FRIENDS OF THE EARTH
124 SPEAR SAN FRANCISCO CALIFORNIA 94105
415 495-4770

December 11, 1979

Dr. Harold Denton
Director of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

RE: TRIGA Reactor; University of California, Berkeley
Docket NO. 50-224

Dear Dr. Denton,

Pursuant to 10 C.F.R. Section 2.206, Friends of the Earth hereby files a Request for Action to the Nuclear Regulatory Commission. Specifically, Friends of the Earth requests that the Nuclear Regulatory Commission order the following:

1. Suspension of all activities under Docket NO. 50-224 at Etcheverry Hall, University of California, Berkeley;
2. Removal of all plutonium and all other radioactive materials and wastes from the Etcheverry Hall site;
3. Permanent revocation of the Regents of the University of California's operating license under Docket NO. 50-224;
4. Holding of public hearings in the City of Berkeley before any reactor operation is resumed.

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I. INTRODUCTION

On August 10, 1966, the TRIGA Mark Three pool-type nuclear reactor achieved critical fuel loading after the Regents of the University of California were granted an operating license by the Atomic Energy Commission. The University research reactor operates at a steady power of 1.0 megawatt, and is capable of a peak pulsed-power of about 2,000 megawatts. The reactor is located in a large laboratory beneath the patio adjacent to Etcheverry Hall on the Berkeley campus. Directly above the reactor is a campus patio and volleyball court. The reactor's cooling water and ventilation systems flow through Etcheverry Hall, a six-story structure. Exhaust from the reactor is also released on the patio level.

The Etcheverry Hall-reactor complex occupies about one-half of the city block on which it is located. Directly south of the reactor lies the University campus. Surrounding the reactor on three sides, to the north, east, and west, is one of the more densely populated neighborhoods in Berkeley, consisting of a large student population and many multi-unit residential dwellings. In the same city block as the reactor are several restaurants, small shops, a grocery store, and other businesses. The southeast corner of the block is a busy intersection where Hearst and Euclid avenues cross at the North Gate of the campus.

This Request for Action is based upon the following considerations: (1) the reactor's seismic design is inadequate according to current seismological data and analysis; (2) the potential threat to public health and safety posed by the reactor is greater than previously estimated; and (3) evacuation plans, in the event of a reactivity accident and/or natural disaster at the reactor site, are inadequate considering the reactor's site in a densely populated urban area.

II. INADEQUATE SEISMIC DESIGN

The main surface trace of the Hayward fault is roughly 40 yards from the reactor site.[1] Hayward fault is an active, right-lateral strike-slip fault. According to U.S. Geological Survey analysis, the active zone of the fault extends out about 300 feet on either side of the main surface fault trace. This active fault zone represents the area in which ground surface ruptures may occur in an earthquake generated by the fault system. This may be a conservative estimate, for data gathered from worldwide studies indicates that the maximum zone width for strike-slip faults may be much greater, capable of producing surface faults in a zone as wide as 3,000 feet.[2]

When the original Safety Analysis Report for the reactor was written, the main trace of Hayward fault was thought to lie within 300 to 1,000 feet east of the reactor. Current fieldwork and analysis by U.S. Geological Survey and the University itself has shown that the main fault trace is, in fact, about 40 yards east of the reactor site. The reactor therefore lies within the active surface rupture zone of the Hayward fault.

There is also a newly discovered surface fault trace within the active zone which runs directly under the reactor. This fault trace is estimated as having been inactive for 100,000 years, and it runs parallel to the presently active trace.[3]

The seismology section of the 1964 Safety Analysis Report states that Berkeley is relatively free of earthquake damage. To quote the S.A.R.; "...no locally severely damaging earthquake has ever been recorded in Berkeley."[4] This statement is misleading. The last large earthquake produced by the Hayward fault was in 1868, estimated at a 7± 1/2 Richter magnitude.[5] No severe damage to man-made structures occurred in Berkeley as a result of that quake for the obvious reason that in 1868, the University campus had not been built, and Berkeley at that time was a sparsely populated rural area. The 1868 quake caused surface fault displacement in the Berkeley hills area, and damage to structures due to the 1868 quake was recorded as far away as Santa Rosa, Sacramento, and Santa Cruz.

Damage was extensive in San Francisco, and in Hayward many buildings were completely demolished.[6]

The Safety Analysis Report relies on "good building design and construction" to insure protection of the reactor structure in the event of a large earthquake. Current seismological analysis of the potential magnitude, ground acceleration, and ground surface rupture which could result from an earthquake generated by Hayward fault have now rendered the 1964 estimates used for design and building of the reactor complex obsolete.

A. RICHTER MAGNITUDE

The U.S. Geological Survey now estimates that an earthquake generated by the Hayward fault could reach a Richter magnitude of 7.5 to 8.5.[7]

B. GROUND ACCELERATION

The reactor was designed to withstand a horizontal ground acceleration of 0.2 g, and in critical areas (areas in which a failure could cause a loss of pool water) the design was calculated to withstand a force of 0.3 g.[8] The firm of Holmes and Narver, which designed and built the reactor structure, state that a vertical acceleration of 0.25 g would cause "...(a) considerable quantity of water (to) be ejected from the reactor pool".[9] The AEC reviewed the TRIGA design in 1965 and concluded that the facility would be damaged if subjected to earthquake forces of .5 g:

> "(we) have been advised that an earthquake with a maximum ground acceleration of 0.5 g might be expected to occur during the lifetime of the facility and that the possibility of shear displacement at the reactor location cannot be disregarded. Accordingly, we have evaluated the possible consequences of an earthquake with these maximum effects, and have concluded that while certain parts of the reactor facility may reach or exceed yield point stresses, it is unlikely that the stresses produced by ground vibrations would be sufficient to rupture the reactor structure or pool tank. Thus, core meltdown would not occur."[10]

It is obvious that the reactor structure was neither designed nor built to withstand the stress that may occur at the reactor site. According to seismology Professor James N. Brune, for earthquakes of a magnitude 7 or more, "we do not have a sufficient data base nor physical understanding to predict ground accelerations very near fault breaks (less than 10 kilmetres distance) with confidence. But available data and physical understanding indicate that accelerations of greater than 2 g are possible, and accelerations of greater than 1 g may be common."[11]

Accelerations far in excess of .5 g have been recorded during several recent earthquakes:

1. The 1971 San Fernando earthquake, magnitude 6.6, recorded 1.25 g horizontal at a distance of 8 km (approximately 5 miles) from the epicenter;
2. The April 6, 1977 earthquake in Iran, magnitude 5.5, recorded .95 g and 1.08 g, vertical and horizontal components respectively;
3. The recent October 15, 1979 Imperial Valley earthquake, magnitude 6.4, recorded .81 g horizontal acceleration and 1.74 g vertical acceleration 26 km (20 miles) from the epicenter.

All three of these earthquakes were smaller than what we may expect from the Hayward fault. All three acceleration measurements were taken farther from the epicenter than the 40 yards from the Hayward fault to the TRIGA. Nevertheless, all three earthquakes produced accelerations far greater than the .5 g which is expected to damage the TRIGA.

C. GROUND SURFACE RUPTURE

Although the TRIGA is within the rupture zone of the Hayward fault, the Safety Analysis Report ignores the possibility of ground surface rupture near or directly beneath the reactor.

According to most structural engineers, it is impossible to design a structure to resist the effects of surface rupture. The U.S. Geological Survey's 1974 analysis of this danger has been clearly stated:

> "Another major earthquake originating in the Hayward or Calaveras fault zones is almost a certainty. If it is accompanied by surface rupture in the fault zone in a built-up area, the damage caused by shearing of structures directly on the line of rupture would no doubt be very great, in addition to the damage caused throughout the San Francisco Bay area by shaking."[12]

The U.S. Geological Survey calculates that ground rupture of as much as 30 feet is possible in a magnitude 8 earthquake on a strike-slip fault such as the Hayward fault.[13] Contrast in this regard the design calculations of the U.C. Nuclear Engineering Department that the maximum amplitude of motion of the reactor core in an earthquake could be no more than 3 inches![14]

A map produced by the U.S. Geological Survey[15]takes into account 3 active fault systems (the Hayward, San Andreas, and Calaveras) which are expected to cause damage in this area. The reactor is mapped as within "Zone A" intensity. "Zone A" is the highest damage rating represented, and is defined as "very violent", comprising the "rending and shearing of rock masses, earth, turf, and all structures along the line of faulting; the fall of rock from mountainsides; numerous landslides of great magnitude; consistent, deep, and extended fissuring in natural earth."

Therefore the complete destruction of the TRIGA and its surrounding structures appears to be a certainty in a major earthquake along the Hayward fault in Berkeley. The earthquake could collapse the entire concrete shield structure (the patio and the volleyball court) above the reactor. Giant chunks of concrete and other debris would fall onto the reactor core, crushing the fuel elements and causing leakage of core materials from the building, and the possibility of a landslide beginning underneath the structure itself cannot be ignored.

D. ETCHEVERRY HALL

No mention is made of the seismic design estimates used for Etcheverry Hall in the Safety Analysis Report. Since pool water is recycled through Etcheverry Hall and the reactor's ventilation system is also dependent upon that structure, it is apparent that the safety of the TRIGA depends on the seismic stability of Etcheverry Hall.

III. A LOSS OF COOLANT ACCIDENT AT THE TRIGA

It is an accepted medical fact that radiation causes cancer in humans. Doses of ionizing radiation can cause leukemia 5 years after exposure; cancer, 12 to 40 years later; and genetic diseases and abnormalities in future generations. Most researchers believe that even the smallest doses can cause cancer and genetic defects. Fetuses, infants, and young children are the most sensitive to radiation.

The TRIGA is small in comparison to a nuclear power plant. It contains, however, a huge amount of radioactive materials. These could be released into the densely populated environment of the East Bay if an earthquake damaged or destroyed the reactor and its containment structures. Contained in the reactor core are at least 10 grams of plutonium, and an estimated 250 grams of total radioactive waste products, of which 14.5 grams are strontium-90. The amounts of radioactive strontium and cesium in the TRIGA are approximately as much as was released by the 1945 Hiroshima bomb.

Release of core materials via any possible route from the reactor structure has lethal implications for the people of the Berkeley community surrounding the reactor site. Plutonium could be transported by atmospheric currents and be inhaled, lodging in the lungs. It is generally accepted that one millionth of one gram of plutonium can cause lung cancer. Once deposited in the lungs, smaller particles may break away to be absorbed into the bloodstream. Because plutonium is chemically similar to iron, it is combined with the iron-transporting proteins in the blood and conveyed to iron storage cells in the liver and bone marrow, inducing liver and bone cancer and leukemia. Plutonium can also cross the placental barrier, reaching a developing fetus. Plutonium is concentrated by the testicles and ovaries, where it causes cancer and genetic mutations.

Once released into the atmosphere, plutonium enters the food chain. Plutonium-239 has a half-life of 24,000 years. Decay to safe levels will take as much as ten half-lives, or 240,000 years (10,000 human generations). Strontium-90 has a half life of 28 years, and cesium has a half-life of 33 years. Once released, strontium and cesium remain dangerous for several hundred years. Strontium-90, like calcium, is absorbed into the bone structure, inducing bone cancer. Cesium is concentrated in the reproductive organs and muscles of the human body.

IV. EMERGENCY REPONSES TO A TRIGA ACCIDENT

Following a major earthquake on the Hayward fault, all roads in the vicinity of the reactor would be blocked with debris. All emergency vehicles and personnel would be immoblized. A substantial proportion of the nearby population would be injured. Immediate evacuation of the area would be impossible.

V. CONCLUSION

The NRC's continued licensing of the TRIGA reactor in the middle of a densely populated urban area is irresponsible. The reactor presents an extremely high risk to public health and safety. The reactor's site in the active zone of the Hayward fault and the outdated seismic design of the reactor's protective structures makes possible a serious radiation accident. The inevitable result of such accidents is generous public exposure to radiation, causing cancer, mutations and birth defects for years to come, and possible permanent evacuation of what is presently much of the University campus and the city of Berkeley.

The reactor, operating at its present location, poses a clearly unacceptable threat to public health and safety.

VI. RELIEF REQUESTED

1. Suspension of all activities under Docket NO. 50-224 at Etcheverry Hall, University of California, Berkeley;
2. Removal of all plutonium and all other radioactive materials and wastes from the Etcheverry Hall site;
3. Permanent revocation of the Regents of the University of California's operating license under Docket NO. 50-224;
4. Holding of public hearings in the City of Berkeley before any reactor operation is resumed.

Respectfully submitted,

Ilene Martino

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Friends of the Earth

W. Andrew Baldwin

W. Andrew Baldwin, Legal Director
Friends of the Earth

REFERENCES CITED IN THE TEXT

1. "Map Showing Recently Active Breaks Along the Hayward Fault Zone and the Southern Part of the Calaveras Fault Zone, California"; 1974 U.S. Geological Survey, Map I-813; by D.H. Radbruch-Hall.

2. "Studies for Seismic Zonation of the San Francisco Bay Region";1975 Geological Survey Professional Paper 941-A; p. A-25.

3. "Area Fault Map, University of California, Berkeley Fault Hazard"; 1978; by Ben Lennert and Associates.

4. 1964 Safety Analysis Report; p. 1-12

5. "Studies for Seismic Zonation of the San Francisco Bay Region";1975 Geological Survey Professional Paper 941-A; p. All.

6. "Map Showing Recently Active Breaks along the Hayward Fault Zone and the Southern Part of the Calaveras Fault Zone, California"; 1974 U.S. Geological Survey, Map I-813; by D.H. Radbruch-Hall.

7. "Predictions of Maximum Earthquake Intensity in the San Francisco Bay Region, California, for Large Earthquakes on the San Andreas and Hayward Faults'; accompanying Map MF-709; 1975 U.S. Geological Survey; p.2.

8. August 20, 1964 Letter to Mr. R. Silver, AEC, from Hans Mark, Chairman of UCB Nuclear Engineering Department.

9. September 12, 1964 Letter to Mr. R.H. Peters, General Dynamic Corporation, General Atomic Division, from Holmes and Narver; signed R.R. Alvy, Chief Engineer.

10. Hazards Analysis by Test and Power Reactor Safety Branch Division of Reactor Licensing; January 13, 1965; p. 3.

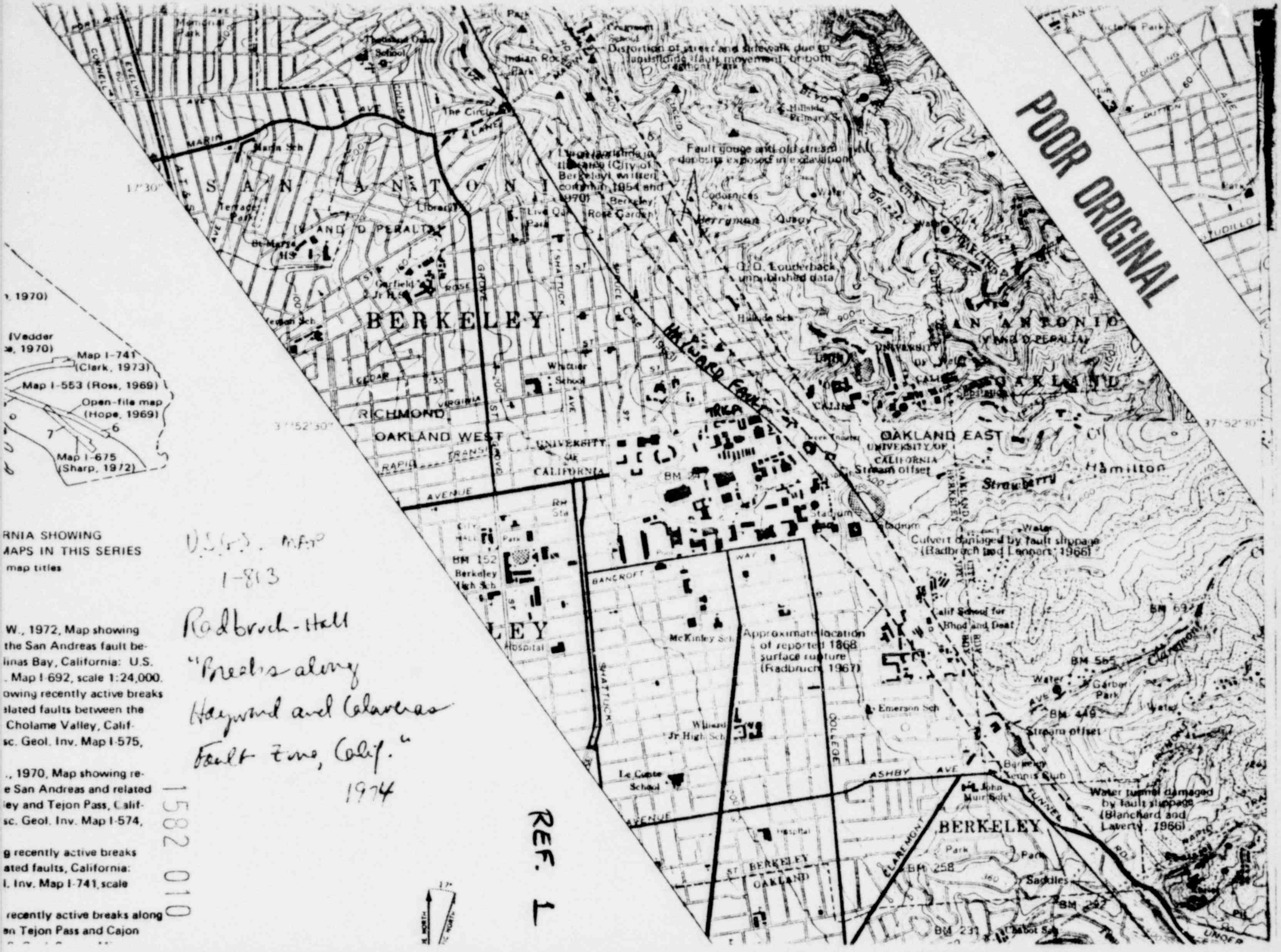
11. April 6, 1979 Letter to Mr. John Farmakides of the U.S. DOE from Dr. James Brune, Professor of Geophysics, Institute of Geophysics and Planetary Physics, Scripps Institution of Oceanography.

12. U.S. Geological Survey Map I-813; 1974.

13. U.S. Geological Survey Professional Paper 941-A; 1975; p.A-30.

14. August 20, 1964 Letter to Mr. R. Silver, AEC, from Hans Mark, Chairman of UCB Nuclear Engineering Department.

15. U.S. Geological Survey Map MF-709; 1975.



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MAPS IN THIS SERIES
map titles

W., 1972, Map showing
the San Andreas fault be-
linas Bay, California: U.S.
. Map I-692, scale 1:24,000.
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elated faults between the
Cholame Valley, Calif-
sc. Geol. Inv. Map I-575,

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U.S.G.S. MAP
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Radbruch-Hall
"Breaks along
Hayward and Calaveras
Fault Zone, Calif."
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that at least locally extended as far as 1 km to several kilometres (thousands of feet to several miles) from the main fault (Lawson and others, 1908). Data from this and numerous other historic faulting events in the world give a basis for estimating the location, character, and maximum amount of ground deformation along many of the faults in the San Francisco Bay region.

Of principal concern in fault-related ground deformation are (1) detailed prediction of the pattern of surface faulting, especially the width of the zone, (2) the amount of displacement across the surface traces of faults, and (3) tectonic distortion of the ground, including uplift, subsidence, and horizontal distortion.

PATTERN OF SURFACE FAULTING

The pattern of surface faulting, especially along the strike-slip faults, involves a main fault zone of varying but generally narrow width along which the principal offsets occur and lesser branch and secondary faults that extend to, or occur at, considerable distance from the main zone (figs. 12, 15). Reverse faults commonly produce more complex rupture zones, and the zones typically are broader and less regular in plan (fig. 16).

Major displacements can be expected along lineaments defined by recognizable fault-caused topographic features (figs. 12, 15). Studies of several surface faulting events indicate that historic ground ruptures closely follow mappable geomorphic features that delineate preexisting fault traces (1857 Fort Tejon—Wallace, 1968; 1906 San Francisco—Lawson and others, 1908, Wallace, 1969; 1966 Parkfield—Brown and Vedder, 1967; 1968 Borrego Mountain—Clark and others, 1972, Clark, 1972; 1971 San Fernando—Yerkes and others, 1974; 1973 Managua— Brown and others, 1973); these observations suggest that patterns of surface faulting are predictable. Clark (1972) estimated, for example, that along about 50 percent of the length of the surface rupture from the Borrego Mountain earthquake of 1968, the position of the main surface fractures could have been predicted to within about 100 m (300 ft) before the earthquake. In the San Francisco Bay region, the San Andreas, Hayward, Concord, Antioch, and a few other faults are mapped in sufficient detail to accurately show the location of fault traces and of the expected future displacements (Brown and Wolfe, 1972; Brown, 1972; Radbruch, 1968a; McLaughlin, 1971; Sharp, 1973; Burke and Helley, 1973). Much of this map information is adequate to influence decisions on structural design and land use.

The confidence with which surface traces can be mapped at a scale of 1:24,000 (1 cm=240 m; 1 inch=2,000 feet) varies considerably depending on frequency and amount of Quarternary displacement, the style of fault movement, and rate of destruction of geomorphic features (controlled largely by climate and local geology and topography). Recent fault traces along strike-slip faults such as the San Andreas can be mapped more confidently than those on faults with dip-slip movement. Consequently, dip-slip faults with youthful movement are only now being recognized in regions where active strike-slip faults have long been known.

ZONE WIDTH

Although the most obvious fault displacement tends to be localized along recognizable and mappable fault lineaments, some permanent ground deformation from fault movement extends outward from the main fault trace. This deformation, manifested as fractures, relatively small surface faults, and local warping, defines an irregular zone that parallels and includes the more obvious and more continuous traces of the main fault.

The width of this zone of surface deformation varies with the type of faulting, earthquake magnitude, the local geologic setting, and perhaps other factors. An example of this variation for strike-slip faulting associated with the Borrego Mountain earthquake is shown in table 3 (Clark, 1972). Because the zone width is so variable and because it seldom can be well defined by surface morphology prior to a major fault event, detailed site studies are usually required for accurate delineation of the zone. Such detailed site information is not yet widely available. In its absence, estimated zone widths are often based on comparison with known patterns of deformation associated with well-documented modern fault geometry accompanying major earthquakes.

Data on zone widths for North American earthquakes in the magnitude range from 5.5 to about 8.5 were analyzed by Bonilla (1970). The data are sparse because only a few events are well documented, but they indicate the general range in width of zones that can be anticipated. For strike-slip faults, the maximum half-width of the zone, from the centerline of the main fault zone to the outer edge of the deformation zone, is about 92 m (300 ft). For dip-slip faults the zone is as much as 900 m (3,000 ft). These values are probably conservative estimates except for very large earthquakes. They have been suggested as the basis for some kinds of planning decisions (Brown, 1972; Hall and others, 1974), but they should be used cautiously and where possible should be supplemented by site investigations. Some evidence from studies of worldwide data suggests that maximum zone width for strike-slip faults may be significantly greater than that cited above and that deformation zones of strike-slip faults may be as wide as those associated with dip-slip faults (U.S. Geological Survey, 1971b, p. A169).

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maximum values to the local damage from earthquakes assigns a modified Mercalli index* of VII to VIII to Berkeley while the town of Hayward (lying about 17 miles to the southeast from Berkeley) has a value of IX. The value of IX is also assigned to the low lying filled ground in the northeastern part of San Francisco where the major damage during the 1906 San Francisco earthquake occurred. The hill area of San Francisco, where the damage was much less severe, has a value of VIII. During the San Francisco earthquake of 1906, Berkeley received only modest damage even though most Berkeley buildings were then not constructed with earthquake resistance in mind.

Modern earthquake resistant design favors basing a building' resistance to horizontal loads on the largest expected local earthquake damage, rather than a frequency vs. magnitude, risk acceptance concept. For California cities, this frequency is higher than for many other states, but the expected maximum values are not. Based on actual local damage experienced during earthquakes in historical times, the following major cities also are rated VIII: Buffalo, New York City, Washington D.C., Chicago, Tulsa, Seattle, Portland, San Diego and the San Francisc hill areas. It is interesting to note that cities considered by Richter to be eligible for the higher value of IX local damage are Charleston South Carolina, Long Island towns, Kansas City, Los Angeles, and the San Francisco filled areas.

Although no locally severely damaging earthquake has ever been recorded in Berkeley, its proximity to the cities of

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*The meaning of the Modified Mercalli indices is given in Richter' article, but is best outlined in TID 7024, pp.63-70.

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Quaternary displacement

Quaternary displacement	Additional factors for assessing earthquake potential					
Offset Quaternary deposits	Estimated recurrence interval (in years) for maximum earthquake, inferred from geologic slip rate[1]	Magnitude of largest historic earthquake	Total known fault length (in kilometres) (estimate of maximum magnitude earthquake in parentheses[8])		Present ability to predict pattern of surface faulting	Comments
Yes (see Cummings (1968)).	100-1,000 (for magnitude 7-8+)	8.3 (see Lawson and others (1908)).[2,3]	1,200 (8½)[9]		Generally good, locally very good.	Right-lateral strike-slip fault, maximum displacement in 1906, 6 m (20 ft).
Yes	10-100 (for magnitude 6-7)	7±½ (see Slemmons (1967)).[2,3]	72 (7.0)	Geyserville to Milpitas, 163 (7.5)	Generally good, locally very good.	Right-lateral strike-slip faults.
Yes (R. D. Brown and E. J. Helley (unpub. data)).		5.7 (see McEvilly (1970)).[4]	72 (7.0)		Generally good, locally very good.	
None observed		3-4 (see Lee and others (1972a,b,c); Wesson and others (1972a,b; 1973)).	35 (6.6)		Locally very good, abundant evidence, fault not well mapped.	
None observed		None known[2]	13 (?)		Locally very good. Fault not well mapped.	
Yes (R. McLaughlin (unpub. data)).		None known[12]	6.4		Locally very good.	
Yes	10-100 (for magnitude 6-7)	6	115 (Hollister to San Ramon) (7.3)		Generally fair, locally very good to very poor	Right-lateral strike-slip faults. Northward extension of Green Valley probable.
Yes (see Gibson and Wollenberg (1968)).		4.3 (see Lee and others (1971)).[4]	9 (?)		---------------	
None observed		5.4 (see Sharp (1973); Murphy and Cloud (1957)).[5]	18 (?) 22 (includes extension across Carquinez straits) (6.3)		Locally very good.	
Yes (M. G. Bonilla and C. M. Wentworth (unpub. data); Dooley (1973)).		2-3 (see Lee and others (1972a,b,c); Wesson and others (1972a,b; 1973)).[5] 4-5, on possible northward extension (R. L. Wesson (unpub. data)).[6]	38 (6.6)		Locally very good.	
Yes (see Fox and others (1973); E. J. Helley (unpub. data)).		2-3 (see Lee and others (1972a,b,c); Wesson and others (1972a,b; 1973)).[5]	17 (?)		Poor.	
Yes (see Dibblee (1972a,b,c)).		3.5 (R. L. Wesson and others (unpub. data)).[4]	20 (minimum estimate) (6.2)		Poor.	Northward extension toward San Jose not well known.
Yes		Not known	82 (7.4)		Poor.	
Yes (see Greene and others (1973); Brabb (1970)).		6.1 (see Richter (1958)).[5,10]	135 (7.4)	200 (includes possible northward extension to San Andreas fault, connecting at Bolinas) (7.6)[11]	Locally very good.	Right-lateral strike-slip fault. Southward extension.
Yes (see Jack (1968); Cooper (1971); K. R. Lajoie, J. Tinsley, and G. Weber (unpub. data)).		None known[12]	3 (?)		Locally very good.	
Yes (see Cummings (1968)).		None known[12]	43 (6.7)		---------------	
Yes (see Greene and others (1973)).		6.1 (see Richter (1958)).[5,10]	42 (across entire bay) (6.7)		---------------	Southward extension on shore probable.
Yes (see McLaughlin (1973)).		5.0 (see McEvilly (1966)).[4]	95 (Portola Valley to Hollister) (7.4) 33 (Mount Madonna to Hollister) (6.7) 55 (Lake Elsman to Hollister) (6.9)		Locally good.	Steep southwest-dipping right-lateral fault, up on southwest side, dip decreases to northwest.
Yes (see Dibblee (1966); Pampeyan (1970); R. McLaughlin (unpub. data)).		3.6 (see Lee and others (1972)).[4]	31 (Portola Valley to Los Gatos) (6.7)		Poor.	Westward-dipping thrust fault.
Yes (R. J. McLaughlin and D. Sorg (unpub. data)).		4.5? (R. L. Wesson (unpub. data)).[5]	33 (Los Gatos to Mount Madonna) (6.7)		Poor.	Westward-dipping thrust fault.
Yes (see Bonilla (1965)).		None known[12]	4 (?)		Very good.	Westward-dipping thrust fault.
Possibly		2-3 (see Lee and others (1972a,b,c); Wesson and others (1972a,b; 1973)).[5]	14 (?)		Poor.	
Yes (see Reiche (1950)).		None known[12]	5 (?)		Poor.	No longer exposed, buried by dredged material.
Yes (see Burke and Helley (1973)).		4.9 (see McEvilly and Casaday (1967); 1899 earthquake[6];	14 (?) 37 (including en echelon northward extension)		Locally very good.	Right-lateral strike-slip fault.

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d in a right-slip sense where they cross the
faults are also known, but historically these
pared to right slip.

OF FAULT BREAKS

on this map were located by interpretation of
vestigation, examination of historical records
nd from the work of other investigators. Traces
the Oakland East quadrangle, from Know-
versity of California (strips A and B), were
Traces between the University of California
p A), are primarily from a thesis by Case (1963);
examination of aerial photographs and field
om the city officials of Berkeley and El Cerrito.
ent of the Calaveras fault zone from south of
pe Lake (strip G) are from maps by
the most conspicuous and topographically
ne is shown between San Felipe Lake and
n (1967b) have mapped numerous additional
shown from San Felipe Valley to the Calaveras
from Crittenden (1951). Data from the
emented by the study of aerial photographs.
nt of the Calaveras fault zone, from San Felipe
Valley (strips E-G), were located by interpretation
d by on-the-ground observation of physiographic
features as exposed gouge zones; no systematic
n this area.

ion and projection was used to transfer lines
in the office or used for compiling data in the
w on the topographic base maps are generally
t, but may be as much as 150 feet off where
small-scale fault features. Geologists and
f these maps should confirm the location of
n control points on the ground and should then
ppropriate means whether they are truly the

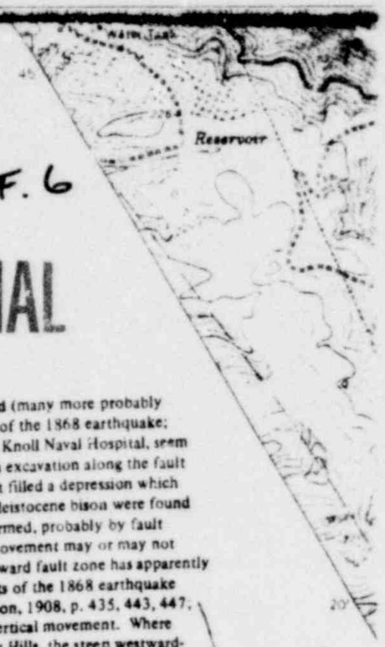
ATING RECENT FAULT BREAKS

ras fault zone was the cause of the catastrophic
. Sudden movement along the Hayward fault
ccurred in 1836 and again in 1868. Both move-
uakes; in 1868 most buildings in Hayward were
ed (Lawson, 1908). Old records indicate that
s fault zone north of the Calaveras Reservoir
earthquake in 1861 (Radbruch, 1968, p. 52-53).
g the San Andreas fault zone near Hollister is
addles an active fault in the fault zone (Tocher,
along the San Andreas fault zone between
by the deformation of fences and by the re-
in paved roads (Brown and Wallace, 1968).
fault zone is dislocating railroad tracks, a culvert,
buildings (Radbruch, Bonilla, and others, 1966;
ewalks, walls, and buildings are being offset in
reep in the Calaveras fault zone (Rogers and Nason,
ng fault breaks that are recognizable by their

dreas fault zone during the 1966 Parkfield-Cholame
er well-defined fault traces (Brown and Vedder,
ace rupture that formed along the Hayward fault
mpanying map, in most places apparently followed
Geomorphic studies of the San Andreas fault zone
, 1968) show that displacements there have re-
e trace.
at ruptures which form at the time of any future
accompanying slow tectonic creep – are likely to
ovement. Thus, the most recently active breaks
ally hazardous by builders, planners, engineers,
defense officials, and others; or by anyone con-
ructures, land utilization, or planned construction
lt breaks. At present, no one can predict when
se faults will recur, or which ones will move next,
e will move again. It should not be inferred, how
fined entirely to these recently active breaks or
of them. Surface fracturing may develop any-
on branching or otherwise related faults beyond
nuities along fault traces or blank spots within the
t stable or unfaulted segments or undisturbed
; they are merely places where no evidence for

ON OF MOST RECENT FAULTING

faults can generally be recognized by topographic
ation that reflect varying ground-water depths or
The most common features are scarps, trenches
ges, offset drainage channels, sag ponds, ponded
d shutter ridges. These features have been devel-
n repeated movements and the continuing effects of
e fault. Horizontal shifts and vertical displacements
few feet result from successive sudden shifts accom-
tervals of slow tectonic creep between earthquakes.
ss of their origin, the displacements pro-
th atio of the fault traces shown on the
e faul icate selected examples of these
the c ces; similar features are present
app . As opposing fault blocks slide
vely c to form sags or sag ponds, or elongate
llel breaks. Other slivers are raised, tilted, or slid
d shutter ridges; elongate horsts may be uplifted
renches or troughs along the fault may reflect in-
and broken rocks in the fault zone, or they may be



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Some of the fault traces which have been recognized (many more probably exist) mark the position of surface rupture at the time of the 1868 earthquake; others, like the one immediately southwest of the Oak Knoll Naval Hospital, seem to be the result of much earlier movement. In 1964 an excavation along the fault trace northwest of the hospital exposed a peat bog that filled a depression which probably was an old sag pond. The remains of a late Pleistocene bison were found in the peat, which indicates that the depression was formed, probably by fault movement, prior to late Pleistocene time; additional movement may or may not have taken place since then. Movement along the Hayward fault zone has apparently been both horizontal and vertical. Eyewitness accounts of the 1868 earthquake describe vertical movement along the fault zone (Lawson, 1908, p. 435, 443, 447; Clark, 1915, p. 149). The following data also imply vertical movement. Where the Hayward fault zone lies at the base of the Berkeley Hills, the steep westward-facing front of the hills appears to be a dissected fault scarp (Buwalda, 1929, p. 190), where the rocks forming the hills apparently moved upward with respect to those west of the scarp. South of Niles, an eastward-facing fault scarp can be seen southwest of Tule Pond and Stivers Lagoon (Clark, 1924), indicating that along this stretch the west side of a fault has moved up relative to the east side, whereas in the vicinity of Irvington a westward-facing scarp indicates the reverse. Offset streams, such as Strawberry Creek on the campus of the University of California (Buwalda, 1929, p. 194) and numerous small offset ravines between Hayward and Niles (Russell, 1926 p. 508), indicate that movement along the faults has been right lateral; that is, rocks on the northeast side of the faults have moved southeast with respect to those on the southwest side.

Movement along faults within the Hayward fault zone has caused two major historic earthquakes with accompanying surface rupture, one in 1836 and one in 1868.

The general location of surface breakage recorded during earthquakes originating within the fault zone is fairly well known, but information regarding the direction and magnitude of displacement is scanty.

Earthquake of 1836. – The 1836 earthquake is thought to have had an intensity of X on the Rossi-Forel scale (Lawson, 1908; Louderback, 1947). However, the area was sparsely populated at the time, and little evidence is available regarding either the kind or amount of damage to manmade structures, or the nature of surface breakage associated with the quake. Cracks reportedly opened between San Pablo and Mission San Jose (Louderback, 1947).

Earthquake of 1868. – The population along both the east and west sides of San Francisco Bay had grown substantially by 1868, and the earthquake of that year caused greater property damage than the one in 1836. However, very little evidence regarding surface rupture was published at the time of the earthquake, and any that may have been compiled at the time was subsequently lost (Lawson, 1908, p. 434). After the 1906 earthquake, which originated on the San Andreas fault, the California State Earthquake Investigation Commission prepared a report on the 1906 disaster (Lawson, 1908). This report contains a review of other severe earthquakes in the San Francisco Bay region, including the earthquake of October 21, 1868. In the course of gathering facts relating to the 1868 earthquake, a representative of the commission reviewed periodicals of the time, obtained eyewitness accounts from residents who experienced the shock, and visited the area of maximum intensity. The results of this investigation were included in the report of the 1906 earthquake and constitute the main body of published information regarding the earthquake of 1868.

Damage to structures due to the 1868 earthquake was recorded as far away as Santa Rosa, Sacramento, and Santa Cruz. Damage was extensive in San Francisco, particularly on "made ground," and in Hayward many buildings were completely demolished. According to the 1906 report, "The fault-trace was characterized for the most part by a crack which in places, particularly on the lower ground, was superficially gaping. Associated with this main crack there were auxiliary branching cracks; and on the alluvial bottom-lands about San Francisco Bay there were numerous secondary cracks which were usually not discriminated by the observers of that day from the fault trace" (Lawson, 1908, p. 447). According to Lawson (1908, p. 434), a crack extended from the vicinity of Mills College, Oakland, to Warm Springs, but evidence of its existence north of San Leandro was obscure. Louderback (1937, p. 5) stated that it seems quite certain that no rupture of the ground took place in the vicinity of the Temescal Dam (Oakland) in 1868. However, according to Mr. Walter T. Steilberg, architect (oral commun., 1965) in 1925 or 1930 Joseph LeConte, professor of mechanical engineering at the University of California, told him that his (LeConte's) father had taken him to see the fault trace of the 1868 earthquake, which extended across the westerly end of the California School for Blind and Deaf and along what is now Warring Street, or between Warring and Prospect, in Berkeley. LeConte said that he was a small boy at the time, and that the trace looked like a plowed furrow.

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From San Leandro to Warm Springs, several cracks were reported. The main fault trace, trending N. 37° W., lay in general near the base of the hills and in most places was within the hill slope, although in other places it cut across the alluvium west of the hills.

An eyewitness account by Mrs. William Haywards (given in the 1906 investigation report) described in detail the course of the main fault rupture through the center of Hayward, as follows: "The crack past diagonally up the Haywards Hill and crost 3 feet from the south corner of the old hotel; past just east of the Odd Fellows' Building, through the Castro lot, tearing off a corner of the adobe house which stood where the jail now is, on through Walpert's Hill toward Decoto. By

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at 99 sites in the San Francisco Bay region (Borcherdt, 1970; Gibbs and Borcherdt, 1974).

Analysis of these recordings shows that certain frequencies of the low-strain ground motions are amplified considerably by certain types of local site conditions. Borcherdt (1970) showed that spectral amplification curves computed with respect to a given bedrock unit to a first approximation isolate the seismic response characteristics of the local site conditions. To isolate the dependence of the observed 1906 intensities on local site conditions (from the dependence of the intensities on distance), intensity increments were defined for each of the recording sites for which 1906 intensity data are available. The intensity increment for each site was defined as the difference between the observed intensity and the intensity predicted by the empirical relation for sites at the same distance on the Franciscan Formation (fig. 3).

The intensity increments are plotted as a function of the Average Horizontal Spectral Amplification (AHSA) values computed with respect to the Franciscan Formation from the recordings of low-strain ground motion (fig. 4) (Gibbs and Borcherdt, 1974). Empirical relations were determined (using the method of least squares) from only the data for sites in the city of San Francisco for which there was "unequivocal" evidence for the degree of ascribed 1906 intensity and from the complete data set. The two empirical relations are similar with intensity increments predicted by either relation differing by less than two-tenths (see fig. 4). The empirical relation ($\delta I = 0.27 + 2.70 \log(AHSA)$) based on only the reliable intensity data in the city of San Francisco is preferred. The means and standard deviations for the samples are given in table 1. The standard error of the regression coefficient for the restricted data set is 0.29 and for the complete data set is 0.33.

The correlation coefficient of 0.95 computed for the preferred empirical relation, $\delta I = 0.27 + 2.70 \log(AHSA)$, shows that a strong correlation exists between the computed intensity increments and the amplifications observed at low-strain levels. The physical meaning of this empirical correlation is complex and does not necessarily imply that amplifications observed at low-strain levels can be extrapolated directly to high-strain levels. However, there are two possible reasons for this correlation: 1) for levels of ground shaking that did not cause ground failure, the higher amplifications indicate those sites that experienced the higher levels of ground shaking and 2) for levels of ground shaking that did induce ground failure, the higher amplifications indicate those sites that were most susceptible to ground failure. In either case, the higher amplifications indicate those sites that experienced greater amounts of damage and, hence, were assigned higher degrees of intensity.

PREDICTION OF MAXIMUM EARTHQUAKE INTENSITY AT SPECIFIC SITES

UC = A ZONE = VIOLENT

Historically, large earthquakes have occurred along both the San Andreas and Hayward faults. Recent fault studies (e.g., Wesson and others, 1975) indicate a high potential exists for future large earthquakes (magnitude, 7.5-8.5) along both faults. As the types of faulting and maximum intensities for future earthquakes on the San Andreas and Hayward faults are similar, the attenuation curve for the 1906 intensities (fig. 3) may be considered useful for predicting intensities of a large earthquake on the Hayward fault as well as one on the San Andreas fault. Such predictions from the attenuation curve for the 1906 intensities (fig. 3) are valid for sites on the Franciscan Formation. For sites not on the Franciscan Formation, intensities can be predicted by using the empirical relation between intensity increment and the low-strain amplification (fig. 4). Hence, for each of the sites with measured low-strain amplifications intensities can be predicted from the two empirical curves for a large earthquake on either fault. Such predictions require only the geologic information needed to delineate the Franciscan Formation as opposed to that needed to delineate the other geologic units.

Intensities are predicted for each of the sites at which amplifications have been measured (table 1). The maximum of the intensities predicted for each site from a large earthquake on the San Andreas fault and a large earthquake on the Hayward fault is shown on sheet 1. The map suggests that a future earthquake on either of the faults could cause as much damage at sites some distance from the faults as at sites in the immediate zones of potential surface faulting. Also, the map suggests that the earthquake hazard is not uniformly distributed throughout the San Francisco Bay region and that large variations in damage might be expected over relatively short distances. The map provides estimates of maximum earthquake intensity for the specific sites shown.

To compare the predicted intensities for an earthquake on the San Andreas with the observed 1906 intensities (table 1, cols. 8 and 9), two types of recording sites were considered. Those sites with ascribed 1906 intensities regardless of the quality of evidence were considered as one sample and those with intensities ascribed on the basis of "unequivocal" evidence were considered as another sample. (The intensity values predicted from the empirical relations based on only the reliable intensity data are plotted as a function of the observed values (fig. 5).) The mean and standard deviation of the difference between the predicted and observed values for the sites with "unequivocal" evidence are 0.03 and 0.39, respectively, and for all of the sites they are 0.06 and 0.73, respectively. The mean and standard deviation for the absolute value of the difference between the predicted and observed values are 0.29 and 0.24, respectively, for the "unequivocal" data and 0.58 and 0.43, respectively, for all the data. The larger values for the sample including all of the data are consistent with the fact that the quality of the intensity evidence is less for this sample. The mean value of 0.29 and the standard deviation 0.24 may be interpreted as indicative of the uncertainty associated with the predicted intensity values at the sites for which low-strain amplifications have been measured.

The maximum earthquake intensities are shown on sheet 1 for the sites at which low-strain amplifications have been measured. The areal density of the sites is not sufficient to draw accurate contours of equal intensity for the entire region; however, the predictions can be extrapolated to a regional scale using available geologic data.

INTENSITY INCREMENTS VS. LOCAL GEOLOGIC UNITS

The amounts of damage from numerous past earthquakes have been observed to depend strongly on the geologic character of the ground (see Duke, 1958, for a comprehensive bibliography). To investigate this dependence for the 1906 earthquake, the intensity increments computed at each of the recording sites are grouped according to the type of underlying geologic unit (table 1, col. 5) (see section on geology at end of report).

The mean of the intensity increments for each group shows that a strong correlation exists between the observed 1906 intensities and the type of geologic unit. The mean intensity increments increase with decreasing "firmness" of the geologic units showing that in general the greatest amounts of damage, excluding that in the immediate zone of surface faulting, occurred on the softest sites. These sites are in general the most likely to significantly amplify ground shaking (Borcherdt and others, 1975). In addition, these sites are the most susceptible to ground failure induced by liquefaction (Youd and others, 1975).

The means for the samples of measured intensity increments computed for the various geologic units (table 1, col. 5) were based on the intensity data from all the recording sites regardless of the quality of evidence. In the authors' opinion, an improved quantification of the intensity dependence on the geologic unit is obtained by considering the intensity increments predicted at each of the recording sites using the empirical intensity increment vs. amplification curve (fig. 4), which is based on only those intensity data for which there was unequivocal evidence. The intensity increments predicted from this curve are tabulated (table 1, col. 6), and grouped according to the type of geologic unit. The means and standard deviations for the various samples are shown at the bottom of each tabulation for the corresponding geologic unit in table 1, cols. 5 and 6. These means and standard deviations were computed for all of the

REF. 8,14

UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA

August 20, 1964

Mr. Robert Lowenstein
Division of Civilian Application
U. S. Atomic Energy Commission
Washington 25, D. C.

Attention: Mr. Richard Silver

Dear Mr. Silver:

The following information is supplied as Amendment No. 1 to our Application for a Construction Permit Relating to a Class 104 Facility License for a Nuclear Reactor at the Berkeley Campus of the University of California, Berkeley, California (Ref. Docket 50-224).

As stated in the previously submitted "Reactor Safety Analysis":

> "A horizontal seismic design coefficient of 0.20 g with a 33 per cent increase in allowable stresses has been adopted for the TRIGA Mark III reactor structure. In order to provide additional safety in the design of the structure as a whole, critical areas (areas in which a failure could cause a loss of water from the reactor pool) will be designed with a higher horizontal coefficient of 0.30 g with a 33 per cent increase in allowable stresses."

Based on this criteria, the core and support structure have been designed to the 0.20 g value.

The calculations for this condition took the following form:

1) The reactor tank full of water (but without the core and support structure) was analyzed to determine the response to a 0.2 g horizontal force. The result was a calculated frequency response for the tank water.

2) The core and support structure in the reactor tank (without water) were analyzed to determine the response to a 0.2 g horizontal force. It was found that the major part of the weight acts at the lower end of the support structure with conditions approaching that of a pendulum. Damping is provided by the restraining force through the coupling to the bridge. A frequency response was determined.

3) The core and support structure were analyzed in the reactor tank (with water) for a coupled response. The maximum stress was calculated to be 18,400 psi. The yield stress on non-welded 6061-T6 aluminum is 35 to 40,000 psi, giving a safety factor of roughly 2 over

the calculated stress. The maximum amplitude of core motion is about 3 inches. For your reactor conditions, it was concluded that the period of the reactor core and support structure in water does not attain resonance with the water in motion. Even if resonance were to occur and the structure exceeded the yield stress, no failure would occur because as the material yields, it would relieve the stresses and unsynchronize the response of the structure with the water in the tank.

Very truly yours,

Hans Mark
Chairman, Department of
Nuclear Engineering

HM:LR:bjd

State of California)
) ss.
County of Alameda)

Before me personally appeared ______________________________ to me known to be the person described in the above application, who signed the foregoing instrument in my presence, and made oath before me to the allegations set forth therein, on the ______ day of _____, 1964.

REF. 10

POOR ORIGINAL

SITE EVALUATION

The proposed site for the TRIGA Mark III reactor does not present any special problems from a hydrological or meteorological viewpoint. However, the site is located within several hundred feet of the Hayward Fault System and within about 20 miles of the San Andreas Fault. We have discussed the seismological and geological characteristics of this location with representatives of the U. S. Coast and Geodetic Survey and U. S. Geological Survey, and have been advised than an earthquake with a maximum ground acceleration of 0.5g might be expected to occur during the lifetime of the facility and that the possibility of shear displacement at the reactor location cannot be disregarded. Accordingly, we have evaluated the possible consequences of an earthquake with these maximum effects, and have concluded that while certain parts of the reactor facility may reach or exceed yield point stresses, it is unlikely that the stresses produced by ground vibrations would be sufficient to rupture the reactor structure or pool tank. Thus, core meltdown would not occur. Further, should core cooling be lost by a rupture of the reactor pool due to differential ground motion, our calculations indicate that natural convection air cooling would be sufficient to prevent core melting due to decay heat.* Even if it is assumed that the ground displacement due to an earthquake is severe enough to cause rupture of a large number of fuel elements by mechanical damage and also results in rupture of the walls and ceiling of the reactor room, the resulting calculated exposures to the public are within Part 100 guidelines. On the basis of these considerations, we have concluded that the site is suitable for a reactor of this type and power level.

* assumed Shutdown

Bad assumpt'n

REACTOR HAZARDS EVALUATION

A TRIGA reactor which is considered a prototype of the TRIGA Mark III reactor has been operating since December of 1961 at the General Atomic Laboratory in San Diego, California. In addition, many other reactors of the TRIGA designs have been constructed and are operating in a manner similar to that proposed by the University of California, Berkeley. The operating experience with these reactors has demonstrated that the important reactor parameters can be confidently predicted. The applicant has analyzed various potential hazards associated with the operation of the reactor. They include (1) release of argon-41 (2) reactivity accidents (3) fuel element cladding failure, and (4) a loss of coolant accident.

Radioactive argon-41, which is produced from neutron activation of the air in various exposure facilities, could be released to the reactor room and to the environment. The applicant's calculations and our independent analysis indicate that release of argon-41 will not exceed the concentrations specified in 10 CFR 20 limits for restricted areas and for non-restricted areas which could be occupied.

The reactivity accident considered by the applicant is assumed to occur after deliberate violation of operating procedures and several interlocks and scrams. In effect, the accident consists of inserting the full worth of the transient rod while the reactor is operating at a high steady power with all control rods

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INSTITUTE OF GEOPHYSICS AND
PLANETARY PHYSICS, A-025
SCRIPPS INSTITUTION OF OCEANOGRAPHY

LA JOLLA, CALIFORNIA 92093

April 6, 1979

Mr. John Farmakides
U.S. Department of Energy
Washington, D.C. 20545

Dear Sir:

I am responding to a request by Mr. Andrew Baldwin, representing Friends of the Earth, that I comment on the seismic design appropriate for the Lawrence Livermore site. My comments are based on the geologic situation as presented in the LLL report by L. H. Wight, "A Geological and Seismological Investigation of the Lawrence Livermore Laboratory Site", and on present knowledge concerning peak ground accelerations expected very close to earthquakes, as presented in my recent testimony before the NRC concerning the Diablo Canyon Nuclear Power Plant. This testimony is attached.

The essential conclusion of my testimony before the NRC was that for large earthquakes (M > 7) we do not have a sufficient data base nor physical understanding to predict ground accelerations very near fault breaks (< 10 km distance) with confidence. Available data and physical understanding indicate that accelerations of greater than 2 g are possible and accelerations of greater than 1 g may be common.

One aspect of the problem discussed in some detail in my testimony, and which may be of crucial importance to the Livermore site, is the phenomenon of directivity focussing of energy in the direction of fault propagation. Rupture along the Tesla fault, as well as along other mapped faults in the region (in the direction of the Livermore site), could result in anomalously high accelerations (> 2g). It is not possible to accurately assess the probability of such an anomalously high acceleration, but the effect is well established and commonly observed in rupture propagation (see pp 3-10 to 3-14 of my testimony).

Also of particular importance to the Livermore site is the conclusion of Ambreysey's that accelerations of greater than 1 g will probably be recorded for even low magnitudes (p 3-8). On April 6, 1977 a magnitude 5.5 shallow earthquake in Iran generated peak accelerations of .95 g and 1.08 g, horizontal and vertical components respectively. (S - T ∿ 1 sec.)

Another part of my testimony which is of critical importance to the Livermore site is the reported results from the Victoria Baja California earthquake swarm of March 1978 (Appendix II of my testimony, pp II-1 to II-7). One event of magnitude 4.9 produced accelerations of about .64 g at a distance of about 10 km. Although final information on the depth, location and mechanism of the event are not yet available, it nevertheless shows that even relatively small events can generate accelerations of over .6 g in an environment of very thick alluvium. This result indicates that the acceleration value of .5 g taken in the L. H. Wight report is not conservative.

Sincerely,

James N Brune

James N. Brune
Professor of Geophysics

JNB:sd

REF. 12

POOR ORIGINAL

ayward. "On a certain piece of ground near
mon board fence, the boards abutting on the
pt one over the other about 5 inches, the ground
that much. * * * A fence which traversed a
the crack, and had the ends of the boards
these boards lapt over one another, until with-
ral inches, the progress of the overlapping
pencil mark. * * * The fence passing diagonally
Lawson, 1908, p. 442). Townley and Allen
displacement at the time of the 1868 quake.
scribed as follows: "A crack 3 to 4 inches
nd struck across toward the county bridge
, crost the creek, demolisht a fence complete-
e residence, where the house was badly
he description indicates that the branch
f B and First Streets toward the northwest,
obably farther, approximately along the line
d fault zone shown on the Hayward quad-
branch crack was reported that extended
eastward toward the hills, and faded out by
t; the sulfur spring is assumed to be the
outheast of the present central district of
he accompanying map because evidence

ings was described by Lawson (1908, p.
t of Mission San Jose, entirely within the
f N. 18° to 20° W., which, converging
south as far as the county line." Several
m Springs gave the following descriptions
ission, just above a place called Peacock
d, which lookt as if the lower part of
* * * Along the hills back of the town
nclair and Stanford ranches the crack
wide, and faulted some 18 inches on the
Mission Peak confirmed * * * The crack
350 to 450 feet from Niles southward,
the county line. In some places the
(Lawson, 1908, p. 444).
ry crack e of Warm Springs and
above accounts plus unpublished notes
06 investigation, and its general trend is

old fault traces for part of its length,
e trace, as for example north of Hay-
coto, where it seems to have swung
entirely new path
long or in the vicinity of the main
Lawson, 1908) further states, "On
lara County, the intensity diminisht
se." Although there was no report
Hill where geomorphic evidence of
ld not be ignored that unrecognized
a may have caused the reported rise

except for those along which creep is taking place at the present time.

As with the Hayward fault zone, movement along the Calaveras fault zone has apparently been both horizontal and vertical, with horizontal movement predominating. In addition, thrusting appears to have been prominent along parts of the zone. Horizontal movement is amply attested by offset streams, shutter ridges, and offset manmade structures. Low, east facing scarps marking the main fault trace north of Hollister indicate vertical movement. Thrusting of the west side over the east was observed in an excavation near the Calaveras Dam (Vickery, 1925, p. 612); thrusting also may account for the nature of the distortion of the Cochrane Bridge at the southeast end of Anderson Lake.

The pattern of recent movement within the Calaveras fault zone appears to vary along the length of the zone. In some places the fault traces, as indicated by physiographic features such as sag ponds, trenches, terraces, and offset drainage, are remarkably straight and extend relatively long distances. One of these is shown on the map south of San Felipe Creek, northeast of the north end of Anderson Lake (strip F). North of San Felipe Creek (strip F) the fault zone seems to consist of a band of short en echelon segments, which can be identified by sag ponds, linear trenches, and clay gouge. Fieldwork shows that rock in the ridges between the trenches in this area is also highly fractured. East of Anderson Lake (strip F) the fault zone consists of a wide band of anastomosing fault traces, clearly delineated by numerous hillside terraces, sag ponds, and terraces.

Southeast of Cochrane Bridge at the south end of Anderson Lake the fault zone appears to consist of straight, narrow breaks, whereas northeast of the bridge it is a confused area of ponds, landslides, and vague linear traces where the physiographic features may be due to a number of en echelon or anastomosing fault traces, a wide band of rock sheared by thrusting, landsliding, or a combination of all four.

No ground rupture at the time of an earthquake has been reported south of the Calaveras Reservoir, although quakes of intensity VII and above have been recorded, especially in the vicinity of Hollister (Tocher, 1959, p. 43).

Earthquake of 1861. — A major earthquake probably originating in the Calaveras fault zone was recorded in 1861; it had an estimated intensity of IX on the Rossi-Forel scale (Townley and Allen, 1939; Wood and Heck, 1941). Ground rupture accompanying the quake was noted about 18 miles northwest of the Calaveras Reservoir, along the west side of the San Ramon Valley (Brewer, 1930; Trask, 1864; Whitney, 1865). The ruptures are presumed to have been tectonic fracturing within the Calaveras fault zone (Radbruch, 1968).

Present-day slippage. — Tectonic slippage ("creep"), like that taking place along the San Andreas and Hayward fault zones, was recognized along the Calaveras fault zone in 1966 (Rogers and Nason, 1971). Creep has offset streets, pipelines, and buildings in the town of Hollister (Rogers and Nason, 1971), as well as fences and other manmade structures north of Hollister, in the San Felipe quadrangle (Rogers and Nason, 1967, 1968, 1971). Damage to the spillway of Coyote Dam (strip I) may be due to fault movement (Radbruch, 1968), and the Cochrane Bridge at the south end of Anderson Lake (strip F), constructed in 1950, appears to have been buckled and twisted by slow fault movement. The horizontal steel I-beam girders that support the floor of the bridge, which is alined north-south, have been distorted both laterally and vertically, so that there is a pronounced bend in them slightly south of the center of the bridge. The north end of the girders has twisted up and to the east with respect to the south end. The girders are supported by four sets of piers, one set on the southwest shore of the reservoir, a second and a third at and near the southwest shore, and the fourth at the northeast shore. The bend in the girders appears to lie between the second and third sets of piers at or near the southwest shore; the first and second sets also appear to be somewhat out of line with the third and fourth (northernmost) sets, with the latter two slightly farther east than the two southernmost sets. The exact amount of deflection has not been measured, but appeared to be about 6 inches laterally and 4 inches vertically in 1968. The railings of the bridge were deformed in the same manner as the girders; in places individual rail segments were bowed convex upward. These deformed railings were replaced in 1968. Apparently the bridge has been subjected to both right-lateral and compressive forces. Some of the forces, particularly compression, could be attributable to landslides. However, there is no evidence of sliding at either abutment, although slides can be seen near the south abutment and are numerous at other places along the shore of the reservoir.

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The second set of piers (northward from the south end of the bridge) appears to be resting on clayey fault gouge, and a pronounced northwest-trending trench southeast of these piers is a physiographic indication of recent fault movement. The complex bridge deformation consisting of right-lateral offset, buckling due to compression, and uplift of the north end could be caused by right-lateral movement and thrusting along a fault extending northwestward across the north-trending bridge alinement, with the rocks on the northeast side of the fault moving up and south-southeast with respect to those on the southwest. Exposures northeast of the fault suggest that this may be the correct interpretation. A combination of thrusting and right-lateral movement has been suggested in the Calaveras fault zone north of the Calaveras Reservoir near Dublin (Gibson and Wollenberg, 1968). However, simple right-lateral movement of a northeast-trending fault crossing the alinement would cause both compression and right-lateral forces to be exerted on the bridge, and, combined with slight uplift on the northeast side of the fault, could result in the bridge deformation observed.

DAMAGE TO STRUCTURES

Another major earthquake originating in the Hayward or Calaveras fault zones is almost a certainty. If it is accompanied by surface rupture in the fault zone in a built-up area, the damage caused by shearing of structures directly on the line of rupture would no doubt be very great, in addition to damage throughout the San Francisco Bay area caused by shaking. The land along the entire length of the Hayward fault zone, from San Pablo to Fremont, is now heavily populated and covered with structures in most places. The 1868 fault trace in Hayward, from Haywards Hill to Walpert's Hill, passes through the center of the main business district. Some parts of the Calaveras fault zone, such as Hollister, are also heavily populated, and many sites that are still not built up are rapidly being developed.

Builders of structures which lie within or cross the Hayward or Calaveras fault zones should take into account the possibility that such structures not only may be damaged by sudden movement, offset, and rupture at the time of an earthquake originating in the fault zone, but may also be subject to constant strain and damage because the opposite sides of faults within the zone are continuously moving very slowly in opposite directions.

[2] The locations of landmarks described in the 1906 report were supplied by Mrs. Zelda Riggs of the Hayward Area Historical Society.

[3] Hayward Daily Review, June 25, 1926; courtesy of the Hayward Area Historical Society.

POOR ORIGINAL

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ment a program of earthquake hazard reduction, but they also indicate a need for further effort and for attention to new discoveries.

About 30 faults in the bay region are potentially capable of producing damaging earthquakes. Most of these can be accurately located, and those that are the largest and potentially most destructive can be very well located. Detailed maps, suitable for most planning and decisionmaking purposes, are available for many of these faults.

Magnitudes of historic earthquakes are known for more than half of the recognized faults. These data indicate that at least eight moderate or large-magnitude events have occurred on known bay region faults and that one very large earthquake (magnitude 8.3) was located on the San Andreas fault. Current methods of estimating maximum magnitude in the absence of historic data are still crude, but they provide an approximate measure of the size of earthquake that can be expected on faults that have no historic record of damaging earthquakes.

Fault displacement of as much as 5 m (16 ft) was recorded after the 1906 earthquake on the San Andreas, and maximum horizontal displacement of as much as 10 m (30 ft) is judged possible with a magnitude 8 earthquake on a strike-slip fault. Estimated upper bounds for displacement (horizontal) accompanying smaller earthquakes on strike-slip faults in the bay region are 6 m (20 ft) for magnitude 7, 2 m (6 ft) for magnitude 6, and 0.5 m (2 ft) for magnitude 5. Vertical displacements associated with earthquakes on strike-slip faults are likely to be less than one-third of the horizontal displacement. Displacement associated with dip-slip faults is more difficult to evaluate, but these evidently are fewer and shorter in the bay region than strike-slip faults.

The nature and areal distribution of deformation related to fault movement includes (1) permanent ground deformation localized as a zone along the fault and (2) systematic deformation of the earth's surface on a regional or subregional scale.

Accurate delineation of the width of the zone of deformation along the fault is best accomplished through careful geologic site studies including, where necessary, trenching, excavation, or other subsurface investigations. Where such data are not available, zone width can be crudely estimated by analogy with measured zones of deformation that have accompanied historic faulting. This method suggests that, for strike-slip faults, permanent ground deformation may be expected to extend for 92 m (300 ft) on either side of a recognizable strike-slip fault trace and 425 m (1400 ft) on either side of a recognizable dip-slip fault trace (Hall and others, 1974). Designation of deformation zones on this basis is admittedly a stop-gap measure and should be re-evaluated with the availability of new geologic data at the site.

Regional or subregional deformation of the earth's crust commonly accompanies major earthquakes. It is manifested predominantly as upwarping or subsidence for dip-slip faults and predominantly as horizontal distortion for strike-slip faults. In the bay region horizontal distortion appears to be the predominant process, although some local vertical warping (about 0.5 m or 1.5 ft) accompanied the 1906 earthquake on the San Andreas. The magnitude of this process and its potential hazard for the bay region are not completely known, but it appears to be less important in evaluation of earthquake hazards than other earthquake effects.

The frequency of recurrence of earthquakes is perhaps the most difficult to assess of all these topics. Until more geologic data are available, recurrence estimates are tentative at best and depend heavily on our knowledge of recurrence of historic earthquakes. The historic record in the bay region is little more than 150 years old, a woefully inadequate sample for faults that have been active for millions or tens of millions of years. But even that record shows a crude pattern of damaging earthquakes on major bay region faults. Attempts to determine recurrence intervals for bay region earthquakes are further complicated by the unresolved relation between fault creep and damaging earthquakes because several bay region faults exhibit fault creep along parts of their length. Despite the need for more accurate data on frequency of recurrence, the phenomenon of recurrence is well established.

Many important questions are still unanswered, but enough is known now to move positively toward reducing the hazard from future earthquakes. Some steps in this direction are obvious. All residents would agree that schools and hospitals should not be located astride the traces of major faults; most would accept requirements for geologic site studies in the deformation zones along major faults; and many would agree on siting restrictions that would locate major highway interchanges, dams, or power plants away from faults that may generate earthquakes. These kinds of actions are ultimately a product of the democratic process, and they depend as much on social and economic values as on our scientific knowledge.

Other steps toward reducing earthquake hazards cannot be taken without more information than is given here. Building codes, for example, are an important mechanism for protecting life and property from earthquakes. But such codes require specific information on the nature of seismic shaking, possible modes of structural response, and other factors that go far beyond the initial geologic process that causes the earthquake. These and other problems relating to hazard reduction are treated in subsequent sections of this report.

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