic waves. As previously discussed, the asymmetry was apparent in the geographical distribution of damages, differences in strong motion records, and even differences in reported Richter magnitudes for the event. Instruments in Northern California reported an average Richter magnitude of 5.7, while instruments in Southern California reported 5.1. Further studies of the influence of the orientation and nature of faulting, and the direction and velocity of rupture may provide useful information for predicting this type of asymmetry in future earthquakes.

Significant strong motion records were obtained from instruments in 5 buildings and at 3 dams in the area. Two of the buildings were well instrumented, each having 9 accelerometers distributed throughout the structure. The duration of strongest ground shaking was 2 to 3 seconds in all areas, and the peak ground accelerations in Goleta were as large as 0.45g, while 0.21g was recorded in Santa Barbara. On the other hand, strong motion instruments located on offshore platforms did not perform properly and no records were obtained from offshore locations. These offshore instruments need improvement in design and maintenance if they are to provide useful data in future earthquakes.

None of the hospitals, fire and police stations, or public schools in the area of strong shaking received serious damage. However, the emergency power supply system at the Goleta Valley Community Hospital was activated, as were such emergency systems in other less critical facilities in the area. This emergency system, which is fueled by natural gas, functioned properly because natural gas service was not interrupted during this earthquake. Had the earthquake been large enough to sever the gas lines, it is not likely that the emergency system would have been functional. Emergency systems in such critical facilities as hospitals should not rely on public utilities.

The lack of structural damage to public schools has again demonstrated the soundness of the provisions of the Field Act under which public schools are currently built in California. An area where public school safety could be improved, however, is in anchoring of acoustical ceilings to prevent their collapse and using fasteners to lock light fixture diffusers positively in place. Acoustical ceilings which met the minimum anchorage and strength requirements now in force performed satisfactorily. It appears, therefore, that earthquake resistance of public schools could be improved by requiring that all acoustical ceilings be brought up to the current minimum standards.

The train derailment and bridge damages indicate the importance of promptly assessing the degree and extent of damages to transportation facilities following even a moderate earthquake. Had the freight train been stopped in time and the track inspected for damages, the derailment would most likely have been averted. The most significantly damaged highway bridges (on Ward Memorial Boulevard) were quite properly closed to traffic until their structural integrity could be ascertained. The closure did not cause any serious traffic problems mainly because (fortunately) UCSB was not in regular session.

The bridge damages also revealed the dependence of earthquake damage on the duration of strong shaking. Had the duration of the Santa Barbara earthquake been several seconds longer, some portions of the most vulnerable bridges would likely have received serious structural damage, which may even have caused collapse.

The nature of earthquake damages received by utilities did not reveal any serious deficiencies in engineering design. However, the fact that electrical power and telephone communications were disrupted is an indication of the importance of public utilities to maintain emergency radio communications at important facilities. For example, the Goleta County Water District's Corona Del Mar plant was without power and radio communications for ten minutes following the earthquake, and without telephone service for over thirty minutes. This limited the plant's ability to contact and direct field personnel to suspected damage locations, and to call in off-duty employees.

The structural integrity of the majority of the buildings in the area of strong shaking was not seriously impaired, although significant damage occurred to a variety of structures in the Goleta area. Had the duration of strong shaking lasted a few seconds longer it is likely that a number of these structures would have sustained serious damage. As in other recent earthquakes, wood or steel structures generally sustained less severe damage than concrete or masonry structures, although some well designed reinforced concrete structures survived with no apparent damage. The overall pattern and extent of structural damage was generally consistent with the intensity of strong shaking recorded by strong motion accelerographs. However, significantly greater damage was sustained in Goleta than would normally be expected for a magnitude 5.1 event at an epicentral distance of 13 to 15 kilometers.

The most common form of structural damage sustained by multistory buildings consisted of diagonal cracking of shear walls, particularly those aligned along the north-south direction and in the lower stories. The most common damage to residential and small commercial buildings consisted of cracking of plaster walls, minor settlement of foundations, the failure of a few unreinforced chimneys, fallen water heaters, and broken glass. In a sense, the earthquake served as a form of massive full scale test of structures which revealed some unexpected weaknesses. For example, several shear walls in Anacapa and Santa Rosa Halls at UCSB were damaged with unexpected severity. Further investigation revealed some areas within these concrete block walls with missing of misplaced steel reinforcement and occasional lack of grout.

The most wide spread damage in residential areas was received by mobile homes. Approximately one in every four such homes in the area was damaged by the earthquake. Many were knocked from their foundation piers and fell mostly toward the south, rupturing utility connections in the process. One mobile home burned to the ground as a result of a gas leak caused by the earthquake, and three other homes were uninhabitable after the quake. This type of damage could likely be prevented by establishing and enforcing mandatory provisions for lateral reinforcement of mobile homes. The large number of mobile homes damaged in this moderate earthquake (approximately 300) is an indication of the urgency of the need for such provisions.

In addition to structural damage the earthquake caused considerable architectural damage and damage to property and equipment. The extent of damage to mechanical equipment in buildings, including elevators, emphasizes the need for sound seismic design. The code requirements now in effect appear to be sufficient to have prevented most of the equipment damage sustained in this earthquake. The seismic resistance of many equipment installations could be greatly improved by simply bringing them up to current standards. In particular, mechanical equipment vibration isolation supports should incorporate seismic restraints, and elevator guide rails should be provided with additional supports when they are not up to current standards. In homes, water heaters should be restrained and anchored.

Much of the property damage occurred when breakable objects fell from shelving. Such damage was occasionally accompanied by considerable health hazards when broken objects contained dangerous chemical or biological substances, as in some laboratories at UCSB. It was proven in some of these laboratories that seismic resistance of shelving may be significantly improved by either tilting the shelves up in the front or providing each shelf with a "lip" in front to prevent objects from sliding out. Such simple measures as these can greatly reduce the extent of damages to stock and glassware in grocery stores, chemical supplies in laboratory storerooms, and the like.

Earthquake effects on soils and dams were relatively minor. Damages consisted of some rock slides in the Santa Ynez Mountains behind Santa Barbara, and a few instances of fill failure due to lateral spreading and differential settlement in soft alluvium near the coast. Some evidence of lurching was noted in soft alluvium near Goleta.

The earthquake caused damage to piles and floats at Marina #1 in the Santa Barbara Harbor, but no damage was reported to other coastal facilities or offshore structures in the Santa Barbara Channel.

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