STATE OF CALIFORNIA
The Resources Agency
Department of Water Resources

BULLETIN No. 116-3

EARTHQUAKE DAMAGE TO HYDRAULIC STRUCTURES IN CALIFORNIA

JUNE 1967

RONALD REAGAN
Governor
State of California

WILLIAM R. GIANELLI
Director
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Canal Offset by Imperial Fault
Imperial Valley Earthquake, May 18, 1940

Typical fault displacement of a small canal in
Southern Imperial County
(U. S. Bureau of Reclamation photograph)

Levee Failure Caused by Foundation Shaking
Imperial Valley Earthquake, May 18, 1940

Damage to the banks of the All-American Canal in Imperial County due to foundation shaking. Photograph shows condition of heavy adobe banks between Drop No. 5 and Ash flume. (U. S. Bureau of Reclamation photograph)

FOREWORD

This Bulletin is a summary of the work performed in accordance with advice from the Department's Consulting Board for Earthquake Analysis given at its July 10-11, 1962, meeting. The Board recommended that the Department "set up a system for collecting and collating reliable information concerning damage to embankments, dams, dykes, river and canal banks and other water resources facilities where this information may be of special value". Bulletin 116-3, "Earthquake Damage to Hydraulic Structures in California", the third of a series, presents significant facts on earthquakes and earthquake damage. These facts embody a high potential of usefulness for engineers, geologists, and others in the planning, design, construction, and operation of earthquake-resistant hydraulic structures.

William R. Gianelli

William R. Gianelli, Director
Department of Water Resources
The Resources Agency
State of California
April 13, 1967

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**Deceased December 14, 1966.

ACKNOWLEDGMENT

Acknowledgment is extended to the following who made available unpublished and out-of-print reports and data: Messrs. Robert Carter and Oscar L. Fudge, Imperial Irrigation District; Mr. Karl V. Steinbrugge, Pacific Fire Rating Bureau.

A significant amount of data was provided from the University of California's unpublished "Earthquake Scrapbook".

Assistance in abstracting information was provided by Gary C. Potter, Graduate Fellow of University of California, Berkeley, and William H. Long, Robin L. Rivett, and Steve C. Swartz, Engineering Student Trainees.

Acknowledgment also is extended to the U. S. Bureau of Reclamation, Denver, Colorado, for permission to utilize photographs and its basic report of the Imperial Valley earthquake of May 18, 1940.

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ABSTRACT

This document describes damage done to hydraulic structures in California and adjacent areas by earthquakes that occurred within the past century.

Unconsolidated alluvium, generally saturated and thick, was the predominant material underlying the damaged structures. Filled ground underlay many in the San Francisco Bay Area. Such soft foundations are especially correlated with damage that occurred many miles from earthquake sources. Distances between earthquake epicenters and damaged structures ranged from a few miles to 190 miles.

The kind of damage varied with the kind of structure. Canals, ditches and dams sustained slumping, fissuring, sloughing, and offset. Pipes were ruptured, telescoped, pulled apart and bent. Storage tanks toppled. Very little information was available on repair time and costs.

Eighty-two earthquakes are identified as responsible for the damage. Comprising damage recorded here are 53 storage structures, 22 dams, 35 major water conduits, 101 water mains and pipes, 5 pumping and power stations, 13 irrigation facilities, 40 petroleum product structures, 9 sewerage structures, and 1 dyke.

INTRODUCTION

Organization of this Document

When completed in 1990, the State Water Project will represent an investment of some $2. 5 billion in reservoirs, dams, powerplants, aqueducts, and pumping plants. But California is earthquake-prone country and today no one would think of building a project of this size without including earthquake-resistant features in the design.

The Department of Water Resources, which is building and will operate the State Water Project, bases its earthquake-resistant designs on techniques developed from known effects of earthquakes on man-made structures and specialized design procedures to calculate the earthquake-induced stresses in hydraulic structures.

The Department's Earthquake Engineering researchers have reviewed the history of earthquake damage to hydraulic structures in California and adjacent areas to:

- Assess the potential hazard to State Water Project structures in any area by relating to what has happened to hydraulic structures in the past.

- Determine the nature of damage that occurs to hydraulic structures in general so recommendations for specific design procedure can be made.

The result is the present document, an annotated listing of 304 cases of such damage.

It is true that earthquake damage very often takes the same form in all man-made structures, whether or not they contain or otherwise involve fluids. A good, strong shake will probably not discriminate-- major hydraulic structures and other major structures will both be damaged.

The absence of historical damage to major hydraulic structures in an area of California does not necessarily mean that such structures in that area will be safe from earthquakes. It more probably means that there were few, if any, hydraulic structures in that area at the time of the most recent severe earthquake.

Some earthquake effects, then, are common to all man-made structures. But, obviously, a dam is not a skyscraper and an aqueduct is not a paved street. A dam, which hugs the ground more determinedly than a skyscraper does, will react differently than a city building to the same earthquake vibrations. Among special effects of vibrations on reservoirs and aqueducts are seiche oscillations that can lead to overtopping. Liquids behave differently than solids when shaken and some earthquake effects can be observed only in hydraulic structures. Thus, designing an earthquake-resistant State Water Project requires specialized techniques.

The techniques of earthquake engineering have been improving rapidly in recent years. One of these techniques is to compare actual damage to expected design performance. However, no one has previously compiled a list of earthquake damage to hydraulic structures. On the other hand, we make no claim that we have included every single case of hydraulic damage in the state's history. We hope that we have included all those that are outstanding and a sizable amount of minor damage to indicate that few places in California are entirely immune to damage. Most of the data presented here were collected by college students, who combed the literature for references to hydraulic damage, within the limits of time and space. Connecting remarks and interpretive editing are kept to a minimum; the original authors are entitled to this treatment. But this faithfulness to original quotations may leave the reader with some questions concerning details of earthquake damage. These are seldom answerable by any of the literature. An important message of this document is, then, that earthquake damage to hydraulic structures needs to be more publicly discussed and documented.

Earthquake Engineering personnel are now expanding the body of data on individual structural features. These data are routinely being stored on magnetic tape for computer retrieval to obtain patterns of damage and conclusions helpful in solving structural problems of State Water Project facilities. In the meantime, it is hoped structural engineers outside the Department will find this document valuable. They may discern for themselves such patterns and conclusions as may be applicable to their problems, from the now-available data.

A final thought about the lessons of earthquake history. A vast body of statistics indicates recent earthquake history is like older earthquake history and the majority opinion sees no reason for the continuity to cease. Earthquake phenomena of the last half century will probably be repeated during the next 100 years. But, by learning from the history of structural response to earthquake phenomena, perhaps we can design our structures so that the future of structural response will be different from its past.

This report places emphasis on damage due to foundation vibration and surface rupture and was not intended to include damage by subsidence, slow creep, or tsunami.

Definition of Terms

Except as otherwise noted, the definitions within quotation marks which immediately follow basic terms were obtained from the "Glossary of Geology and Related Sciences", American Geological Institute, 1957.

Earthquake. "Groups of elastic waves propagating in the earth, set up by a transient disturbance of the elastic equilibrium of a portion of the earth."

Epicenter. "The point on the earth's surface directly above the focus of an earthquake."

Fault. "A fracture or fracture zone along which there has been displacement of the two sides relative to one another parallel to the fracture. The displacement may be a few inches or many miles."

Fault Displacement. "Relative movement of the two sides of the fault measured in any direction when that direction is specified."

Intensity. "A number describing the effects of an earthquake on man, on structures built by him, and on the earth's surface."

The number is rated on the basis of an earthquake intensity scale; the scale in common use in the United States today is the Modified Mercalli Scale of 1931. Prior to 1931, the Rossi-Forel scale was in common use. The Modified Mercalli scale as abridged and rewritten by Richter, 1958, is:

MODIFIED MERCALLI INTENSITY SCALE OF 1931

I. Not felt. Marginal and long-period effects of large earthquakes.

II. Felt by persons at rest, on upper floors, or favorably placed.

III. Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.

IV. Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV wooden walls and frame creak.

V. Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.

VI. Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Trees, bushes shaken visibly, or heard to rustle.

VII. Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices, also unbraced parapets and architectural ornaments. Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.

VIII. Steering of motor cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.

IX. General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. General damage to foundations. Frame structures, if not bolted, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluviated areas sand and mud ejected, earthquake fountains, sand craters.

X. Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.

XI. Rails bent greatly. Underground pipelines completely out of service.

XII. Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

Left-handed Offset. The horizontal component of faulting which is left lateral as in "Left-lateral fault. A strike-slip fault in which the movement is such that an observer walking toward the fault along an index plane (bed, dike, vein, etc.) must turn left to find the other part of the displaced index plane".

Magnitude. The definition of magnitude originally proposed by Dr. C. F. Richter is as follows:

"The magnitude of any shock is taken as the logarithm of the maximum trace amplitude, expressed in microns (thousandths of a millimeter), with which the standard short-period torsion seismometer (period T_o = 0.8 sec., magnification V = 2800, damping h = 0.8 or nearly critical) would register that shock at an epicentral distance of 100 kilometers (62 miles)."*

*Richter, C. F. "An Instrumental Earthquake Magnitude Scale." Seismological Society of America Bulletin. Vol. 25, p. 7. 1935.

Subsequent attempts to relate magnitude to the total energy released by an earthquake in the form of elastic waves has resulted in some revision and redefinition of magnitude. Magnitude is intended to be an objective, instrumentally determined rating of the size of a given earthquake. Magnitude can be calculated from the wave amplitude recorded by seismographs at any distance from the source of a quake. Each upward step of one magnitude unit means a 32-fold increase in the energy released by the earthquake at its source. The scale has no arbitrary "ceiling", but 8.9 appears to be the largest magnitude of any known earthquake.

Right-handed Offset. The horizontal component of faulting which is right lateral as in "Right-lateral fault. A strike-slip with right-handed (right-lateral) separation".

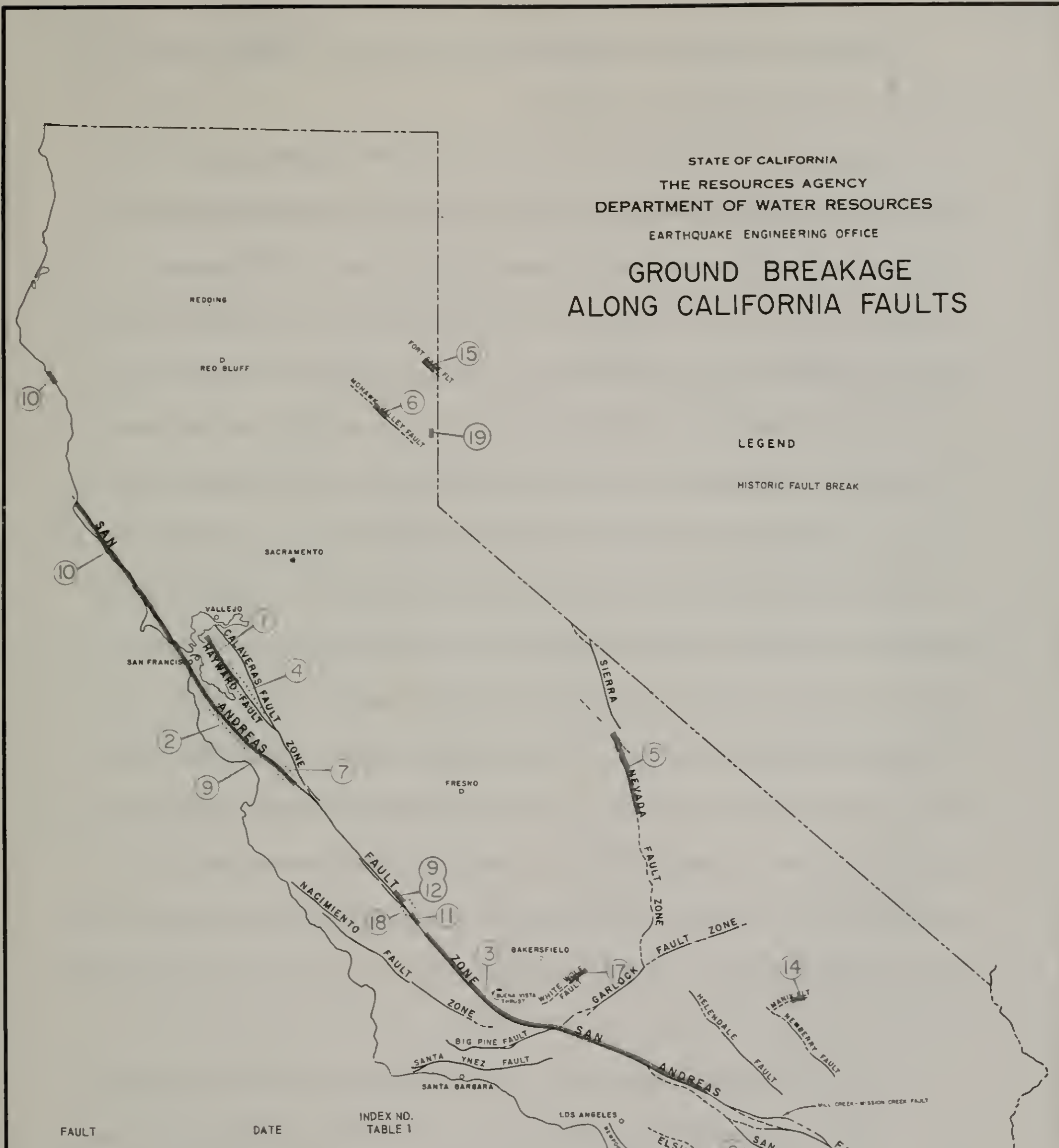
THE EARTHQUAKES

This document identifies 82 earthquakes as responsible for damage to hydraulic structures in and near California between October 8, 1865, and September 12, 1966.

The majority professional opinion holds that California earthquakes are the ground motions that result when blocks of material snap past each other in the earth's crust. This snapping motion occurs along planes called faults. The fault movement itself is usually not apparent at the surface of the crust--that is, the earth's surface. The vast majority of the ground cracks and fractures commonly associated with earthquakes result from the ground motions--from the vibration and shocks radiating from the abrupt fault movement.

Sometimes, however, an earthquake is powerful enough to display fault movement at the surface. Among earthquakes of this kind within historic time was the outstanding San Francisco earthquake of 1906. Figure 1 shows the California earthquakes that resulted in fault movement at the earth's surface, and the extent of surface rupture along the fault trace. The dotted lines indicate reoccurrence of surface rupture during an earthquake after earlier rupture by a previous earthquake. The second column of numbers in the legend refers to the number of an earthquake listed in Table 1, "Earthquakes Damaging to Hydraulic Structures in California", pages 16-35. Even though surface faulting occurred, not all of the earthquakes designated in Figure 1 damaged hydraulic structures.

FIGURE I



FAULT	DATE	INDEX NO. TABLE 1
1. HAYWARD	JUNE 10, 1836	–
2. SAN ANDREAS	JUNE, 1838	–
3. SAN ANDREAS	JANUARY 9, 1857	–
4. HAYWARD	OCTOBER 21, 1868	2
5. SIERRA NEVADA	MARCH 26, 1872	–
6. MOHAWK VALLEY	JANUARY 24, 1875	–
7. SAN ANDREAS	APRIL 24, 1890	3
8. SAN JACINTO	DECEMBER 25, 1899	–
9. SAN ANDREAS	MARCH 2, 1901	–
10. SAN ANDREAS	APRIL 18, 1906	7
11. SAN ANDREAS	MARCH 10, 1922	19
12. SAN ANDREAS	JUNE 7, 1934	30
13. IMPERIAL	MAY 18, 1940	34
14. MANIX	APRIL 10, 1947	43
15. FORT SAGE	DECEMBER 14, 1950	50
16. SUPERSTITION HILLS	JANUARY 23, 1951	52
17. WHITE WOLF	JULY 21, 1952	56
18. SAN ANDREAS	JUNE 27, 1966	76
19. UNKNOWN	SEPTEMBER 12, 1966	77

The extent of ground breakage varied, as did the degree of horizontal or vertical offset at the surface.

The San Andreas fault fractured during eight of the 19 earthquakes. In the San Francisco earthquake of 1838, breakage extended possibly 40 miles and, in the Fort Tejon earthquake of 1857, possibly 135 miles, accompanied in the latter case by possibly 20 feet or more of horizontal offset. In 1890, the year of the Monterey Bay earthquake, fissures were reported near Chittenden east of Watsonville, and, in 1901, the year of the Stone Canyon earthquake, some surface cracks were hundreds of feet long and vertical displacement in some places totaled a foot. Cracks six to 12 inches wide occurred over a quarter of a mile in the Cholame Valley earthquake of 1922. In the first Parkfield earthquake (1934) two zones of cracks developed on the northeast and southwest edges of the crest of Middle Mountain for a distance of about two miles northwest of Parkfield, both zones close to the surface traces of two faults in the San Andreas fault zone. In the second Parkfield earthquake (1966) rupture was reported to have occurred over a distance of about 20 miles, horizontal displacement ranged from two to four inches and vertical displacement was not observed.

But the most extensive surface breakage along the San Andreas--indeed, the most extensive along any fault--occurred during the San Francisco earthquake of 1906. Andrew H. Lawson and a team that investigated the effects of the quake found rupture over a length of 180 miles, from San Juan Bautista north to Point Arena, where the fault trace disappears into the Pacific Ocean. Vertical displacement of three feet and horizontal displacement of fully 21 feet in alluvium and 15. 5 in rock was reported in Marin County.

The Hayward fault fractured twice. In the Hayward earthquake of 1836, rupture was reported along a 40-mile length; and, in the Hayward earthquake of 1868, along a shorter length, 20 miles, but with secondary fractures between San Leandro and Warm Springs.

Ground breakage along the Sierra Nevada fault occurred in the Owens Valley earthquake of 1872. Rupture was reported to have occurred over a distance of about 45 miles; numerous vertical scarps 10 to 23 feet high and both right- and left-hand offset of nine to 20 feet were reported.

In the Mohawk Valley earthquake of 1875, along the Mohawk Valley fault, faults were noted with small displacement in Pleistocene sediments and a fissure formed in tuffs and breccia beds.

In the San Jacinto earthquake of 1899, investigators found rupture along two miles of the San Jacinto fault.

In the Imperial Valley earthquake of 1940, rupture was reported to have occurred along a 40-mile trace of the Imperial fault, with vertical displacement of four feet and horizontal displacement of about 19 feet.

In the Manix earthquake of 1947, breakage was found over a distance of about a mile of the Manix fault. The trace consisted chiefly of open cracks, though two to three inches of left-hand offset was observed. Some writers have theorized that the displacement was a secondary feature resulting from a main, subterranean displacement on a northwest-trending fault presumed buried by local Pleistocene lake beds.

In the Herlong earthquake of 1950, rupture was reported to have occurred over a distance of about 5. 5 miles, with five to 18 inches of vertical movement. Horizontal offset was not reported along the Fort Sage fault.

In the Superstition Hills earthquake of 1951, breakage was reported to have occurred over a distance of about 1-3/4 miles of the Superstition Hills fault, with slight right-hand displacement.

In the Kern County earthquake of 1952, rupture was found along 17 to 20 miles of the White Wolf fault. A complex pattern was observed, with a variety of fracture types, trends and directions of displacements. Investigators found four feet of vertical movement and a small amount of both right- and left-hand offset.

The California Department of Water Resources reported ground breakage along an unknown fault in the Russell Valley north of Truckee after the Truckee earthquake of 1966. The cracking and ground breakage suggest a tectonic origin possibly related to subsurface faulting. No information is available on measured amounts of vertical or horizontal movement.

Earthquakes that result in surface fracture are rare enough to warrant special attention. But the vast majority of the 82 earthquakes that caused damage to hydraulic structures in and adjacent to California did not open the surface.

Seventy-seven earthquakes in and adjacent to California between 1865 and 1966 caused damage to hydraulic structures in California. Sixty-two of these earthquakes occurred in California, 10 occurred in the offshore areas of California, three occurred in western Nevada, and two occurred in Mexico south of Imperial Valley.

The damaging earthquakes in California occurred in seven of the state's 11 geomorphic provinces: Coast Ranges (33), Sierra Nevada (9), Peninsular Ranges (7), Salton Trough (7), Transverse Ranges (3), Great Basin (2), and Mojave Desert (1).

Which faults are associated with these 62 earthquakes are often unknown, but we do know that six, and suspect that three others, occurred on the San Andreas. All other faults have experienced considerably less activity. These are the White Wolf, Hayward, possibly Sierra Nevada, Calaveras-Sunol, Agua Caliente, San Jacinto, Imperial, Mission Creek, Fort Sage, Manix and possibly Newport-Inglewood.

Epicenters of the damaging earthquakes occurred in 25 counties extending from Humboldt on the north to San Diego and Imperial on the south. Eight counties had three or more damaging earthquakes: Kern (9), Santa Clara (8), Imperial (7), Los Angeles (4), Riverside (4), San Benito (4), Contra Costa (3), and Humboldt (3).

Magnitudes of the 62 earthquakes ranged from 3. 8 to 8. 3. Three caused extensive damage to hydraulic structures in California: San Francisco, April 18, 1906, San Andreas fault, Magnitude 8. 3; Imperial Valley, May 18, 1940, Imperial fault, Magnitude 7. 1; and Kern County earthquake of July 21, 1952, White Wolf fault, Magnitude 7. 7. The remaining smaller earthquakes, ranging from 3. 8 to 7. 0, were less damaging.

Maximum intensities--indexes of damage caused rather than of source energy--ranged from V to XI on the Modified Mercalli scale.

Epicenter and fault statistics of all 77 earthquakes are shown graphically on the map in Figure 2, "Epicenters and Faults of Earthquakes Damaging to Hydraulic Structures in California". Complete statistics on these earthquakes, including the number of the case quoted in this document, are shown in tabular form in Table 1.

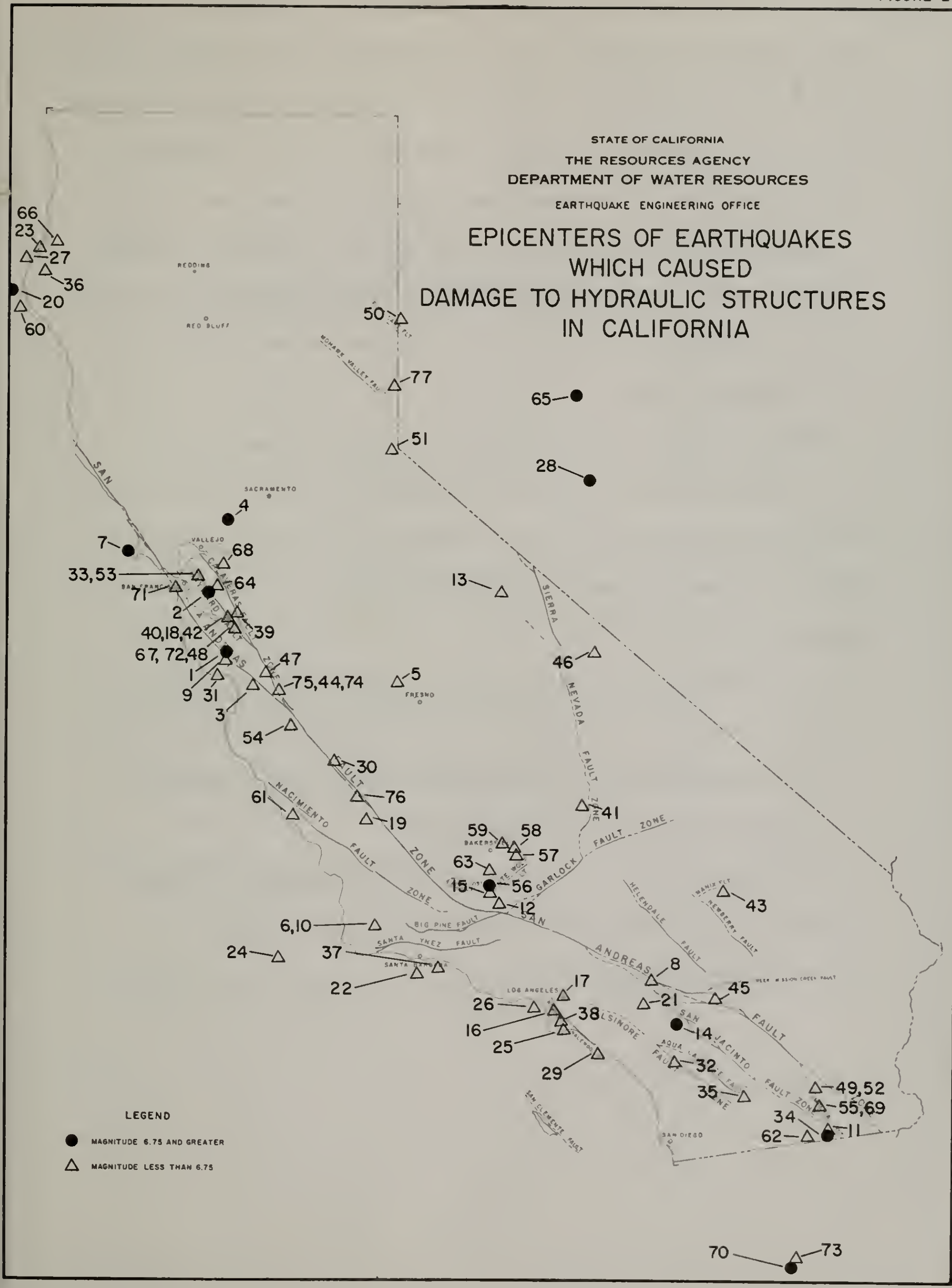
Four of the 77 earthquakes did damage to hydraulic structures outside California as well as within the state's borders. An additional five earthquakes did no damage in the state but left their mark on structures in northern Mexico and western Arizona and Nevada.

These nine earthquakes, all between 1915 and 1954, caused significant damage to hydraulic structures outside of California. Three of the nine earthquakes occurred in the Imperial Valley, California; four occurred in western Nevada; and two occurred in northern Mexico south of Imperial Valley.

The three California earthquakes, causing damage in northern Mexico, occurred on active California faults, one on the Imperial fault, May 18, 1940, and two probably on the southeastward extension of the San Jacinto fault, June 22, 1915, and January 1, 1927. Magnitudes of the three earthquakes ranged from 5-3/4 to 7.1, and maximum intensities ranged from VIII to X.

Ground breakage by these three earthquakes was reported only for the Imperial Valley fault of May 18, 1940, where the Imperial fault ruptured over a 40-mile length with 4' vertical and 19' horizontal movement recorded.

Four earthquakes causing extensive damage in western Nevada and some damage in California occurred on active Nevada faults, one on the Cedar


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
EARTHQUAKE ENGINEERING OFFICE
EPICENTERS OF EARTHQUAKES WHICH CAUSED DAMAGE TO HYDRAULIC STRUCTURES IN CALIFORNIA
LEGEND
MAGNITUDE 6.75 AND GREATER
MAGNITUDE LESS THAN 6.75
REDDING
RED BLUFF
SACRAMENTO
VALLEJO
FRESNO
LOS ANGELES
SAN DIEGO
SAN ANDREAS FAULT ZONE
SIERRA NEVADA FAULT ZONE
GARLOCK FAULT ZONE
NACIMIENTO FAULT ZONE
BIG PINE FAULT
SANTA YNEZ FAULT
HELENDALE FAULT
SAN JACINTO FAULT ZONE
SAN CLEMENTE FAULT
MOHAWK VALLEY FAULT
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28
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7
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64
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40,18,42
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Mountain fault, December 20, 1932, two earthquakes on the Rainbow Mountain fault, July 6 and August 23, 1954, and one of the Dixie Valley and Fairview Valley faults, December 16, 1954. Magnitudes of the four earthquakes ranged from 6. 6 to 7. 3, and maximum intensities ranged from IX to X.

Ground breakage occurred on all four Nevada earthquakes. Length of rupture ranged from 11 miles to 55 miles, vertical displacement ranged from a few inches to 12 feet, and horizontal displacement ranged from none-reported to 12 feet.

The two northern Mexico earthquakes, causing damage near the U. S. - Mexican border on December 30 and December 31, 1934, probably occurred on the extension of the San Jacinto fault in Mexico. Magnitudes of the two earthquakes ranged from 6. 5 to 7. 1, and maximum intensities ranged from IX - X.

Ground breakage apparently occurred during the Baja California, Mexico, earthquake of December 31, 1934. Movement possibly occurred on the southeast extension of the San Jacinto fault. This conclusion is based on interpretation of aerial photographs.

Epicenter and fault statistics of the nine earthquakes that damaged structures in areas beyond the California state border are shown under "Damage Adjacent to California".

TABLE I

EARTHQUAKES DAMAGING TO
HYDRAULIC STRUCTURES IN CALIFORNIA

EXPLANATION:

Earthquakes are numbered in chronological order and indicated on Figure 2.

Intensity - Maximum damage intensity at the epicenter in the Modified Mercalli Scale (I-XII)

Magnitude - Richter Scale (maximum observed is 8.75)
* -- Magnitude approximated from intensity information using conversion, page 353, Richter (1958)

Fault Displacement Description -
V -- Vertical movement
H -- Horizontal (strike slip) movement
L -- Length of rupture

Related Damage Cases - Numbers refer to numbered descriptions (Case numbers) in text

No.	Earthquake	Fault	Date	County	Epicenter	
					Lat. N.	Long. W.
1	Santa Cruz Mountains	Possibly San Andreas	Oct. 8, 1865	Santa Cruz and Santa Clara	37°	122°
2	Hayward	Hayward	Oct. 21, 1868	Alameda	37.5°	122°
3	Monterey Bay Region	Unknown, possibly San Andreas	Apr. 24, 1890	San Benito-Santa Cruz	37°	121.5°
4	Vacaville	Unknown	Apr. 19, 1892	Napa	38.5°	122.5°
5	Pine Ridge	Unknown	Jul. 13, 1894	Fresno	37°	120°
6	Los Alamos	Unknown	Jul. 27, 1902	Santa Barbara	34.5°	120.5°
7	San Francisco	San Andreas	Apr. 18, 1906	Marin	38°	123°

Intensity	Magnitude	Fault Displacement Description	Related Damage Cases	References
VIII-IX	Unknown possibly 6-7*	(No rupture reported)	165, 230	Holden, 1898, pp. 66-67. Townley, 1939, pp. 46-47 Wood, 1966, pp. 10, 25.
IX-X	Unknown possibly 7*	V-slight down throw SW side; H-3 ft. approximately; L-20 miles approximately. Numerous cracks reported associated with the main fault trace between San Leandro and Warm Springs. A secondary crack was formed east of Warm Springs and paralleled the Hayward fault for a distance of approximately 4 miles.	111, 166	Freeman, 1932, pp. 183-186. Holden, 1899, pp. 76-80 Lawson, 1908, pp. 434-448. Lawson, 1921, pp. 459-460. Louderback, 1942, p. 330 Radbrunch, 1965, p. 1. Richter, 1958, p. 476. Townley, 1939, p. 52. Wood, 1966, pp. 10, 25.
VII	Unknown possibly 6*	(No rupture reported) Fissuring reported in the San Andreas fault zone near Chittenden east of Watsonville.	231	Holden, 1899, pp. 148-151. Townley, 1939, p. 81. Wood, 1966, pp. 11, 27.
IX	Unknown possibly 7*	(No rupture reported) Fissures were found in the bed of Putah Creek one-half mile west of Winters, and in the adjoining roadway and fields.	167	Richter, 1958, p. 533. Townley, 1939, p. 88. Wood, 1966, pp. 11, 27.
Unknown	Unknown	(No rupture reported)	54	Townley, 1939, pp. 95-96. Wood, 1966, pp. 11, 27-28.
VIII	Unknown possibly 6*	(No rupture reported) Fissures and cracks reported in the ground.	168, 232	Townley, 1939, p. 117. Wood, 1966, pp. 12, 29.
XI	8.3	V-3 ft.; H-21 ft. in alluvium, 15 ft. in rock; L-180 miles. Total length of horizontal movement may have approached 270 miles assuming continuous movement between San Juan in San Benito County and Telegraph Hill in Humboldt County.	1, 10-46, 55-62, 76, 81-86, 92, 107, 108, 112-117, 169-179, 212, 233-240, 270, 271.	Benioff, 1964, p. 1399. Buwalda, 1937, p. 341. Chinnery, 1961, pp. 370-371. Evison, 1963, pp. 877-878. Freeman, 1932, pp. 59-61, 191-192, 231-241.

No.	Earthquake	Fault	Date	County	Epicenter	
					Lat. N.	Long. W.
7	San Francisco (Continued)					
8	San Bernardino	Unknown	Sep. 19, 1907	San Bernardino-Riverside	34°	117°
9	Laurel	Unknown	Nov. 8, 1914	Santa Cruz	37°	122°
10	Los Alamos	Unknown	Jan. 11, 1915	Santa Barbara	34.5°	120.5°
11	El Centro - Calexico	Unknown, possibly southeastward extension of San Jacinto fault.	Jun. 22, 1915	Imperial	32.8°	115.5°
12	Tejon Pass	Unknown, possibly San Andreas	Oct. 22, 1916	Kern	34.9°	118.9°
13	Owens Valley	Unknown	Jul. 6, 1917	Inyo	Unknown possibly 37.6°	Unknown possibly 119°

Intensity	Magnitude	Fault Displacement Description	Related Damage Cases	References
		Significant breakage occurred on faults outside the San Andreas Rift, mainly in the Point Reyes Peninsula, San Francisco Peninsula, and Santa Cruz Mountains.		Hayford, 1907, pp. 69-104. Lawson, 1908, pp. 53-113. Louderback, 1937, pp. 1-5, 15-32. Macelwane, 1946, p. 2. Reid, 1911, pp. 413-414. Richter, 1958, pp. 469, 476-487. Schlocker, 1964, pp. 2-5, 21-26. Taliaferro, 1943, p. 161. Tocher, 1958, pp. 147-152. Tocher, 1959, p. 44. Townley, 1939, pp. 128-132. Wallace, 1949, p. 799. Whitten, 1949, p. 84. Willis, 1938, p. 798. Wood, 1966, pp. 12, 19-20. Woodford, 1960, p. 413.
VII	6	(No rupture reported)	87	Richter, 1958, p. 469. Townley, 1939, p. 146. Wood, 1966, pp. 12, 29.
VII	Unknown possibly 5*	(No rupture reported)	180	Townley, 1939, pp. 173-174. Wood, 1966, pp. 12, 30.
VIII	Unknown possibly 6*	(No rupture reported)	2, 181, 217, 241, 242.	Townley, 1939, p. 174. Wood, 1966, pp. 12, 30.
VIII	6.25	(No rupture reported)	93	Allen, 1965, p. 769. Townley, 1939, pp. 180-181. Wood, 1966, pp. 12, 30-31.
VII	6	(No rupture reported)	63	Allen, 1965, p. 769. Townley, 1939, pp. 190-191. Wood, 1966, pp. 12, 31.
VI-VII	Unknown	(No rupture reported)	109	Townley, 1939, p. 197. Wood, 1966, pp. 12, 31.

No.	Earthquake	Fault	Date	County	Epicenter	
					Lat. N.	Long. W.
14	San Jacinto	San Jacinto	Apr. 21, 1918	Riverside	33.75°	117°
15	Maricopa	Unknown	Feb.16, 1919	Kern	35°	119°
16	Inglewood	Unknown, possibly Newport-Inglewood fault zone	Jun. 21, 1920	Los Angeles	34°	118.5°
17	Los Angeles	Unknown	Jul. 16, 1920	Los Angeles	34°	118.5°
18	San Jose	Unknown	Sep. 9, 1920	Santa Clara	37.4° Approximate	121.8° Approximate
19	Cholame Valley	San Andreas	Mar. 10,1922	San Luis Obispo	35.75°	120.25°
20	Cape Mendocino	Unknown	Jan. 22, 1923	Offshore Humboldt	40.5°	124.5°
21	San Bernardino Valley	Unknown	Jul. 22, 1923	Riverside	34°	117.25°

Intensity	Magnitude	Fault Displacement Description	Related Damage Cases	References
IX	6.8	(No rupture reported) The ground was cracked in many places in the region of the faulted zone, but there was no surface evidence of displacement.	94, 110, 118, 119, 243.	Allen, 1965, p. 769. Townley, 1939, pp. 201-203. Wood, 1966, pp. 13, 31.
VII	Unknown possibly 5*	(No rupture reported)	213	Townley, 1939, p. 209. Wood, 1966, pp. 13, 32.
VIII	Unknown possibly 6*	(No rupture reported)	120	Richter, 1958, p. 533. Townley, 1939, p. 216. Wood, 1966, pp. 13, 32.
VI	Unknown possibly 5*	(No rupture reported)	121	Townley, 1939, p. 217. Wood, 1966, pp. 13, 32.
V	Unknown possibly 4*	(No rupture reported)	272	Townley, 1939, pp. 217-218.
IX	6.5	(No rupture reported) Cracks 6 to 12 inches wide occurred over a distance of one quarter mile along the San Andreas fault in Cholame Valley. Interviews with local residents suggest that a surface rupture did occur on the San Andreas fault in this area, although geologists did not visit the area.	244	Richter, 1958, pp. 533-534. Tocher, p. 148. Townley, 1939, pp. 224-225. Wood, 1966, pp. 13, 32.
VII-VIII	7.3	(No rupture reported)	182	Townley, 1939, pp. 227-228. Wood, 1966, pp. 13, 32.
VII	6.25	(No rupture reported)	122	Townley, 1939, pp. 229-230. Wood, 1966, pp. 13, 32.

No.	Earthquake	Fault	Date	County	Epicenter	
					Lat. N.	Long. W.
22	Santa Barbara	Unknown, possibly one of the faults associated with the Elwood oil field.	Jun. 29, 1925	Offshore, Santa Barbara	34.3°	119.8°
23	Humboldt Bay	Unknown	Aug. 20, 1927	Humboldt	41°	124°
24	Point Arguello	Unknown, on the edge of the continental shelf, north margin of the Murray fracture zone.	Nov. 4, 1927	Offshore, Santa Barbara	34.5°	121.5°
25	Whittier	Unknown	Jul. 8, 1929	Los Angeles	34°	118°
26	Santa Monica Bay	Unknown	Aug. 30, 1930	Offshore, Los Angeles	33.9°	118.6°
27	Eureka	Unknown	Jun. 6, 1932	Offshore, Humboldt	40.8°	124.3°
28	Cedar Mountain, Nevada	Cedar Mountain	Dec. 20, 1932		38.75°	118.°
29	Long Beach	Newport-Inglewood fault zone	Mar. 10, 1933	Offshore, Orange County	33.6°	118°
30	Parkfield	San Andreas	Jun 7, 1934	Monterey	35.9°	120.5°

Intensity	Magnitude	Fault Displacement Description	Related Damage Cases	References
VIII-IX	6.3	(No rupture reported)	64, 123, 273.	Richter, 1958, p. 534. Townley, 1939, p. 235. Wood, 1966, pp. 13, 33.
VIII	Unknown possibly 6*	(No rupture reported)	183, 184	Wood, 1966, pp. 13, 34.
IX-X	7.5	(No rupture reported)	185, 245	Richter, 1958, p. 534. Wood, 1966, pp. 13, 34.
VII	4.7	(No rupture reported)	246	Wood, 1966, pp. 13, 34.
VII	5.2	(No rupture reported)	65, 124	Wood, 1966, pp. 13, 34.
VIII	6.4	(No rupture reported)	47, 125, 186.	Neumann, 1934, pp. 7-8. Wood, 1966, pp. 13, 34-35.
X	7.3	V-24 inch maximum; H-34 inch maximum right-hand offset; L-Individual displacements a few hundred feet to 4 miles. Effects attributable to faulting were found in a belt 4 to 9 miles wide and 38 miles long trending about N21°W.	126	Eppley, 1965, p. 64. Richter, 1958, pp. 469, 507-508. Wood, 1966, pp. 14, 20.
IX	6.3	(No rupture reported)	48, 127-133, 247-249.	Neumann, 1935, pp. 9-14. Richter, 1958, pp. 497-499. Wood, 1966, pp. 14, 35.
VIII	6	(No rupture reported) Two zones of cracks were developed in the soil on the northeast and southwest edges of the crest of Middle Mountain for a distance of about 2 miles northwest of Parkfield.	187	Byerly, p. 233. Neumann, 1936, pp. 26-27, 48-50. Richter, 1958, p. 534. Wood, 1966, pp. 14, 35.

No.	Earthquake	Fault	Date	County	Epicenter	
					Lat. N.	Long. W.
30	Parkfield (Continued)					
31	Santa Cruz	Unknown	Dec. 30,1934	Offshore, Santa Cruz	Unknown	Unknown
32	Aguanga	Agua Caliente	Nov. 3, 1935	Riverside	33°30'N	116°55'W
33	Berkeley	Probably Hayward	Mar. 8, 1937	Contra Costa	37.8°	122.2°
34	Imperial Valley	Imperial	May 18, 1940	Imperial	32.7°	115.5°
35	Verruga	Unknown	Jun. 4, 1940	San Diego	33°07'	116°25'
36	Scotia	Unknown	Oct. 22, 1940	Humboldt	Unknown	Unknown
37	Santa Barbara	Unknown	Jun. 30, 1941	Offshore, Santa Barbara	34.4°	119.6°
38	Torrance-Gardena	Unknown	Nov. 14, 1941	Los Angeles	33.8°	118.2°

Intensity	Magnitude	Fault Displacement Description	Related Damage Cases	References
		These zones paralleled and were close to the surface traces of two faults in the San Andreas zone. The zones of cracks were about 25 feet wide. The individual cracks were arranged en echelon. The largest single crack was about 55 feet long, 9 inches wide and 18 inches deep. There was no evidence that the cracks penetrated into the underlying sandstones and shales, nor of vertical or horizontal displacement along the cracks.		
V	Unknown, possibly 4*	(No rupture reported)	88	Neumann, 1936, p. 34.
Unknown	4.5	(No rupture reported)	134	Calif. Dept. of Water Resources, 1962. Neumann, 1937, p. 37.
VII	4.5	(No rupture reported)	135, 136, 188, 250, 274.	Neumann, 1940, pp. 14-16. Wood, 1966, pp. 14, 36.
X	7.1	H-19'; L-40 miles approximately. Some indication that faulting in Mexico may have continued southward from areas of observed rupture, thus increasing length to in excess of 40 miles	49, 95-97, 137-139, 218.	Allen, 1942, pp. 768-769. Neumann, 1958, pp. 20-24. Richter, 1958, pp. 488-494. Ulrich, 1941, pp. 16-24. Wood, 1966, pp. 14, 20-21
Unknown	5	(No rupture reported)	98	Calif. Dept. of Water Resources, 1962. Neumann, 1942, p. 25.
VI	Unknown, possibly 5*	(No rupture reported)	189	Neumann, 1942, p. 28.
VIII	5.9	(No rupture reported)	140	Neumann, 1943, pp. 10-11. Richter, 1958, pp. 534-535. Wood, 1966, pp. 14, 36.
VII-VIII	5.4	(No rupture reported)	190, 191, 251, 252.	Neumann, 1943, pp. 17-18. Wood, 1966, pp. 14, 37.

No.	Earthquake	Fault	Date	County	Epicenter	
					Lat. N.	Long. W.
39	Mount Hamilton Area	Probably Calaveras	Oct. 25, 1943	Santa Clara	37.4°	121.7°
40	San Jose	Unknown	Aug. 27, 1945	Santa Clara	37.3°	121.8°
41	Walker Pass	Unknown, possibly Sierra Nevada fault zone	Mar. 15, 1946	Kern	35.7°	118.1°
42	Santa Clara	Unknown	Apr. 25, 1946	Santa Clara	37°34'	121°55'
43	Manix	Manix	Apr. 10, 1947	San Bernardino	35°	116.6°
44	Hollister	Unknown	Aug. 10, 1947	San Benito	36.9°	121.4°
45	Desert Hot Springs	Unknown, possibly Mission Creek fault, a branch of the San Andreas.	Dec. 4, 1948	Riverside	33.9°	116.4°
46	Eureka Valley	Unknown	Feb. 11, 1949	Inyo	37.1°	117.8°
47	Gilroy-Hollister	Unknown	Mar. 9, 1949	Santa Clara	37°	121.5°
48	San Jose	Unknown	Jun. 22, 1949	Santa Clara	37°20'	121°41'

Intensity	Magnitude	Fault Displacement Description	Related Damage Cases	References
VI	5.5	(No rupture reported)	141, 192, 253.	Bodle, 1945, pp. 15-16. Wood, 1966, pp. 14, 37.
VI	4.5	(No rupture reported)	142	Bodle, 1947, pp. 14-15. Calif. Dept. of Water Resources, 1962. Wood, 1966, pp. 14, 37.
VIII	6.3	(No rupture reported)	77-79	Bodle, 1948, pp. 9-12. Richter, 1958, pp. 518-519. Wood, 1966, pp. 14, 37.
VI	3.8	(No rupture reported)	143	Bodle, 1948, p. 13. Calif. Dept. of Water Resources, 1962.
VII	6.4	V-none observed; H-2 to 3 inches left-hand strike slip; L- approximately 1 mile. Some conjecture that displacement on the Manix fault was a secondary feature resulting from the main displacement on a northwest-trending fault that presumably is buried by local Pleistocene lake beds.	50, 66, 99, 193, 194, 214.	Allen, 1965, pp. 768-769. Buwalda, 1948, p. 1367. Evison, 1963, pp. 875-876. Murphy, 1950, pp. 17-20. Richter, 1947, p. 179. Richter, 1958, pp. 516-518. Wood, 1966, p. 14, 38.
VI	5	(No rupture reported)	144	Murphy, 1950, p. 25. Wood, 1966, pp. 14, 38.
VII	6.5	(No rupture reported)	80, 100, 145, 146, 195, 196.	Murphy, 1951, pp. 19-23. Wood, 1966, pp. 15, 38.
VI	5.6	(No rupture reported)	219	Murphy & Ulrich, 1951, p. 9. Wood, 1966, pp. 15, 38.
VII	5.3	(No rupture reported)	197	Murphy, 1951, pp. 9-11. Wood, 1966, pp. 15, 38.
Unknown	4.1	(No rupture reported)	89	Calif. Dept. of Water Resources, 1962. Murphy & Ulrich, 1951, p. 15.

No.	Earthquake	Fault	Date	County	Epicenter	
					Lat. N.	Long. W.
49	Calipatria	Unknown	Jul. 29, 1950	Imperial	33.1°	115.6°
50	Herlong	Fort Sage	Dec. 14, 1950	Lassen	40.1°	120.1°
51	Lake Tahoe area, Nevada	Unknown	Jan. 22, 1951		39°05'	119°57'
52	Superstition Hills	Superstition Hills	Jan. 23, 1951	Imperial	32°59'	115°44'
53	Berkeley Hills	Unknown	Jul. 23, 1951	Contra Costa	37.9°	122.3°
54	Mulberry	Unknown	Jul. 29, 1951	San Benito	36.6°	121.2°
55	Brawley	Unknown	Dec. 5, 1951	Imperial	33.1°	115.4°
56	Kern County	White Wolf	Jul. 21, 1952	Kern	35°	119°
57	Tejon Ranch	Unknown, possibly White Wolf	Jul. 22, 1952	Kern	35°	118.8°
58	Caliente	Unknown, possibly White Wolf	Jul. 25, 1952	Kern	35.3°	118.5°

Inten- sity	Magni- tude	Fault Displacement Description	Related Damage Cases	References
VIII	5.4	(No rupture reported)	67, 101, 220.	Murphy, 1952, pp. 10-11. Wood, 1966, pp. 15, 39.
VII	5.6	V-5" to 18"; H-none observed; L-approximately 5.5 miles. On the west side of Fort Sage Mountains 3 separate fault scarps were formed, 2 in rock and 1 in alluvium.	198	Gianella, 1957, pp. 173-176. Murphy, 1952, pp. 14-15. Richter, 1958, p. 516. Wood, 1966, pp. 15, 39.
V	4.8	(No rupture reported)	68	Calif. Dept. of Water Resources, 1962. Murphy & Cloud, 1953, p. 8.
VII	5.6	V-none observed; H-slight right lateral displacement; L-1-3/4 mile.	102, 103	Allen, 1965, p. 768. Murphy & Cloud, 1953, pp. 8-10. Wood, 1966, pp. 15, 39.
VI	3.9	(No rupture reported)	199	Murphy & Cloud, 1953, pp. 11-12. Wood, 1966, pp. 15, 39.
VI	5.4	(No rupture reported)	221	Murphy & Cloud, 1953, p. 12. Wood, 1966, pp. 15, 39.
VII	4.5	(No rupture reported)	104	Wood, 1966, pp. 15, 40.
XI	7.7	V-4 feet; H-small amount of left and right-hand strike slip faulting; L-17-20 miles. A single, simple continuous surface fault trace did not develop, but rather a complex rupture pattern occurred with a variety of fracture types, trends and directions of displacements.	3, 4, 51, 52, 69-72, 105, 147-149, 200-203, 215, 222-226, 229, 254-260, 275, 276.	Allen, 1965, pp. 768-769. Buwalda, 1952, pp. 648-650. Buwalda, 1954, p. 1335. Dibblee, 1955, pp. 27-30. Evison, 1963, pp. 179-180. Oakeshott, 1954, pp. 331-337. Richter, 1958, pp. 519-531. Steinbrugge, pp. 283-299. Whitten, 1955, pp. 78-80. Wood, 1966, p. 21.
VII	5.4	(no rupture reported)	150	Murphy & Cloud, 1954, p. 35. Wood, 1966, pp. 15, 22.
VII	5.7	(No rupture reported)	227	Murphy & Cloud, 1954, pp. 35-36. Richter, 1958, pp. 519-531. Wood, 1966, p. 15.

No.	Earthquake	Fault	Date	County	Epicenter	
					Lat. N.	Long. W.
59	Bakersfield	Unknown, possibly White Wolf	Aug. 22, 1952	Kern	35.3°	118.9°
60	Petrolia	Unknown	Sep. 22, 1952	Offshore Humboldt	40.2°	124.4°
61	Bryson	Unknown	Nov.21, 1952	San Luis Obispo	35.8°	121.2°
62	Imperial	Unknown	Jun. 13, 1953	Imperial	32.8°	115.7°
63	Wheeler Ridge	Unknown, possibly White Wolf	Jan. 12, 1954	Kern	35°	119°
64	San Leandro	Unknown	Dec. 16, 1954	Alameda-Contra Costa	37.7°	122.1°
65	Dixie Valley, Nevada	Dixie Valley and Fairview Valley Faults	Dec. 16, 1954		39.3°	118.2°
66	Eureka	Unknown	Dec. 21, 1954	Humboldt	40.8°	124.1°
67	San Jose	Unknown	Sep. 4, 1955	Santa Clara	37.4°	121.8°
68	Concord	Probably Calaveras or Sunol	Oct. 23, 1955	Contra Costa	38°	122.1°
69	Brawley	Unknown	Dec. 16, 1955	Imperial	33°	115.5°

Intensity	Magnitude	Fault Displacement Description	Related Damage Cases	References
VIII	5. 8	(No rupture reported)	151	Murphy & Cloud, 1954, pp 37-39. Wood, 1966, pp. 15, 21,22
VII	5. 4	(No rupture reported)	204	Murphy & Cloud, 1954, pp. 41-42. Wood, 1966, pp. 15, 40.
VII	6	(No rupture reported)	205	Murphy, 1954, pp. 44-46. Wood, 1966, pp. 15, 40.
VII	5. 5	(No rupture reported)	106	Murphy & Cloud, 1955, pp. 15-17. Wood, 1966, pp. 15, 40.
VII-VIII	5. 9	(No rupture reported)	228, 261-264.	Murphy & Cloud, 1956, pp. 12-14. Richter, 1958, p. 526. Wood, 1966, p. 15.
VI	3. 8	(No rupture reported)	152.	Murphy & Cloud, 1956, p. 43. Wood, 1966, pp. 16, 42.
X	7. 1	V-12 feet; H-12 feet; L-approximately 55 miles. Northern fault zone shows at least 7 feet of dip-slip and little or no strike slip. The southern fault zone has up to 12 feet of vertical and horizontal movement.	5, 53, 277	Murphy & Cloud, 1956, pp. 37-43. Richter, 1958, pp. 512-515. Wood, 1966, pp. 21-22.
VII	6. 6	(No rupture reported)	6, 90, 153, 154, 206, 265.	Murphy & Cloud, 1956, pp. 43-50. Richter, 1958, p. 535. Wood, 1966, pp. 16, 42.
VII	5. 8	(No rupture reported)	155, 156	Murphy & Cloud, 1957, pp. 22-24. Wood, 1966, pp. 16, 42.
VII	5. 4	(No rupture reported)	73, 157, 158.	Murphy & Cloud, 1957, pp. 25-29. Richter, 1958, p. 535. Wood, 1966, pp. 16, 42.
VII	5. 4	(No rupture reported)	207	Murphy & Cloud, 1957, pp. 32-33. Wood, 1966, pp. 16, 42.

No.	Earthquake	Fault	Date	County	Epicenter	
					Lat. N.	Long. W.
70	Baja California near El Alamo, Mexico	San Miguel	Feb. 9, 1956		31.8°	115.9°
71	Daly City	San Andreas	Mar.22, 1957	San Mateo	37.7°	122.5°
72	San Jose	Unknown	Oct. 30, 1958	Alameda-Santa Clara	37.5°	121.8°
73	Baja California, Mexico	Unknown	Nov. 30, 1958		32.3°	115.8°
74	Hollister	Unknown	Jan. 19, 1960	San Benito	36.8°	121.4°
75	Hollister	San Andreas	Apr. 8, 1961	San Benito	36.7°	121.3°
76	Parkfield	San Andreas	Jun. 27, 1966	Monterey	35.54°	120.54°
77	Truckee	Unknown	Sept. 12, 1966	Sierra	39°40'	120°05'

Intensity	Magnitude	Fault Displacement Description	Related Damage Cases	References
VI	6.8	V-36 inch maximum; H-31 inch maximum; L-12 miles. Cracks along line of rupture were uniformly open and arranged en echelon. Direction was always right-lateral and up to the northeast.	159	Allen, 1965, p. 769. Brazee, 1958, pp. 19-23. Shore, 1958, pp. 106-111 Wood, 1966, pp. 16, 43.
VII	5.3	(No rupture reported)	7, 160, 161, 208, 266, 267, 278.	Brazee, 1959, pp. 22-28 Oakeshott, 1959, p. 127. Richter, 1958, p. 535. Wood, 1966, pp. 16, 43.
VI	4.2	(No rupture reported)	162	Brazee, 1960, pp. 21-22 Wood, 1966, p. 17.
VI	5.8	(No rupture reported)	163, 268	Brazee, 1960, pp. 22-24 Wood, 1966, pp. 17, 44.
VI	5.1	(No rupture reported)	209	Talley, 1962, pp. 19-21. Wood, 1966, pp. 17, 45.
VII	5.6	(No rupture reported)	8, 91, 164, 210.	Lander, 1963, pp. 17-20. Wood, 1966, pp. 17, 45.
VII	5.5 (larger of two shocks)	V-none observed; H-2 to 4 inches; L-15 miles approximately. Surface fault fractures consist of a series of large numbers of minor fractures arranged in an en echelon, chevron pattern. Many fractures were open cracks 2 to 4 inches wide developed by local tension. Some fractures were closed and the soil was forced up into pressure ridges or mole tracks a few inches high as a result of local compression.	9, 211, 269.	Calif. Dept. of Water Resources, 1966. Harding & Others, 1966. Oakeshott, July 1966, pp. 150-151. Oakeshott, August 1966, p. 965.
VII	6.5	(No rupture reported) Cracks and ground breakage in Russell Valley area suggest a tectonic origin possibly related to subsurface faulting.	74, 75, 216.	Calif. Dept. of Water Resources, 1967, p. 5. Cloud, 1966, pp. 2-6.

DAMAGE IN CALIFORNIA

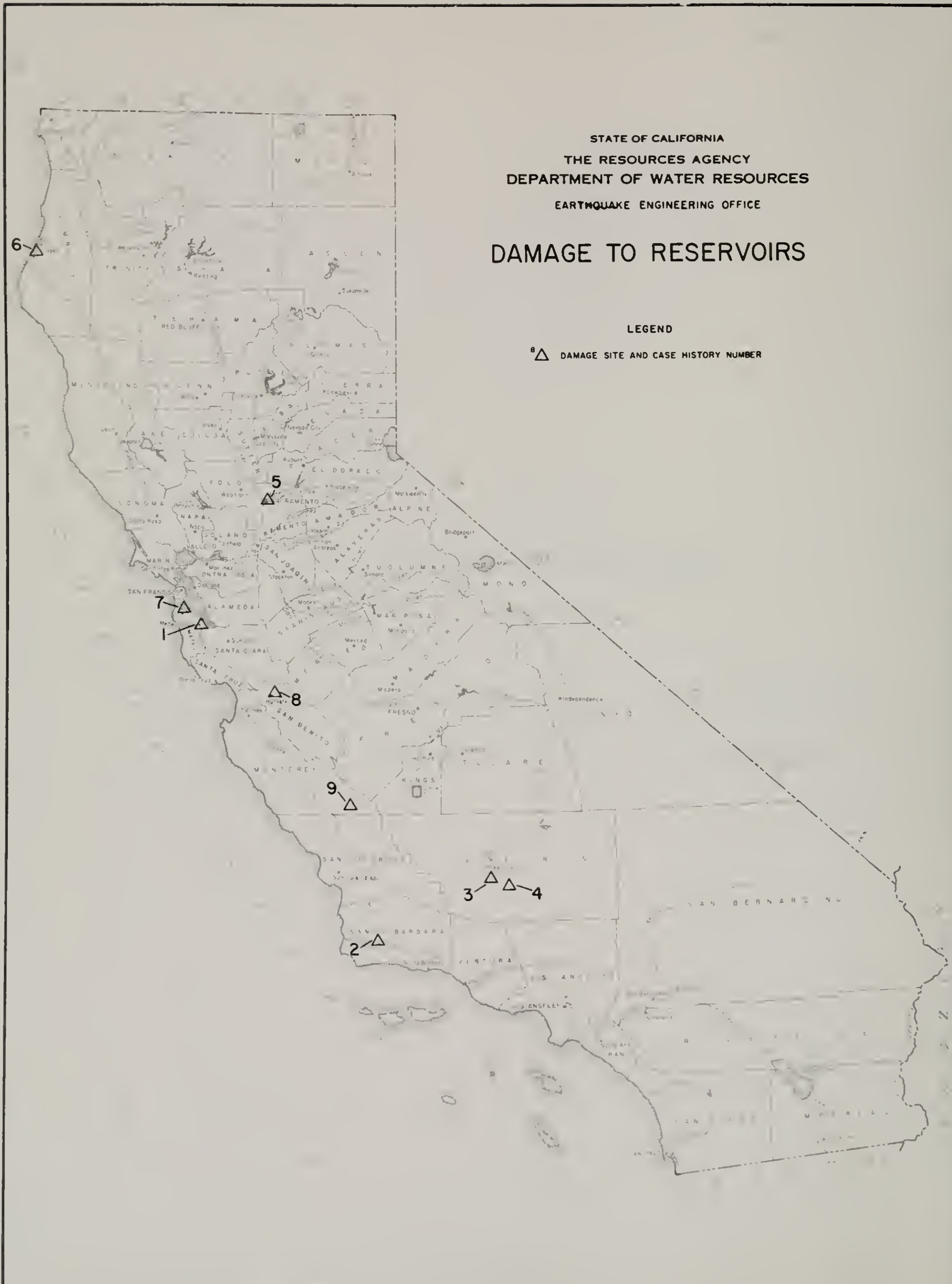
CATEGORY I

STORAGE STRUCTURES

(Cases 1-53)

The following category has been subdivided into two groups. Cases 1-9 concern reservoir damage and Cases 10-53 concern damage to water tanks.

FIGURE 3


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
EARTHQUAKE ENGINEERING OFFICE
DAMAGE TO RESERVOIRS
LEGEND
8△ DAMAGE SITE AND CASE HISTORY NUMBER
1
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9

RESERVOIRS

(Cases 1-9)

1. BEAR GULCH COMPANY RESERVOIR, West of Stanford University, San Mateo County, 55 miles from epicenter of San Francisco earthquake of April 18, 1906. Geologic Formation: Alluvium overlying Tertiary marine sediments. San Andreas fault.

"The water in the reservoir ..., 3.25 miles west of Stanford University, is reported to have been thrown about 25 feet beyond the dam on the southeast side of the lake. Water pipes along the road leading from the reservoir toward Menlo Park had been pulled apart..." Lawson, p. 259.

2. RESERVOIRS, Los Alamos, Santa Barbara County, 3 miles from epicenter of Los Alamos earthquake of January 11, 1915. Geologic Formation: Alluvium. Unknown fault.

"... water was splashed from open reservoirs ..." Beal, March 1915, p. 19.

3. RESERVOIRS, 15 miles south of Bakersfield, Kern County, 3 miles from epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Alluvium. White Wolf fault.

"Slumping and rupture of the reservoirs resulted in water flowing into surrounding fields .... In many cases, existing cracks in the surface opened by earth movement were enlarged by escaped water ..." Marliave, pp. 8-9.

4. RESERVOIR, Comanche Point Road, Kern County, 10 miles from epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Probably alluvium. White Wolf fault.

"Reservoir cracked. Pump fell into reservoir. Water level lowered a few feet." USC&GS, "Abstracts", MSA-75, p. 32.

5. FILTERED WATER RESERVOIR, Sacramento, Sacramento County, 185 miles from epicenter of Dixie Valley, Nevada, earthquake of December 16, 1954, Intensity VI. Geologic Formation: Deep alluvium. Dixie Valley and Fairview Valley fault.

"It will be noted that the damage occurred in the center, away from the damping effects of the east and west counterforte walls, and away from the gap in the baffle wall. No damage to the wood roof was noted, although the sheathing was square-laid. The inspection also revealed that no deterioration had occurred to the structural members and that the construction followed the plans. The vertical amplitude of the water was restricted to slightly more than 1 foot, owing to the fact that the top of the baffle wall was only about 1 foot above the water surface." Steinbrugge and Moran, October 1957, p. 340.

6. RESERVOIR, Eureka, Humboldt County, 4 miles from epicenter of Eureka earthquake of December 21, 1954, Intensity VII. Geologic Formation: Filled ground and older Quaternary slightly compacted alluvium. Fault unknown.

"Damage was done ... to the main reservoir in Eureka, which consists of an excavation plus embankments, the embankments being constructed of earth removed from the excavation. The reservoir, divided into two compartments by a structural reinforced concrete wall, has a total capacity of 20,000,000 gallons. The interior surfaces are lined with concrete reinforced with mesh. The reservoir was leaking prior to the earthquake, and after the shock the leakage jumped to an estimated 1,700,000 gallons per day. The concrete lining broke near a tile drain .... It would seem that the condition might have been getting progressively worse and that the earthquake brought on the crisis." Steinbrugge and Moran, April 1957, p. 138.

7. PALISADES RESERVOIR, Daly City, San Mateo County, 4 miles from epicenter of Daly City earthquake of March 22, 1957. Geologic Formation: Soft, sandy Merced formation. San Andreas fault.

"The 1,600,000-gallon reinforced-concrete Westlake Palisades water reservoir (partly underground) had a 4-foot crack on one side extending upward from the ground." USC&GS, "Abstracts", MSA-93, p. 20.

8. RESERVOIR, Harris Ranch, Cienega Road, near Hollister, San Benito County, about 9 miles from epicenter of Hollister earthquake of April 8, 1961, Intensity VII. Geologic Formation: Very soft alluvium. San Andreas fault.

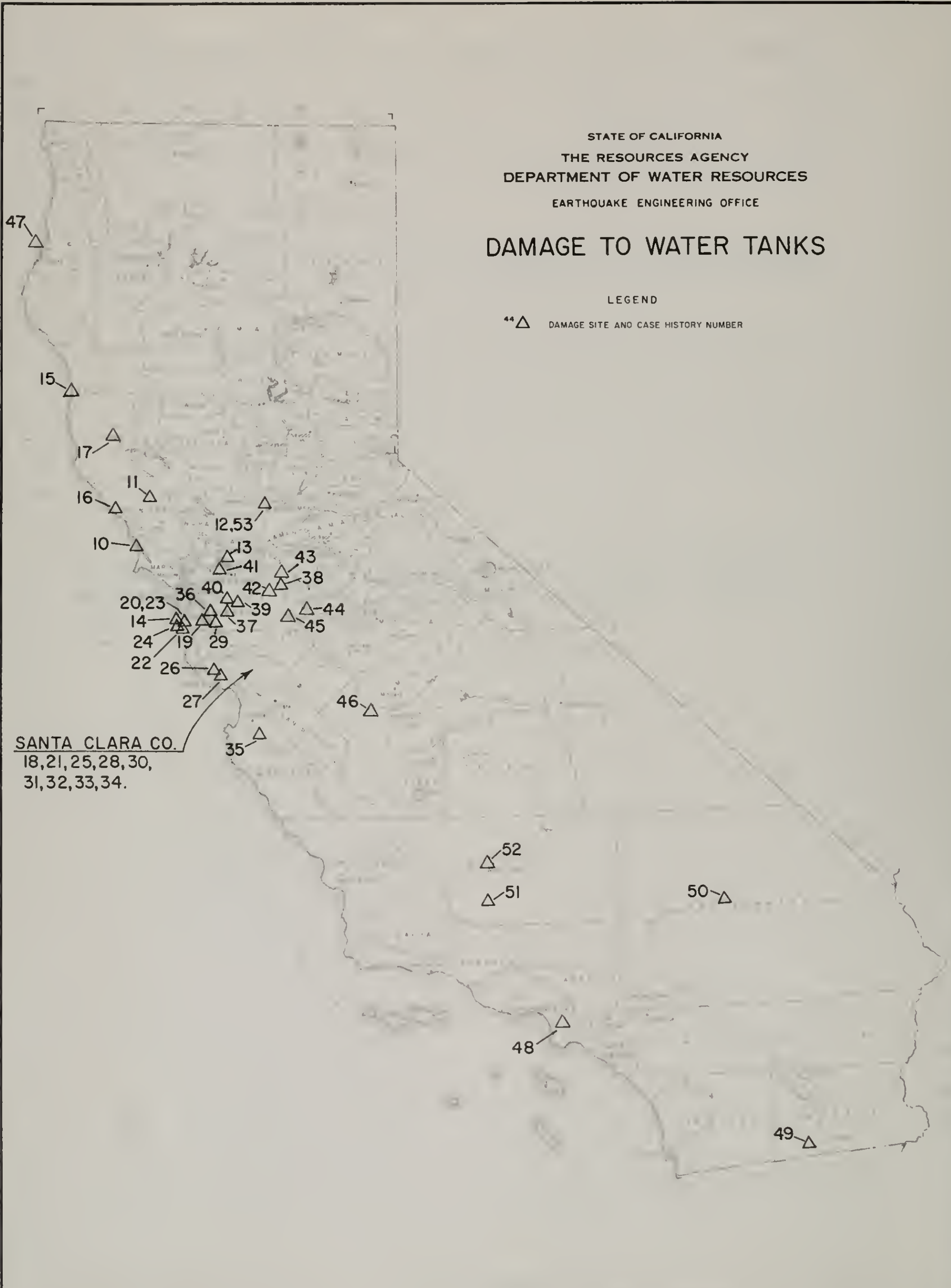
"... concrete-lined reservoir cracked and water level lowered 5 inches ...." USC&GS, "U. S. Earthquakes", 1961, p. 19.

9. POOL, Henry Miller Ranch (2.3 miles from South Parkfield), Monterey County, approximately 15 miles from epicenter of Parkfield earthquake of June 27, 1966, Intensity VII. Geologic Formation: Probably alluvium. San Andreas fault.

"Ground crack, about 1.3 cm wide, was observed about 30 feet behind the house, running parallel with the house and through the swimming pool... Damage to the pool was estimated at about $1,000." Cloud, p. 23.

WATER TANKS

(Cases 10-53)


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
EARTHQUAKE ENGINEERING OFFICE
DAMAGE TO WATER TANKS
LEGEND
44 △ DAMAGE SITE AND CASE HISTORY NUMBER
47
15
17
11
16
12,53
10
13
41
43
38
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39
20,23
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SANTA CLARA CO.
18,21,25,28,30,
31,32,33,34.
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DAMAGE TO WATER TANKS

(Cases 10-53)

The 100,000-gallon water tank for the town of Imperial, California, collapsed.
- Taken May 21, 1940, by C. A. McDougall -

The following 37 cases concern damage to water tanks caused by the San Francisco earthquake of April 18, 1906, San Andreas fault.

10. WATER TANKS, Inverness, Marin County, 10 miles from epicenter

Geologic Formation: Alluvium.

"The phenomena connected with 5 water tanks seemed worthy of special mention, because the simplicity and symmetry of the structures were such that the directions of displacement must represent closely directions of earth movement. A large tank containing water for the village supply stood on the mesa about 0. 5 miles from the shore of the bay, its foundation rising a little above the ground. It was thrown in a direction almost due west and completely demolished, the planks and staves constituting its sides and bottom being strewn over a space of 50 feet.

"The other four tanks were situated along the base of the hill between Inverness and the head of the bay, and held water for sprinkling the road. Each one stood on a square pedestal of braced timbers about 10 feet high. The tank nearest Inverness fell to the west, its pedestal yielding and being crusht. The next fell to the southwest, and tank and pedestal were both crusht. The third was shifted 4. 5 feet westward on its pedestal, both tank and pedestal remaining uninjured. The pedestal of the fourth stood unchanged, and the tank was thrown from it toward the west-northwest, being overturned as it fell." Lawson, p. 194.

11. WATER TANK, Windsor, Sonoma County, 36 miles from epicenter.

Geologic Formation: Alluvium.

" . . . the water-tank at the railway station was overthrown." Lawson, p. 205.

12. WATER TANKS, Sacramento, Sacramento County, 75 miles from epicenter. Geologic Formation: Alluvium.

"The damage at the gas plant was very slight. The gas holders rocked to such an extent that considerable water was thrown out of the tanks, and the seals of the holder sections were partially emptied, allowing gas to escape." Lawson, p. 216.

13. WATER TANKS, Collinsville, Solano County, 49 miles from epicenter.

Geologic Formation: Peat.

" ... chimneys and water-tanks were overthrown." Lawson, p. 217.

14. WATER TANK, Montara Point, San Mateo County, 38 miles from epicenter. Geologic Formation: Weathered Montara granite.

" ... there was some damage to a wooden tank house. One of the tanks, which was previously known to be old and rotten, collapsed entirely." Lawson, p. 252.

15. WATER TANK, Mendocino, Mendocino County, 105 miles from epicenter. Geologic Formation: Marine terrace deposits.

"Only one out of a considerable number of water-tanks was wrecked." Lawson, p. 175.

16. WATER TANK, Doda's Ranch, South of Fort Ross, Sonoma County, 59 miles from epicenter. Geologic Formation: Alluvium.

" ... he [a ranch hand] saw the water-tank thrown vertically upward about 5 feet and then fall in ruins." Lawson, p. 182.

17. WATER TANKS, Ukiah, Mendocino County, 73 miles from epicenter.

Geologic Formation: Stream terrace deposits and alluvium.

"The railroad lost a large water-tank which was thrown down and demolished, tho a large oil-tank near by appears to be uninjured. The shock caused an old sheet-iron tank full of water to break loose at numerous points around the bottom and lose its contents in short order." Lawson, p. 186.

18. WATER TANKS, Stanford University, Santa Clara County, 45 miles from epicenter. Geologic Formation: Alluvium.

"The water-tank at the Faculty Club-house was wrecked and a water-tank in the fields east of Alvarado Row was overthrown. The large covered tanks west of the stock farm, beside the county road, were not thrown down, but much water was spilt from them." Lawson, p. 257.

19. WATER TANKS, Menlo Park, San Mateo County, 42 miles from epicenter. Geologic Formation: Alluvium.

"A mile [from the Catholic Seminary, between the seminary and] ... Fairoaks Station, a water-tank only 12 feet high was thrown down .... A water-tank beside the road, passing north of the cemetery 1.5 miles southwest of Menlo Park Station, was thrown down ...." Lawson. p. 259.

20. WATER TANKS, Redwood City, San Mateo County, 38 miles from epicenter. Geologic Formation: Alluvium.

"Along the two roads leading from Redwood [City] to Portola, out of 23 big public water-tanks 20 were thrown down." Lawson, p. 259.

21. WATER TANKS, Mountain View, Santa Clara County, about 47 miles southeast of epicenter. Geologic Formation: Alluvium.

"In the new town of Mountain View ... out of 46 large water-tanks 20, or 43 per cent, fell .... In the village of Old Mountain View ... 33-1/3 per cent of the water-tanks (3 out of 9) fell ....

"Two and a half miles southwest of Mountain View Station ... a water-tank was so badly wrenched that it had to be braced to keep it from falling; another tank, on a side hill west of San Antonio Creek, had collapsed." Lawson, p. 260.

1.75 miles southwest of Mountain View Station, "... a water-tank 8 feet high was thrown down .... Between Sunnyvale and Lawrence ... a tank and wind-mill were thrown to the ground ... [half a mile south of there,] a water-tank beside the road had been destroyed." Lawson, p. 261.

22. WATER TANKS, Searsville Lake, San Mateo County, about 46 miles southeast of epicenter. Geologic Formation: Alluvium.

"Along the road leading from Searsville Lake southeast thru Portola, the water-tanks were all thrown down .... The water-tank at the fork of the road in front of Mr. Preston's house was thrown down, and the big tank at the fork of the road, at the site of the old village of Searsville, was also thrown down." Lawson, p. 263.

23. WATER TANKS, Bear Creek, San Mateo County, 41 miles from epicenter. Geologic Formation: Alluvium.

"Between Redwood City and Woodside, all of the public water-tanks were thrown down or had to be rebuilt .... A water-tank 20 feet high fell ...." Lawson, p. 265.

24. WATER TANK, Half Moon Bay, San Mateo County, 37 miles from epicenter. Geologic Formation: Alluvium.

"... 0.5 mile ... south [of Canada Verde] a water-tank lay flat across the road." Lawson, p. 266.

25. WATER TANKS, South of Congress Springs, Santa Clara County, 55 miles from epicenter. Geologic Formation: Alluvium.

"Southeast of the reservoir [of San Jose Water Company] the chimneys and water-tanks were down. Two water-tanks at and near the bend of the road [about 200 feet east of the fault] were standing, but 0.5 mile northwest of this place a water-tank had fallen." Lawson, p. 267.

26. WATER TANK, Near Boulder Creek, Santa Cruz County, 75 miles from epicenter. Geologic Formation: Alluvium.

At an old mill "... the water-tank, built on a frame 15 feet high, was shaken so that it fell the next Monday night." Lawson, p. 269.

27. WATER TANK, Road from Santa Cruz to Scott Valley, Santa Cruz County, 75 miles from epicenter. Geologic Formation: Alluvium.

"A 4,000-gallon tank was moved and burst open, letting out 2,000 gallons of water." Lawson, p. 272.

28. WATER TANK, Santa Clara, Santa Clara County, 65 miles from epicenter. Geologic Formation: Alluvium.

"The Santa Clara city water-tower, with large tanks on top, fell to the southwest." Lawson, p. 275.

29. WATER TANK, Newark, Alameda County, 52 miles from epicenter. Geologic Formation: Alluvium.

"At the depot the water-tank fell ..." Lawson, p. 279.

30. WATER TANK, Milpitas, Santa Clara County, 65 miles from epicenter. Geologic Formation: Alluvium.

"A water-tank and wind-mill were thrown down, support and all, about a mile south of town. They fell to the south. Another tank, north of town, appears to have fallen to the west." Lawson, p. 280.

31. WATER TANK, Evergreen, Santa Clara County, 72 miles from epicenter. Geologic Formation: Alluvium.

"A water-tank fell northeast and southwest ..." Lawson, p. 283.

32. WATER TANK, 5 miles south of Madrone, Santa Clara County, 85 miles from epicenter. Geologic Formation: Alluvium.

"A water-tank was thrown down." Lawson, p. 283.

33. WATER TANKS, San Jose, Santa Clara County, 70 miles from epicenter. Geologic Formation: Alluvium.

"Numerous wind-mills and tanks capsized ... 5 or 6 water-tanks on the roadside fell. One of these seemed thrown to the north-east, but others were twisted and scattered as tho by a mixture of all motions .... Half a mile southeast of Fisher's, a water-tank was down .... A quarter of a mile south of the 15-mile house, on the county road, a water-tank was thrown down." Lawson pp. 284-287.

34. WATER TANK, 3 miles west of San Jose, Santa Clara County, 70 to 96 miles from epicenter. Geologic Formation: Alluvium to bedrock.

Near Meridian, "all water-tanks on open frames fell, but those that were boarded in stood." Lawson, p. 287.

35. WATER TANKS, Gonzales, Monterey County, 132 miles from epicenter. Geologic Formation: Alluvium.

" . . . water-tanks were thrown down." Lawson, p. 297.

36. WATER TANK, Alvarado, Alameda County, 48 miles from epicenter. Geologic Formation: Alluvium.

At the Alameda Sugar Company "the 2 great platforms carrying the molasses tanks, supported by numerous vertical props 10 feet 10 inches high, resting on concrete foundations, fell down altogether . . . . The tanks were all damaged and over 1,000,000 pounds of molasses flowed away . . . . At the school-house the water-tank fell owing to the collapse of its supports." Lawson, pp. 304-305.

37. WATER TANKS, Niles and Livermore Valley, Alameda County, 55 miles from epicenter. Geologic Formation: Alluvium.

"A 50,000-gallon water-tank fell at the Niles railway station. Similar tanks were thrown down at the stations at Pleasanton [and] Livermore . . . . This was due to imperfect construction rather than to the violence of the shock." Lawson, p. 306.

38. WATER TANK, Lathrop, San Joaquin County, about 70 miles east of epicenter. Geologic Formation: Alluvium.

A water tank was thrown down at the Lathrop railway station. "This was due to imperfect construction rather than to the violence of the shock." Lawson, p. 306.

39. WATER TANK, Livermore, Alameda County, 60 miles from epicenter. Geologic Formation: Alluvium.

"The Southern Pacific Company's 20,000-gallon water-tank fell in a north-northwest direction . . . ." Lawson, p. 309.

40. WATER TANK, Dublin, Alameda County, 50 miles from epicenter.

Geologic Formation: Alluvium.

"A water-tank 2 miles east fell from its supports, probably owing to the weakness of the latter." Lawson, p. 309.

41. WATER TANKS, Concord, Contra Costa County, 40 miles from epicenter. Geologic Formation: Alluvium.

"A water-tank at the depot was thrown down." Lawson, p. 310.

42. WATER TANK, Tracy, San Joaquin County, 75 miles from epicenter.

Geologic Formation: Alluvium.

"The water-tank of the Southern Pacific railroad at Tracy fell . . . ." Lawson, p. 311.

43. WATER TANK, Stockton, San Joaquin County, 80 miles from epicenter.

Geologic Formation: Alluvium.

"One water-tank was overturned, the supporting framework being insufficiently braced; this tank fell about 15° east of south." Lawson, p. 312.

44. WATER TANK, Modesto, Stanislaus County, 100 miles from epicenter.

Geologic Formation: Alluvium.

"A water-tank belonging to J. Urie, 2.5 miles southwest of Modesto, was overthrown to the west." Lawson, p. 315.

45. WATER TANKS, Westley, Stanislaus County, 92 miles from epicenter.

Geologic Formation: Alluvium.

" . . . several large water-tanks were demolished. These demolished water tanks thru the country seem to have been rotated about one-fifth counter-clockwise." Lawson, p. 315.

46. WATER TANK, Mendota, Fresno County, 156 miles from epicenter.

Geologic Formation: Alluvium.

"The railroad tank, two-thirds full of water at the time, was shaken down; but it was very insecurely built and only a very small vibration was necessary to overthrow it." Lawson, p. 318.

47. WATER TANK, Samoa, Humboldt County, 18 miles from epicenter of Eureka earthquake of June 6, 1932. Geologic Formation: Sand spit. Fault unknown.

"Tank holding 150,000 gallons of water broke and all water escaped." USC&GS, "Abstracts", Vol. 1-4, p. 14.

48. WATER TANK, South Gate, Los Angeles County, 50 miles from epicenter of Long Beach earthquake of March 10, 1933. Geologic Formation: Alluvium. Newport-Inglewood fault zone.

"At South Gate there were two very similar 150,000 gallon steel water tanks on high steel towers about three blocks apart, one on poured-in-place concrete footings tied together and resting on piles and the other on spread footings. The tank on spread footings collapsed, while the one on piles, which was full of water at the time, stood up, although the x-bracing was stretched and some of the columns showed lateral deformation." Nishkian, p. 476.

49. WATER TANK, Imperial, Imperial County, 10 miles from epicenter of Imperial Valley earthquake of May 18, 1940. Geologic Formation: Very soft alluvium. Imperial fault.

"City water tank collapsed." USC&GS, "Abstracts", MSA-26, 1940, p. 16.

50. WATER TANK, Tankersley House, San Bernardino County, 8 miles from epicenter of Manix earthquake of April 10, 1947. Geologic Formation: Probably alluvium. Manix fault.

"Reservoir dug in ground did not spill water but a slightly raised tank did." USC&GS, "U. S. Earthquakes", 1947, p. 18.

51. WATER TANK, 3 miles north of Wheeler Ridge, Kern County, 5 miles northeast of epicenter of Kern County earthquake of July 21, 1952, Intensity VIII. White Wolf fault.

"Three farm water tanks thrown down." USC&GS, "U. S. Earthquakes", 1952, p. 20.

52. WATER TANKS, Bakersfield, Kern County, 21 miles from epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Alluvium. White Wolf fault.

"Of the 12 wind designed tanks in the area, two collapsed, seven had broken or stretched rods and three were not damaged after July 21, 1952 .... Tank No. 11, which was an old wind designed tank brought into the area and reinforced for 10% gravity in accordance with the Uniform Building Code, failed." Steinbrugge and Moran, 1955, p. 249.

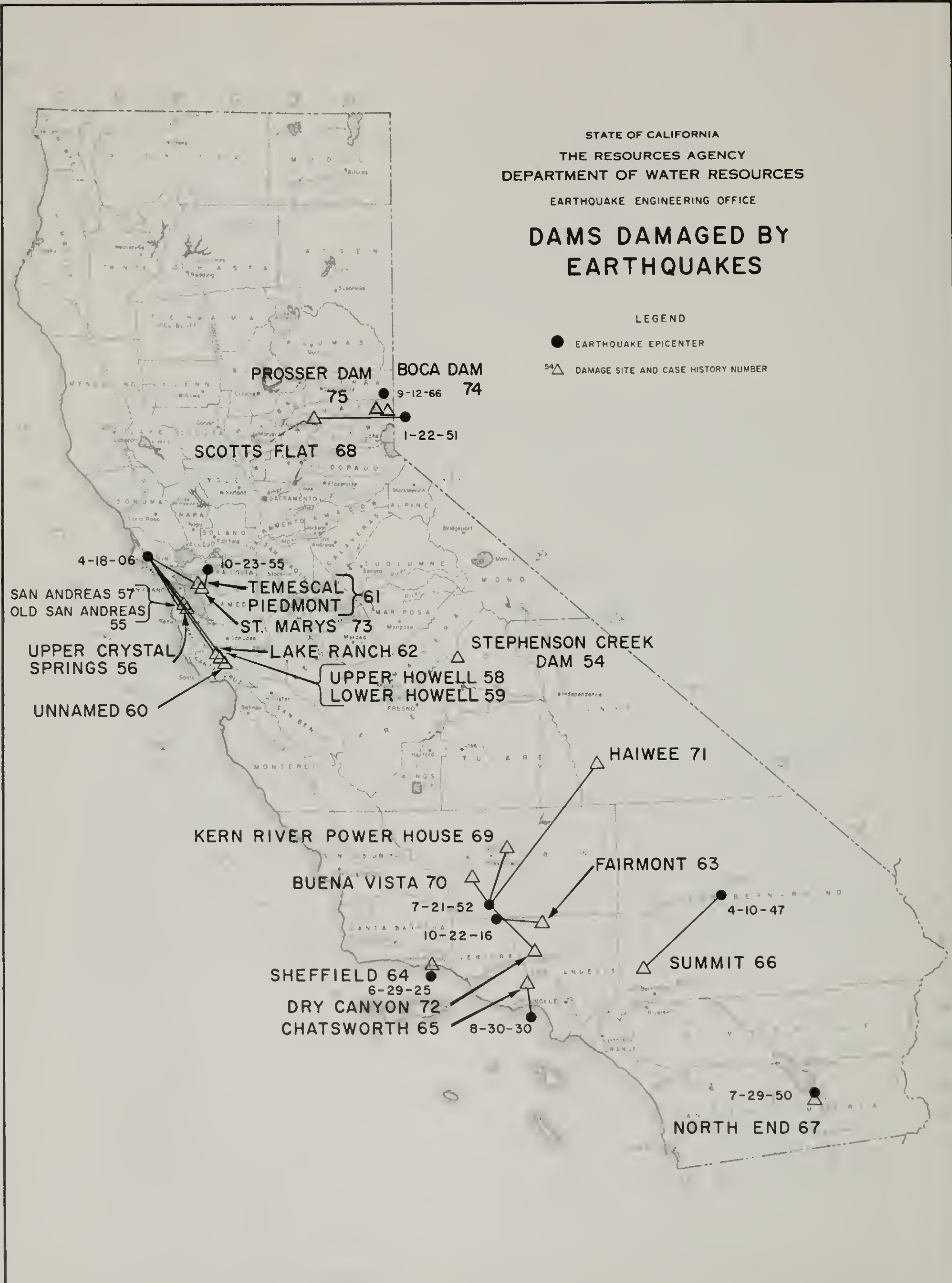
53. CLARIFIER TANK, Campbell Soup, Sacramento, Sacramento County, 185 miles from epicenter of Dixie Valley, Nevada, earthquake of December 16, 1954, Intensity VI. Geologic Formation: Deep alluvium. Dixie Valley and Fairview Valley fault.

"The damage was first discovered on December 23, 1954, by which time the Eureka earthquake had also occurred. While the possible effects of the Eureka earthquake cannot be overlooked, it seems probable that most, if not all, of the damage occurred on December 16, 1954. Plant personnel state that the damaged feedwell was in good repair, and it appears that the type of damage is only explainable by water motion. However, the amplitude of motion must have been small, since the water level was at the overflow line; the overflow is continuous about the tank. Neglecting the effects of the tank's interior appurtenances, the computed fundamental natural period of the water is about 9 seconds." Steinbrugge and Moran, Oct. 1957, pp. 343-344.

CATEGORY II

DAMS

(Cases 54-75)


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
EARTHQUAKE ENGINEERING OFFICE
DAMS DAMAGED BY EARTHQUAKES
LEGEND
EARTHQUAKE EPICENTER
54 DAMAGE SITE AND CASE HISTORY NUMBER
PROSSER DAM 75
BOCA DAM 74
9-12-66
1-22-51
SCOTTS FLAT 68
4-18-06
10-23-55
TEMESCAL
PIEDMONT
61
SAN ANDREAS 57
OLD SAN ANDREAS 55
ST. MARYS 73
UPPER CRYSTAL SPRINGS 56
LAKE RANCH 62
STEPHENSON CREEK DAM 54
UPPER HOWELL 58
LOWER HOWELL 59
UNNAMED 60
HAIWEE 71
KERN RIVER POWER HOUSE 69
FAIRMONT 63
BUENA VISTA 70
7-21-52
4-10-47
10-22-16
SUMMIT 66
SHEFFIELD 64
6-29-25
DRY CANYON 72
CHATSWORTH 65
8-30-30
7-29-50
NORTH END 67

54. STEPHENSON CREEK DAM, Pineridge, Fresno County, 40 miles east of epicenter of Pineridge earthquake of July 13, 1894. Geologic Formation: Mesozoic-Paleozoic, metamorphic and granitic rocks. Fault unknown.

" . . . a recent earthquake (July 13?) injured the dam across Stephenson Creek. The joints in the masonry were damaged sufficiently to allow the water to pass through, but is believed that no permanent injury was done." Townley and Allen, p. 95.

The following eight Dam Cases concern structures damaged by the San Francisco earthquake of April 18, 1906, San Andreas fault.

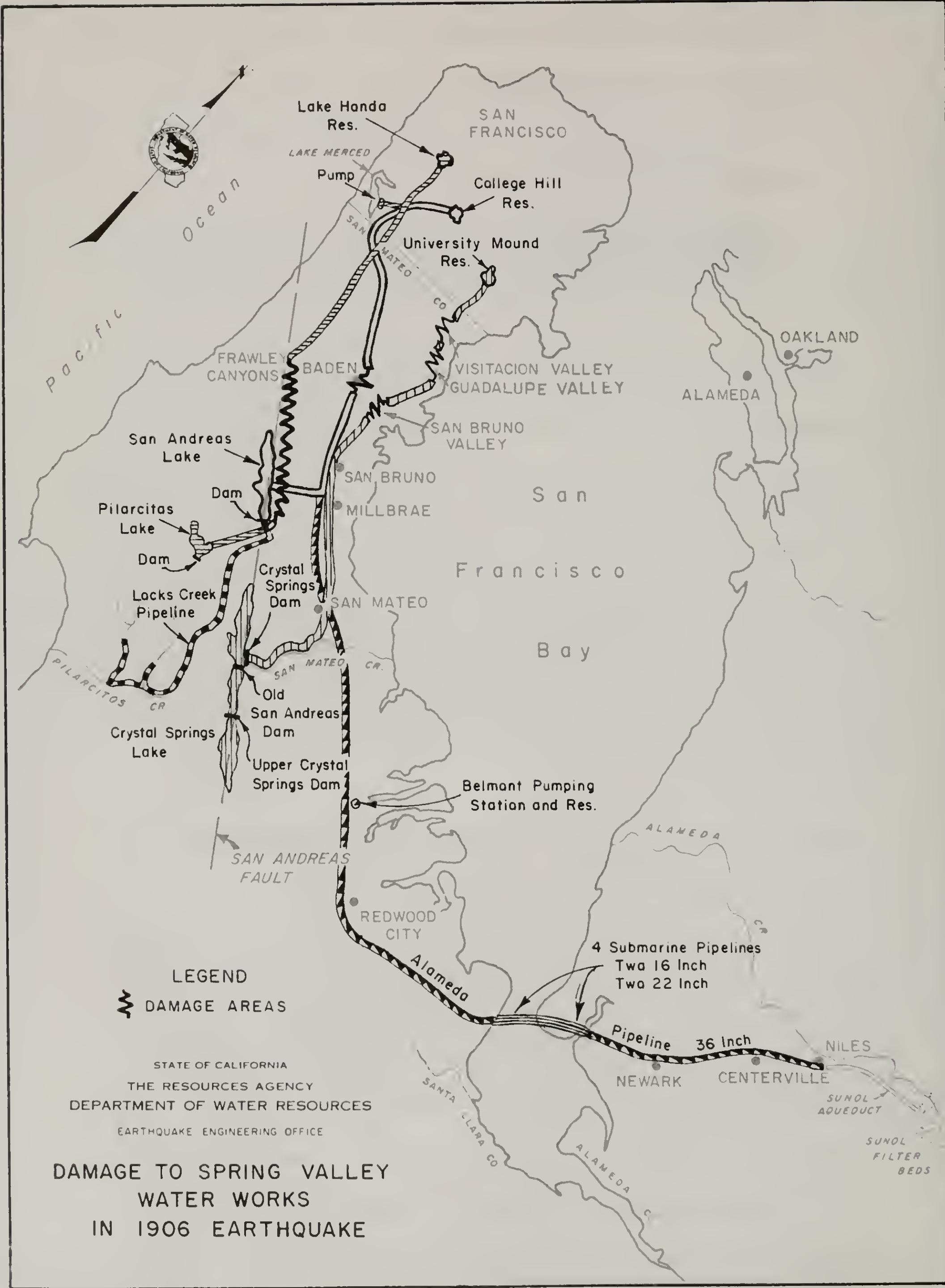
55. OLD SAN ANDREAS DAM, San Mateo County, 39 miles from epicenter. Geologic Formation: Franciscan (See Figure 6).

"At the time of the 1906 earthquake this earth dam was completely submerged [in Crystal Springs Lake], and when uncovered in 1931 it was found that an offset had occurred due to the fault movement. The fault passed through the dam at right angles to the crest and about 30 feet from the east spillway. The displacement along the fault was about 7 feet. The only visible damage to the dam was a crack 2 inches wide extending vertically up the brick face of the spillway." Ambraseys, p. 334.

56. UPPER CRYSTAL SPRINGS DAM, San Mateo County, 42 miles from epicenter. Geologic Formation: Franciscan and Santa Clara.

"Where the fault intersected the dam, the structure was dislocated and offset by about 8 feet. Longitudinal and transverse cracks appeared on the top of the dam, and some of the former, about 6 inches wide, were found to extend to a depth of 4 feet. The transverse cracks were less well defined and indicated a general distortion on each side of the fault line. The facts indicate also that in addition to the offset of the dam along the line of the fault, there was considerable compression in the direction normal to it [the dam]." Ambraseys, p. 333.

This dam was not in use as a water-impounding structure in 1906. A stabilizing pipeline through the dam connected Upper and Lower Crystal Springs Lakes (see Figure 6).



STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
EARTHQUAKE ENGINEERING OFFICE

DAMAGE TO SPRING VALLEY
WATER WORKS
IN 1906 EARTHQUAKE

57. SAN ANDREAS DAM, San Mateo County, 40 miles from epicenter.

Geologic Formation: Older alluvium and Franciscan. (See Figure 6.)

"The dam showed a severe distortion for a distance of more than 150 feet. Cracks were found to run parallel to the crest as well as in a transverse direction near the central abutment. ... a crack about 3 inches wide was found to extend longitudinally along the center line for the entire length of the dam." Ambraseys, p. 333.

58. UPPER HOWELL DAM, Santa Clara County, 71 miles from epicenter.

Geologic Formation: Franciscan.

"The fault runs through the reservoir crossing the dam near its east abutment. Cracks were formed at this point which extended through the body of the dam. There was also a longitudinal crack on top of the structure and considerable settlement of the upstream face." Ambraseys, p. 334.

59. LOWER HOWELL DAM, Santa Clara County, 71 miles from epicenter.

Geologic Formation: Franciscan.

"The fault ... intersects the Lower Howell Dam. A break 4 to 6 feet wide was formed through the body of the earth dam. A 10-inch outlet pipe in the area of the breach was broken by the fault and considerable damage seems to have been done to the dam from the water which escaped from this pipe .... It is noteworthy, however, that the fault at this point produced very little displacement and the seismic intensity was comparatively low." Ambraseys, p. 334.

60. UNNAMED DAM, near Howell Dams, Santa Clara County, 71 miles from epicenter. Geologic Formation: Franciscan.

"In the vicinity of the fault, near the Howell dams an unidentified composite earth-concrete dam was reported to have failed." Ambraseys, p. 334.

61. PIEDMONT DAM, Alameda County, 32 miles from epicenter.

Geologic Formation: Franciscan sandstone and shales.

"The dam was completed only a few months before the earthquake and had just been filled for the first time. The results of the earthquake were a few transverse and longitudinal cracks near one end of the dam, and a settlement in the centre of about 6 inches. A survey of the dam in 1930 showed a lateral deflection of the crest of 6 inches downstream and at the same time, it was estimated that the upstream concrete facing had settled 18 inches at crest level." Ambraseys, p. 335.

62. LAKE RANCH DAM, Congress Springs, Santa Clara County, 70 miles from epicenter. Geologic Formation: Franciscan sandstone and shales.

"The fault intersects another earth dam at about 2 miles south of the village of Congress Springs (west of Saratoga). This structure, the Lake Ranch dam, was built in 1877 and no description of the dam construction has been found. The 1906 fault movement did not intersect the main structure but crossed a small subsidiary dyke about 3 feet high. The water in the reservoir is said to have had run over this dyke, but no damage to the main structure was reported. A short distance to the northwest of the dam an elevated water tank was found undamaged . . . ." Ambraseys, p. 334.

"Starting at the upper reservoir about 2 miles south of Congress Springs, the fault trace was followed to its southern end near San Juan. From the upper reservoir, thru which the fault past, cracking the dams at each end, a fairly continuous series of cracks a few inches wide runs down the southwest side of Lyndon Creek . . . ." Lawson, p. 109.

63. FAIRMONT DAM, Los Angeles County, 27 miles from epicenter of Tejon Pass earthquake of October 22, 1916. Geologic Formation: Pleistocene non-marine. Unknown fault, possibly San Andreas.

"Although it is known that the Fiarmont dam was subjected to moderate shocks during the Tejon Pass and Santa Monica earthquakes and that it has settled near the left abutment, no details are available on its actual behavior. The owner of the dam does not consider that this structure had suffered any damage in the past." Ambraseys, p. 336.

64. SHEFFIELD DAM, 1.5 miles north of Santa Barbara, Santa Barbara County, 11 miles from epicenter of Santa Barbara earthquake of June

29, 1925. Geologic Formation: Alluvium and Eocene sandstone.

Fault unknown, offshore.

"The failure of the dam released 45 million gallons of water which flooded the lower part of Santa Barbara. There was about 20 feet of water in the reservoir when the earthquake occurred. At the first series of shocks the downstream portion of the central part of the dam moved out as though it were hinged at the left abutment. The great mass of the centre, about 300 feet in length, moved 100 feet downstream and much of the material was washed out by the escaping water. During its movement the central part of the dam remained practically intact and the plant growth on the downstream side of the displaced mass was later found to be undisturbed." Ambraseys, pp. 339-340.

65. CHATSWORTH DAM, Los Angeles County, 12 miles from epicenter of Santa Monica Bay earthquake of August 30, 1930. Geologic Formation: Marine sediments of Mesozoic age and river channel deposits.

Fault unknown, offshore.

"As a result of the shock, localized seepage developed through the embankment and a few hours after the shock the flow of water amounted to 8 gallons per minute and it was very turbid. . . . The dump fill on the upstream face of the dam slid into the reservoir, and a crack running over the entire length of the crest was opened. Smaller cracks on both upstream and downstream faces of the dam also opened up. The width of these cracks varied from 4 to 3 inches extending 5 to 12 feet into the body of the fill." Ambraseys, p. 341.

66. SUMMIT DAM, San Bernardino County, 65 miles from epicenter of Manix earthquake of Alril 10, 1947. Manix fault.

" . . . it was badly cracked by the earthquake shock." Ambraseys, p. 344.

67. NORTH END DAM, near Calipatria, Imperial County, 2 miles from epicenter of Calipatria earthquake of July 29, 1950. Geologic Formation: Alluvium. Fault unknown.

"The earthquake shock at the site was rather strong and old sheet piling on the spillway broke as the dam settled. The ground near the downstream toe [of the dam] cracked and nearby irrigation ditch embankments sloughed. In August 1st of the same year, a light shock of VI MM shook the dam again and ground fissures opened wider in the vicinity of the structure." Ambraseys, p. 345.

68. SCOTTS FLAT DAM, 5 miles east of Nevada City, Nevada County, 75 miles from epicenter of Lake Tahoe area, Nevada earthquake of January 22, 1951. Geologic Formation: Pliocene volcanic rock. Fault unknown.

"On the morning of the slide an employee of the Irrigation District had visited the dam. As he was leaving the area, he felt an earthquake shock and returned to the dam to find a slide 75 feet wide at the mid height of the slope and 60 feet wide at the downstream edge of the crest." Ambraseys refers to this dam as Yuba Dam. Ambraseys, p. 346.

69. KERN RIVER POWERHOUSE DAM, 10 miles northeast of Bakersfield, Kern County, 30 miles from epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Alluvium. White Wolf fault.

"At the Kern River powerhouse . . . at the bottom of Kern Canyon, boulders fell from both sides of the steep canyon wall, breaking water-gates, sections of the concrete dam, roofs, waterlines, and sewers." USC&GS, "U. S. Earthquakes", 1952, p. 18.

70. BUENA VISTA DAM, Buena Vista Lake, Kern County, 17 miles from epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Very soft alluvium. White Wolf fault.

"Along a length of 200 feet of the west portion of the dam, a settlement of over 2 feet was measured while over a length of 75 feet the settlement amounted 2-1/2 feet and an incipient slide area was revealed. The height of the structure at this point was only 8 feet. A continuous crack was found to run along the crest of the dam for over 2000 feet located between the railroad track and the upstream slope of the structure. In many places the track subsided 6 to 8 inches and moved horizontally." Ambraseys, p. 347.

71. SOUTH HAIWEE DAM, Inyo County, 96 miles from epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Alluvium and Tertiary volcanics. White Wolf fault.

"... numerous cracks about 6 feet deep along a 700 foot section of the crest where the dam has its maximum height. In some places the width of the cracks amounted to over 1 inch but in general the cracks were about 1/4" wide. These cracks were located near the upstream edge of the crest. The cracking formed an arcuate pattern starting at the upstream edge and extending across the crest and on to the downstream slope. Fissures also appeared running parallel to the face of the dam adjacent to the rip-rap. The general pattern of cracking indicated that a slide was about to start but had not moved more than a few inches. A series of levels run on the crest of the dam two weeks after the shock showed a settlement of the crest of 1 inch." Ambraseys, p. 348.

72. DRY CANYON DAM, Los Angeles County, 46 miles from epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: About 75' of Recent alluvium above sandstone bedrock. White Wolf fault.

"The seismic intensity ... produced several cracks running parallel to the axis of the dam along the entire crest and located approximately 5 feet from the downstream edge of the crest. These cracks had a maximum width of 2 inches and were found to extend a depth of 16 feet down to the hydraulic fill core. An incipient slide towards the lake displaced the fill by about 4 inches, while cracking occurred over the downstream third of the crest width. This movement also caused bulging of the concrete facing and parapet wall on the upstream slope. The dam settled nearly 3 inches and results from check surveys of the structure showed a horizontal displacement of about 2-1/2 inches towards the reservoir." Ambraseys, p. 347.

73. SAINT MARY'S DAM, near Moraga, Contra Costa County, 12 miles from epicenter of Concord earthquake of October 23, 1955. Geologic Formation: Alluvium. Probably Calaveras or Sunol fault.

" ... a crack 3 inches wide had developed along the upstream face of the dam. This crack was continuous from the right end of the dam to the spillway and again from the spillway to the left end of the dam .... Near the center of the dam ... the wall had undergone a displacement downstream of about 2 inches." Ambraseys, p. 351.

" ... two systems of cracks occurred in the fill of the main dam. Most notable was a single crack, 1-2 inches wide, at the surface, which was continuous from the spillway to the right abutment and located directly above the concrete core wall. The concrete core wall near the center of the dam shifted 1/2 inch in a downstream direction ...." USC&GS, "U. S. Earthquakes", 1955, p. 26.

74. BOCA DAM, Nevada County, about 5 miles south of epicenter of Truckee earthquake of September 12, 1966. Fault unknown.

Geologic Formation: Terrace deposits.

" ... two cracks in Boca Dam over the contacts between the fill and the vertical concrete side-walls of the spillway chute. During the Magnitude 4.5 aftershock at 3:53 p.m. on September 14, dust was observed puffing from one of the cracks. On September 15, the Bureau of Reclamation drilled holes down the cracks with a bucket auger. The cracks were shallow. The concrete spillway chute walls and wing walls were undamaged." California Water Resources, p. 4.

75. PROSSER DAM, about 3 miles east of Hobart Mills, Nevada County, about 5 miles south of epicenter of Truckee earthquake of September 12, 1966. Geologic Formation: Right abutment - Terrace underlain by glacio-fluvial deposits; left abutment - volcanic rock. Fault unknown.

"Inspection of the cracking along the crest of the dam indicated that most of the cracking was longitudinal .... The only transverse cracks that could be identified were two cracks adjacent to the spillway bridge structure .... These were normal cracks that would be expected to develop where fill comes up against a concrete structure ....

"All other cracks were longitudinal. The pattern was the following: about 5 feet upstream of the downstream break point of the crest there was a system of longitudinal cracking that could be traced ... from the left [east] abutment . . . to beyond the old creek-bed channel. There was a major crack system in which the cracks were anywhere from a 1/4 inch wide to maybe an inch wide. Upstream along the break point on the crest there was another crack system which was much tighter and which extended about as far to the west as the lower ones.

"There was in particular a major zone extending to the east of the spillway [which is at the east abutment] for about 100 feet from the centerline to the downstream break point . . . . [This zone] obviously had settled . . . . Other cracking, which stood out but which does not appear to be of any severity, was noted in the pervious backfill around both the spillway and outlet works stilling basins . . . ." Gordon, p. 3.

CATEGORY III

MAJOR WATER CONDUITS

(Cases 76-110)

CATEGORY III

MAJOR WATER CONDUITS

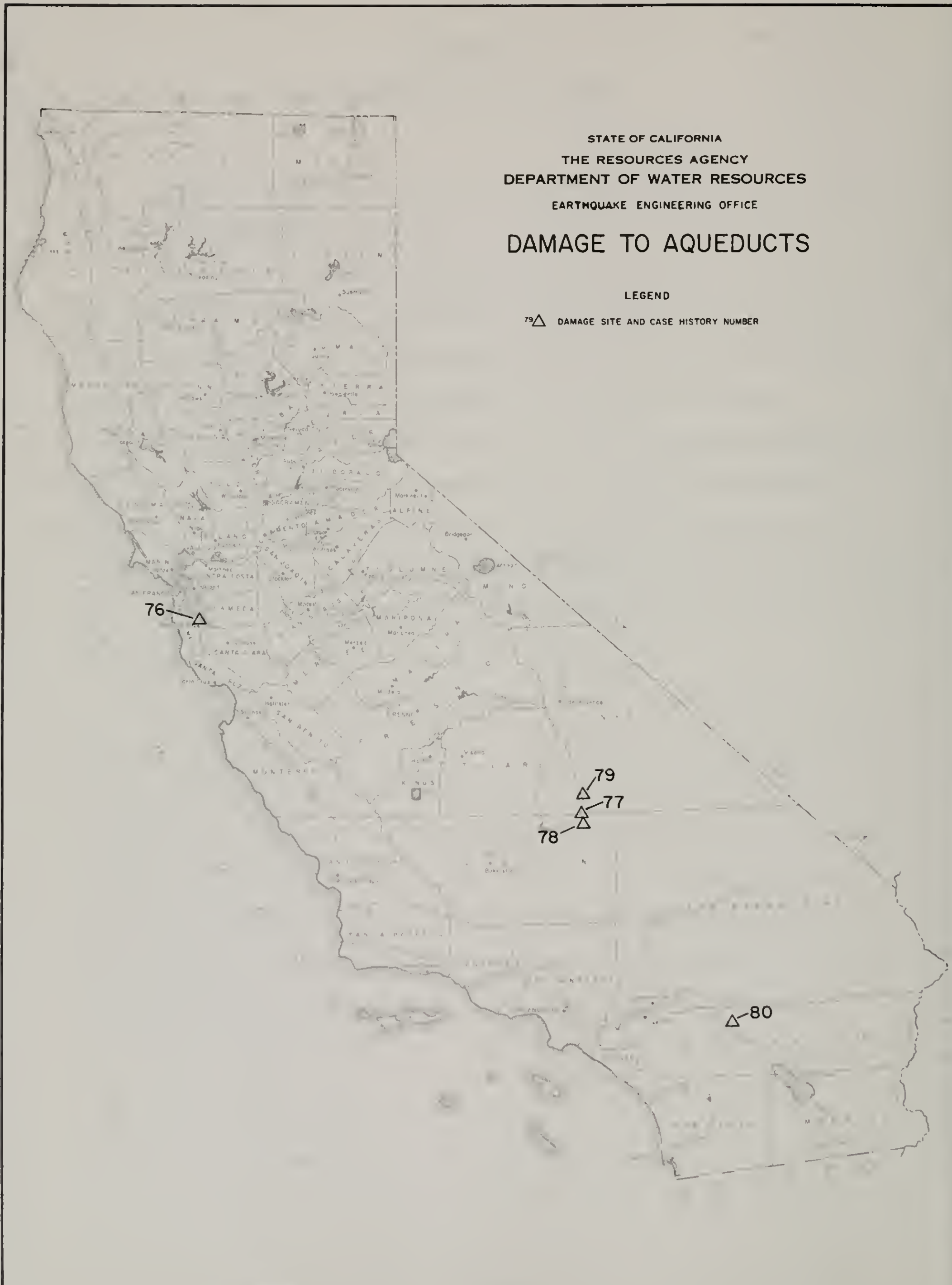
The cases listed here are major conduits serving whole communities or large agricultural regions.

The reader's attention is drawn here to the distinction we are making between aqueducts and pipelines within Category III. Although both have similar structural features, aqueducts are commonly differentiated by their longer length, compared to the length of pipelines. It should be noted that the great distance traversed by aqueducts could mean that they would be subjected to many secondary effects of earthquakes. Reaches of an aqueduct that are close to an epicenter would normally be subjected to highest damage intensities but other reaches of the same aqueduct, even those many miles from an epicenter, could be breached by secondary effects like landslides, slumping, and rock falls.

Distribution conduits within urban and semi-urban areas are listed in Category IV, Distribution Lines; and distribution systems within agricultural regions are listed in Category VI, Irrigation Pipes and Standpipes. The major subject of Category III is delivery conduits, rather than distribution conduits. The careful reader would do well, however, to scan both Categories III and IV if he is interested in any aspect of urban-bound or in-urban water conduits, and Categories III and VI if he is interested in any aspect of farm-bound or on-farm water conduits.

AQUEDUCTS

(Cases 76-80)


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
EARTHQUAKE ENGINEERING OFFICE
DAMAGE TO AQUEDUCTS
LEGEND
79 DAMAGE SITE AND CASE HISTORY NUMBER
76
77
78
79
80

76. ALAMEDA PIPELINE, 36", Niles to San Mateo, Alameda and San Mateo Counties, about 58 miles southeast of epicenter of San Francisco earthquake of April 18, 1906 (see Figure 6). Geologic Formation: Undifferentiated Cretaceous, Miocene, and Pliocene sandstone and shale beneath Sunol Aqueduct. Unconsolidated, saturated alluvium, marshland, and bay mud beneath Alameda pipeline and submarine pipes. San Andreas fault.

"Neither the Sunol filter beds, on the Alameda Creek System, nor the Sunol Aqueduct and 36-inch pipe line, on the east side of the bay, nor the four submarine pipe lines were injured; only a slip-joint, on one of the two 16-inch shore connections, was pulled apart several inches, on the east side of the bay; and two 8-inch blow-offs, at the west shore connection of one of the 16-inch pipes, were broken off by the shock . . . These minor injuries were quickly repaired, and Alameda Creek water has since been crossing under the Bay of San Francisco and pumped at Belmont Pumping Station. We now receive from there about fourteen and a half million gallons a day, no more being required from there at present.

"The Alameda pipe line, on the east side of the Bay of San Francisco, gives one of the best illustrations of the suddenness of the earthquake shocks. The ... pipes bring water from the Sunol filter beds through an aqueduct, consisting of concrete tunnels and heavy redwood flume, along Niles Canon, to a point near Niles. Here the 36-inch pipe starts, descending gradually for about eight miles, in a south-westerly direction, through Centerville and Newark, to a bridge passing over the Newark marsh for fully 9,000 feet, to a navigable slough, which is about 30 feet deep and 300 feet wide. Through this slough four submarine pipes (two 16-inch and two 22-inch) run--the former laid in 1887 and the latter in 1901. These submarine pipes are connected at both ends to the 36-inch wrought-iron pipe, each submarine pipe being controlled by two gates. At the westerly side of the above slough those four submarine pipes are connected together, each one with a shut-off gate and each one with a blow-off. The 36-inch pipe then proceeds southwesterly, on the same kind of additional trestle, for over 7,000 feet, to Dumbarton Point, which is located on the easterly shore of the narrow neck of the Bay of San Francisco. At this point the 36-inch pipe again divides into two 16-inch and two 22-inch ball-joint submarine pipes, each one with gates and blow-offs, which pipes run parallel to each other and underneath the bay--the two 16-inch being to the south and 90 feet from the 22-inch pipes. These pipes again join at the San Mateo shore, at Ravenswood into one 36-inch pipe, with exactly the same construction as at the above described slough; and thereafter the 36-inch goes southwestwardly through the marsh on a pile trestle for nearly 2,000 feet, and from there, for fully nine miles, in a ditch underground, through Menlo Park and Redwood City to Belmont Pumping Station, where the same discharges the water into a reservoir. From this reservoir the water is pumped into a standpipe and runs to San Francisco.

"At the time when we built the first submarine lines and the 36-inch pipe, during 1887 and 1888, fearing that the watchman might shut the submarine gates down too suddenly, with a strong current of water flowing from Niles tank towards the submarine pipes, I put on an automatic safety valve at the east side of the slough and the bay, in order to lessen or avoid all shock danger to the eight or nine miles of 36-inch pipe that might be caused by the sudden shutting off of the submarine pipe gates. These automatic safety valves had a number of large rubber disks, which were regulated carefully to open automatically at the slightest shocks above the normal pressure. East of this shock valve I had a tall air chamber, where any air in the 36-inch pipe would collect and could be let out. I knew that the bottom of the bay and the bottom of the slough were not perfectly level, and that there might be high places in the pipe where any air getting into the same might accumulate. I therefore put up these air chambers to prevent any air from entering the submarine pipes. Eastwardly from the air chamber and close to the same was placed a vacuum valve, on top of the 36-inch pipe, which would open instantly and automatically, the moment the pressure was taken off the pipe by a break, or whenever it was emptied, for repair purposes, by opening a blow-off gate.

"At the time of the earthquake, on the morning of April 18, the water was coming westwardly, at the rate of fully 16 million gallons daily, through the 36-inch pipe, having a mean velocity of fully 3-1/2 feet per second. The water was flowing ... to the reservoir at Belmont. When the shock came the vacuum valve instantly dropped and let air into the pipe, showing that at that point east of San Francisco Bay the first shock observed came in a southwestwardly direction. It further showed that this shock was much more rapid than the velocity with which the water flowed in the same direction. The vacuum valve fell down, and when the reaction, shock came, from southwest to northwest, the valve closed suddenly, throwing up a stream of water into the air while closing. At the same instant the safety valve nearby opened automatically, closing when the shock was passed, and thus by discharging quite a quantity of water relieved the long 36-inch pipe to the east from the effect of the shock, which might have been disastrous." Schussler, pp. 32-33.

77. LOS ANGELES AQUEDUCT, Sand Canyon, Inyo County, 5 miles from epicenter of Walker Pass earthquake of March 15, 1946. Geologic Formation: Probably alluvial fan deposit. Fault unknown, possibly Sierra Nevada fault zone. Intensity IV.

"In Sand Canyon, a few miles east of the epicenter, large boulders were rolled down onto the line of the Los Angeles Aqueduct. Part of the roof and side wall were torn off by these boulders; this damage was repaired in about two days. Minor cracks were produced in the ground and in concrete along the aqueduct." USC&GS, "U. S. Earthquakes", 1946, p. 9.

78. LOS ANGELES AQUEDUCT, Kern County, 5 miles from epicenter of Walker Pass earthquake of March 15, 1946. Geologic Formation: Probably alluvial fan deposits. Fault unknown, possibly Sierra Nevada fault zone.

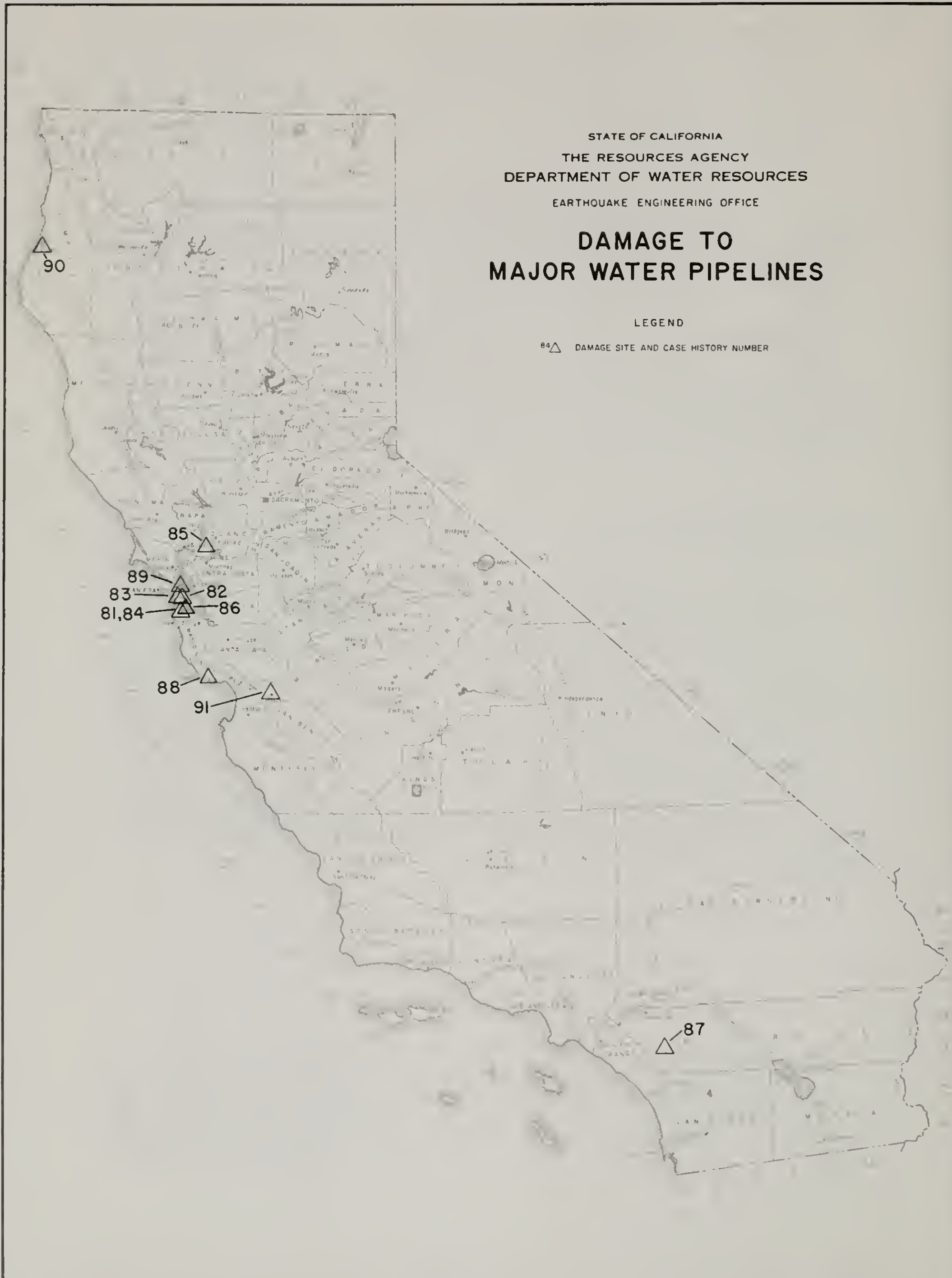
"... about 2 miles north of Walker's Pass ... on inspecting aqueduct ... there were indications of new movement, with cracks running N-S." The aqueduct runs north-south in this area. USC&GS, "Abstracts", MSA-49, p. 19.

79. LOS ANGELES AQUEDUCT, Little Lake, Inyo County, 20 miles from epicenter of Walker Pass earthquake of March 15, 1946, Intensity VI. Geologic Formation: Probably alluvial fan deposits. Fault unknown, possibly Sierra Nevada fault zone.

"Aqueduct showed many cracks." USC&GS, "U. S. Earthquakes", 1946, p. 11.

80. COLORADO RIVER AQUEDUCT, Little San Bernardino Mountains (about 11 miles northeast of Palm Springs), Riverside County, at epicenter of Desert Hot Springs earthquake of December 4, 1948, Intensity VII. Geologic Formation: Very soft alluvium. Fault unknown, possibly Mission Creek fault.

"At the aqueduct line in the San Bernardinos slumpings of gravel sidings and cracks over gravel fills were noted." USC&GS, "U. S. Earthquakes", 1948, p. 20.


STATE OF CALIFORNIA
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84 DAMAGE SITE AND CASE HISTORY NUMBER
90
85
89
83
82
81,84
86
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PIPELINES

(Cases 81-91)

In 1906, as now, San Francisco obtained much of its water from a system of reservoirs and pipelines in San Mateo County. Figure 6 shows the three integral parts of the system in existence at the time of the San Francisco earthquake of April 18, 1906, along the San Andreas fault. Each of the three parts consisted in turn of three smaller segments--a lake draining a nearby natural watershed in San Mateo County, a pipeline to the city, and a terminal in-city reservoir. Thus, the Pilarcitos part consisted of Pilarcitos Lake, Pilarcitos Pipeline, and Lake Honda Reservoir. The San Andreas part terminated in College Hill Reservoir. And the Crystal Springs triplex ended at University Mound Reservoir.

81. PILARCITOS PIPELINE, 30", Pilarcitos Lake to Lake Honda Reservoir, San Mateo County, about 40 miles southeast of epicenter of San Francisco earthquake. Geologic Formation: Predominately slightly compacted sand, silt and clay (Merced formation, Pliocene age), and Pleistocene marine terrace deposits consisting of sand and clay. Minor amount of Franciscan formation (bedrock) and alluvium.

> "The greatest damage to any of the transmission lines [in the San Francisco water supply system] was to the 30-inch Pilarcitos pipe .... This line was practically destroyed for a distance of 6 miles from the San Andreas dam to Frawley Gulch, in which distance its location almost coincided with the fault line, crossing and re-recrossing it at several points. More than 19 ruptures were counted in this distance, the pipe in some places being pulled apart as much as 5 or 6 feet ... and in others telescoped for nearly as great a length. . . . North of Frawley Gulch the damage was much less severe ...." Eckart, pp. 190, 192.

"About 2 miles from the upper end of San Andreas Lake the fault encounters the 30-inch, laminated, wrought-iron pipe of the Spring Valley Water Company, which prior to the earthquake conveyed the water from Pilarcitos Lake to San Francisco. The metal of the pipe is about 0. 1875 inch thick and coated with asphaltum. The pipe is buried in the soil at a depth of 3 to 4 feet. The point of intersection is near Small Frawley Canyon. Here the course of the pipe swings from a northwesterly to a more northerly course, and the fault consequently intersects it at an acute angle. At the point of intersection, the pipe was obliquely sheared apart and telescoped upon itself, effecting a shortening of about 6 feet. The amount of the transverse offset involved in the shear was about half the diameter of the pipe. The portion north of the break was moved east and telescoped southerly. For 0. 875 mile southeast of this point, the path of the fault lay on the northeast side of the pipe and nearly parallel to it, but a short distance away. About 220 yards southeast of the intersection, where the pipe, buried a few feet below the surface, ascends a rising slope, the pipe had completely collapsed for a distance of several yards, due doubtless to the establishment of a partial vacuum within the pipe at the time of the shock, owing either to the leakage below, or the propulsion of the water induced by the shock . . . .

"At a point about a mile from the upper end of San Andreas Lake, the fault intersects a bend in the pipe at two places, and here again the pipe was telescoped. . . . The conditions at one of these intersections are thus described by Mr. Robert Anderson:

" 'The pipe makes an angle of about 15° with the fault-trace, the end of the pipe on the north side of the fault running that much nearer the north. The ends of the pipe on opposite sides of the fracture were therefore thrust into each other. The furrow was at this place divided into several smaller ones, the disturbed zone covering an area of considerable width. The pipe was broken in three places within 100 feet. In one place it was telescoped 58 inches, ... in another 17 inches, and in a third, the one farthest north, 41 inches.'

"Near the head of the lake, the pipe was again intersected by the fault, with results described by Mr. Anderson as follows:

" 'The pipe line runs almost parallel with the fracture, but slightly more to the west at this point, so that the acute angles made by the ends of the pipe with the furrow were in this case on opposite sides of the furrow to those in the two previous instances. . . . The movement was in the same direction as before, therefore a pulling apart of the pipe took place instead of a compression. There occurred two breaks in the pipe ... the main one at the crossing of the fault, and the other 150 yards away on the north-east side of the fault, but very near it, the pipe being almost parallel with it. At the main break, the pipe was pulled apart 59 inches, and at the other one 21.5 inches, making a total displacement of 6.666 feet.... ' " Lawson, Vol. 1, pp. 95-97.

" . . . Half a mile below the dam, the fault again crost the Pilarcitos pipe. A note by Mr. Anderson ... is as follows:

" 'It is a 2-foot pipe made of iron 1 inch thick. The fault broke it at an upward bend. An elbow at the bend was crusht by the compression and thrown down, while the two remaining ends were brought about 22 inches nearer together. At the same time they were faulted past each other a distance of 20 inches .... ' " Lawson, Vol. 1, p. 100.

"The earthquake, having torn a crack or fault, several miles in length, along and across the upper or 30-inch Pilarcitos pipe line, had either completely destroyed it, tearing and telescoping it in a number of places, or at least had so injured it, that it would be many months, to say the least, before it could be put into service again, if at all. At the large Frawley Canon the Pilarcitos 30-inch pipe was thrown some 60 feet to one side. It was torn in two for over 100 feet and thrown bodily; in two parts, and about at right angles to its original line; so that, no matter what construction could have been put there, it could not have been maintained there, owing to the evidently great violence of the shock. Other portions of the Pilarcitos 30-inch pipe were destroyed by the earthquake, pulling the pipe apart in many places, while, at other places, it was telescoped ....

"The southern, or San Mateo County, portion of the 30-inch Pilarcites pipe line being destroyed, but the northerly portion, near San Francisco, being but slightly damaged, the latter was immediately repaired, and, by starting the Lake Merced Pumping Station to pumping from Lake Merced Reservoir, in San Francisco County, where there was over a thousand million gallons of water on hand at the time of the earthquake, we were able, at nine o'clock on the evening of April 18, or sixteen hours after the earthquake, to send a stream of between six and seven million gallons of water per twenty-four hours past Lake Honda Reservoir ... into and through the Western Addition. This regular daily supply, added to the 31,000,000 gallons stored in Lake Honda Reservoir, at 7 A.M. of April 18, largely assisted in keeping a water supply passing through the Western Addition during the entire progress of the fire and thereafter." Schussler, pp. 29-30.

82. SAN ANDREAS PIPELINE, 37", San Andreas Lake to College Hill Reservoir, San Mateo County, about 40 miles southeast of epicenter of San Francisco earthquake. Geologic Formation: Franciscan formation; Merced formation, slightly compacted sand, silt, and clay; Pleistocene marine terrace deposits, sand and clay; and unconsolidated Quarternary alluvium.

"The San Andreas pipe line ... was badly ruptured at only one point, near Baden, where it crossed a piece of marsh on trestle; some minor damage was suffered at other points. Temporary repairs to this line were completed and delivery of water resumed within 62 hours." Eckart, p. 193.

"A 54 inch steel pipe has since been constructed to provide gravity flow from the San Andreas reservoir to Lake Honda .... Particular attention was given to avoiding the fault line in laying out the route of the 54-inch pipe, and the route selected is as far removed as is practicable from the older San Andreas line, which continues in service, in large measure as an alternate line." Eckart, p. 197.

83. CRYSTAL SPRINGS PIPELINE, 44", Crystal Springs Lake to University Mound Reservoir, San Mateo County, about 40 miles southeast of epicenter of San Francisco earthquake. Geologic Formation: Small portion of pipeline in weathered Franciscan formation, and sand, silt, and clay of the Merced formation. Major portion of the alignment, particularly where damage occurred in San Bruno, Guadaloupe, and Visitacion Valleys, underlain by unconsolidated, water-saturated, fine-grained bay sediments--"swamp".

"The 44-inch Crystal Springs pipe line ... was badly ruptured in several places, in ditch, between the dam and Millbrae, and also where it crossed through marshes on trestle at San Bruno, Guadaloupe, and Visitacion valleys .... In the marshes the pipes were thrown completely off the trestles, which were demolished down to the pipe and cap foundation. A total length of 2850 feet of line was thus affected." Eckart, pp. 192-193.

"The 44-inch Cyrstal Springs pipe line was badly ruptured in seven places between the Crystal Springs dam and Millbrae Station, and also where, on a substantial pipe trestle, it had to cross the three swamps or marshes in the three respective valleys, viz: the San Bruno, Guadaloupe and Visitacion Valleys. Those portions of these long pipe crossings that crossed over the softer portion of these marshes in an almost northerly direction, having been subjected by the earthquake to a number of violent shakings from southwest to northeast and vice versa, were completely demolished down to the pipe and cap foundation, which latter, in almost every case, were left uninjured. In some cases, where the 44-inch pipe had been thrown straight up in the air first, it had, in its downward course, not only destroyed the strong superstructure but had, in several instances, crushed the heavy timer caps bolted down to the tops of the piles.

"In no case was one of the piles injured." Schussler, p. 29.

"One feature of the destruction of the bridge and pipe across the San Bruno marsh was that some of the pipe was thrown to the west and some to the east as much as four or five feet.

"Most of the broken 44-inch pipe was ruptured in the round seams and in lengths from thirty to fifty feet. There was one piece, though, about 800 feet long, of this 44-inch pipe, which was mostly lying on the west side, but so curved that it made quite a snake-like appearance, and that pipe we examined carefully, as to the strain received by the round seams, and we did not find even the slightest appearance of a strain in the rivet seam or a crack in the asphaltum coating. I attribute this remarkable flexibility of this 44-inch pipe to the high elastic limit and the great degree of ductility of the laminated iron used in its construction. We re-established, by careful survey, the straight line and grade of the pipe, and found that neither the original straight line of the piles nor the grade of their tops had been disturbed by the earthquake. Meanwhile, with a lot of jack-screws, we worked the long 800-foot piece of pipe carefully, until the survey showed it was straight in line and grade and in place, on the newly completed trestle." Schussler, p. 31.

"The following are extracts from the report of Professor Derleth [Charles Derleth, Jr.], which appeared in the Engineering News of May 17, 1906, published in New York:

***

" 'The Crystal Springs conduit at the time of writing is not supplying water to the City. It is mainly a 44-inch laminated wrought-iron pipe, about 1/4 inch in thickness with riveted joints, rivits 1/2-inch in diameter. This pipe is ruptured in a number of places, but mainly where it crosses the marshes. The worst destruction has occurred in a distance of about 1, 600 feet, where the pipe crosses a marsh between San Bruno and South San Francisco. In this place the pipe rests upon a wooden floor, supported by pile bents. These piles on the average penetrate the mud to a depth of about 40 feet. It appears to the writer that this marsh shook like a bowl of jelly, the vibrations being mainly in a south southeasterly direction, or nearly at right angles to the length of the trestle. It appears that during the vibrations of the earthquake the trestle moved with mother earth, the pipe due to its inertia tending to remain quiet. As a result the pipe was alternately thrown from one side to the other of the trestle floor and its box covering was generally smashed. The pipe broke along transverse circular joints, sometimes by tension, sometimes by crushing. On May 2, when the writer visited this pipe line, the work of repair had been already considerably carried out, and within a surprisingly short time the city will be receiving water through this large conduit. ' " Schussler, pp. 39, 41.

Repair Time

"I at once determined that it would take about two weeks (provided all repair pieces were at hand and the necessary large amount of heavy lumber was at once available which would be required for the rebuilding of a total (in the three valleys) of about three thousand feet of bridge and relaying and reriveting thereon the large 44-inch wrought-iron pipe. This total distance of destroyed bridges and broken pipes, in the three valleys, afterwards turned out to be 2, 850 feet." Schussler, p. 29.

" . . . From Crystal Springs a new ... [60-inch] line ... is ... being constructed .... Here, again, as far as is practicable, the new line has been kept away from the old lines and from the marshes where trouble was experienced in 1906. Provision is made for cross connection of this new line with the 54-inch San Andreas line, and also with the old 44-inch Crystal Springs line, in order to give flexibility in operation by permitting elimination of certain parts of the lines should rupture occur .... The old Crystal Springs line will be retained, providing a dual transmission system from Crystal Springs to San Francisco." Eckart, pp. 197-198.

84. LOCKS CREEK PIPELINE, 44", northwest of Crystal Springs Lake, San Mateo County, about 40 miles southeast of epicenter of San Francisco earthquake of April 18, 1906. Schussler (p. 32) describes this as "one of the main feeders of the San Andreas Reservoir." (See Figure 6 .) Geologic Formation: Weathered Franciscan formation consisting of slightly compacted sand, silt, and clay. Pipe buried under several feet of soil. San Andreas fault.

" ... Mr. Anderson writes: 'Just above the northern end of Crystal Springs Lake, a 44-inch water main made of iron 0.125 inch thick runs up the hill from the lake valley in a direction about N. 28°E. This line is buried all the way under several feet of soil. The fault crosses it at the base of the hill, in its N. 37°W. course, thus making an acute angle of 65° with the pipe line. At the intersection of the fault and the pipe line, the heavy rivets of the pipe were torn out all the way around at a section joint and the two sections were jammed into one another a distance of 4 feet 4 inches .... There was no lateral displacement, the whole movement having been taken up by the telescoping, but there was a bending of the pipes at the point of the break, ... this same pipe was broken on the northeast side of the fault about 400 feet further up the hill. The break occurred at the junction of 2 sections, the rivets having been sheared off and part of the rim torn away at the rivet holes. The ends were pulled apart 3.375 inches ....' " Lawson, pp. 100-101.

85. WATER PIPELINE, Benicia, Solano County, 45 miles from epicenter of San Francisco earthquake of April 18, 1906. Geologic Formation: Alluvium. San Andreas fault.

"The water pipe for the city was temporarily broken." Lawson, p. 214.

86. BEAR GULCH COMPANY WATER PIPELINE, 3-1/2 miles west of Stanford, San Mateo County, 55 miles from epicenter of San Francisco earthquake of April 18, 1906. Geologic Formation: Alluvium over-

lying Tertiary marine sediments. San Andreas fault.

"Waterpipes along the road leading from the reservoir [of the Bear Gulch Company] toward Menlo Park had been pulled apart." Lawson, p. 259.

87. PIPELINE, Santa Anita Mountains, Riverside County, distance from epicenter of San Bernardino earthquake of September 19, 1907, unknown. Geologic Formation: Alluvium. Fault unknown.

"... the pipeline of the Pacific Light and Power Company in the Santa Anita Mountains was broken." Townley and Allen, p. 146.

88. SANTA CRUZ PIPELINE, Santa Cruz County, distance from epicenter of Santa Cruz earthquake of December 30, 1934, unknown. Fault unknown.

"Two light earthquakes struck ... breaking the big Santa Cruz water supply pipe line near the Antonetti artichoke ranch." UC, Clipping from Santa Cruz Sentinel, January 1, 1935.

89. WATER PIPELINE, Golden Gate Park, San Francisco County, 40 miles from epicenter of San Jose earthquake of June 22, 1949. Geologic Formation: Sand dunes. Fault unknown.

"The light tremblor broke a thirty-six inch water main under the Strawberry Hill reservoir .... The resulting breakage undermined a portion of the hill beneath the reservoir, breaching its walls and producing an eighty-six foot waterfall. ... The accident emptied the reservoir of 800,000 gallons of water and left park buildings without fire protection for nearly 36 hours. Repairs to the reservoir will cost $40,000 to $50,000 .... [About $25,000 additional] will be used to dredge out an estimated 15,000 cubic yards of sand washed into the lake." UC, Clipping from San Francisco Examiner, June 24, 1949.

90. PIPELINE, 36" wood-stave and 30" steel pipe, main water supply for Eureka, Humboldt County, from Sweasey Dam 10 miles east of Eureka, approximately 8 to 10 miles west of epicenter of Eureka

earthquake of December 21, 1954. Geologic Formation: Unconsolidated alluvium and marshland, saturated. Fault Unknown.

Three breaks occurred in alluvium and marsh areas as follows: "... wood-stave pipe [36-inch] pulled partly out of a concrete block; this location was a transition section between wood-stave (above ground) to steel pipe (below ground) to allow roadway passage.

"The central break, at Gannon Slough, occurred in a marsh area where the steel pipe [30-inch] went under a creek ....

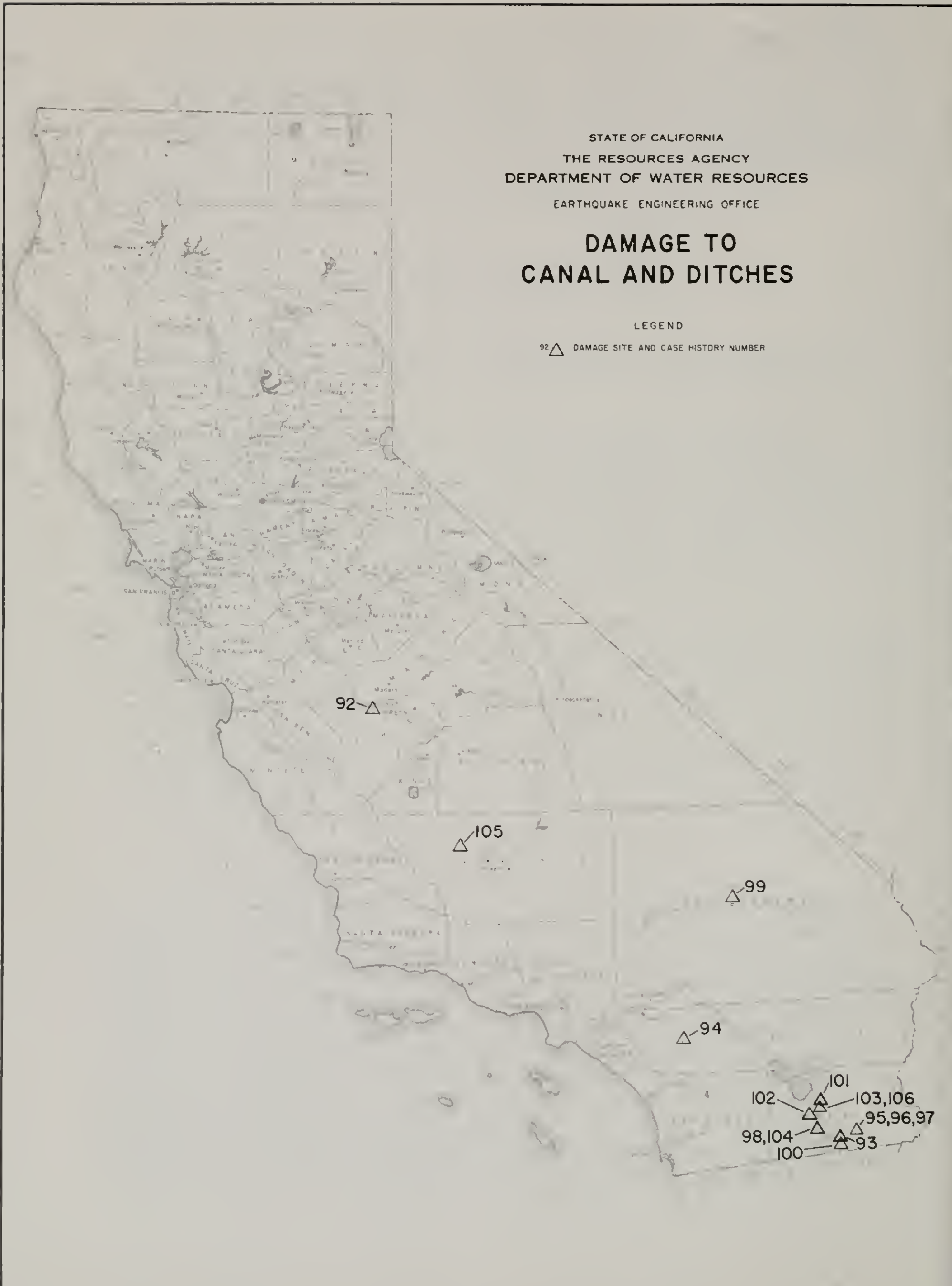
"Comparable damage occurred in a similar situation at the third rupture, [30-inch steel pipe] .... In the marsh areas the steel pipe was encased in concrete, laid underground, and supported on piling."

Repair time: "Repair to this last break [Freshwater Slough] was particularly difficult and finally required laying pipe on a new bridge crossing the creek; ... and required that the pipeline be shut down for forty-eight hours ...." No information available on repair time for Korblex and Gannon Slough breaks. Cost of repair: "Cost of repair was about $25,000." No estimate available for other breaks. Steinbrugge and Moran, April 1957, pp. 137-138.

91. PIPELINE, Old Hollister line, Hollister-Cienege district, San Benito County, approximately 8 to 10 miles north of epicenter of Hollister earthquake of April 8, 1961, Intensity VII. Geologic Formation: Unconsolidated alluvium, older Pleistocene alluvium and undifferentiated Pliocene sediments. San Andreas fault.

"The old Hollister water line, bringing water from the Cienega Valley to Hollister, was ruptured at two places in the area to the east of the W. A. Taylor Winery. One break occurred in 10-inch cast-iron pipe about 24 inches below grade. Pacific Fire Rating Bureau investigators reported this break was examined when repairs were made and that the cracks suggested the line had been cracked prior to the earthquake and that water surging through the lines may have caused the final break. They also reported the second break occurred in 10-inch rivited pipe which was very badly corroded and that the 'break' was actually corroded holes in the 1/8-inch-thick pipe. On April 14, the Hollister City Manager reported additional earthquake damage was being uncovered daily on the water line bringing Cienega Valley water to Hollister ....

Repair time: "The two major breaks [in the old Hollister line] had been repaired [by April 14, a period of 6 days] but water was still not reaching the Sally Flat Reservoir from the Cienega wells. It was reported Hollister would be supplied with water from the two municipal wells until the 6-mile-long, 10-inch line could be restored." USC&GS, MSA-110, p. 8.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CANAL AND DITCHES
LEGEND
92 △ DAMAGE SITE AND CASE HISTORY NUMBER
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103,106
95,96,97
98,104
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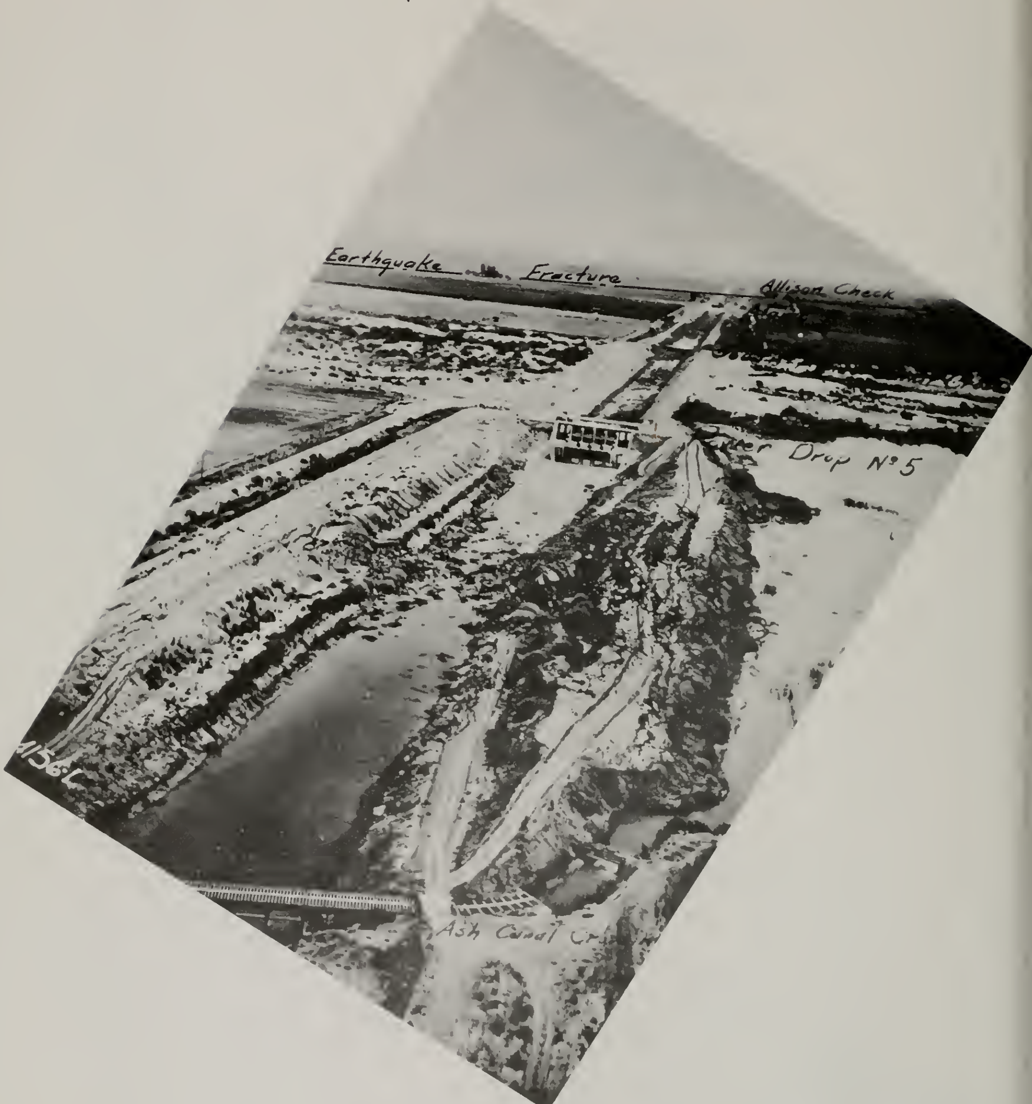
100

CANALS AND DITCHES

(Cases 92-106)

CANALS AND DITCHES

(Cases 92-106)



Aerial view of the All-American Canal looking eastward, showing lake on the south side which served as a desilting basin for the Ash Canal.
- Taken May 23, 1940, by Imperial Irrigation District -

92. CANALS, near Mendota, Fresno County, about 160 miles southeast of epicenter of San Francisco earthquake of April 18, 1906. Geologic Formation: Alluvium. San Andreas fault.

At a ranch-house about 15 miles southeast of Mendota, "... Milk and water were thrown from their receptacles, and considerable damage was done by the breaking out of the head gates in the canals." Lawson, p. 318.

93. DITCHES, Heber and Calexico, Imperial County, at epicenter, El Centro - Calexico earthquake of June 22, 1915, Intensity VIII. Geologic Formation: Alluvium. Fault unknown, possibly southeast extension of San Jacinto fault.

"Fortunately, none of the ditches or intakes of the extensive irrigation system [in Heber and Calexico] was broken, although a few cracks were formed parallel to the levees, due to the lurching of the soil." Beal, September 1915. p. 143.

94. CONCRETE CANALS, San Jacinto and Hemet, Riverside County, approximately 2 to 10 miles from epicenter of San Jacinto earthquake of April 21, 1918. Geologic Formation: Unconsolidated alluvium, saturated. San Jacinto fault.

"Concrete irrigation canals were broken at a number of places near San Jacinto and Hemet." Townley, p. 49.

95. ALL AMERICAN CANAL, Imperial County, most damage occurred within 10 miles of epicenter of Imperial Valley earthquake of May 18, 1940. Geologic Formation: Unconsolidated alluvium, saturated, thick section. Imperial fault.

"At the international boundary the All-Americal Canal was approaching completion, but no water had yet been admitted. The earth banks were badly shattered in many places; there was large stepwise lurching, and slumping down into the excavations. The embankments were broad, with sufficient roadway for trucks; they were intersected and offset by the fault trace; the north-south offset on the northern embankment amounted to 14 feet 10 inches." Richter, C. F., 1958.

" . . . Concrete structures were examined; and the only damage found was at the Yule No. 3 Turnout, Drop No. 5, New Briar Flume and Bridge Crossing, and the Temporary Timber Flume for the Ash Canal.

"The fracture which marks the shift of the earth's surface crossed the Yule No. 3 Turnout between the headwall and outlet. The outlet transition structure was moved northward about 2.5 feet; the gate structure was moved westward about 6.5 feet and northward about 2.5 feet....

"At Drop No. 5, the gate structure and power house were found to have settled 0.12' in relation to adjacent Bench Marks, as yet unchecked; in general, all of the structures resting on piles have settled from 0.09' to 0.12'. Movement in the vertical joint on the right side of the inlet transition immediately upstream from the gate structure left the upstream side of the joint 2-1/2 inches lower than the downstream side . . . [At]the bottom of the joint, concrete was broken from the downstream side of the joint .... The rubber water stop is exposed, but does not appear to be damaged. On the continuation of this joint across the bottom, the upstream side has settled 0.37' in the right, 0.20' center, and 0.33' on the left, below the downstream side. Several inches of earth cover this concrete floor, and it has not yet been determined why the joint at the top of the wall shows less displacement than the joint on the floor. All joints upstream from the gate structure show some permanent movement . . . . At the joint between the canal paving and inlet transition on the left side ... settlement of the backfill allowed the upstream slab to move outward. This movement varied from nothing at the base of the slope to 1-1/2 inches at the top. Swinging of the counterweights against the adjacent walls, spalled concrete from the corners. There was no change in alignment of the structure.

" At the New Briar flume and bridge, the superstructure was moved laterally, causing some chipping of concrete at the corners and shifting the roller supports 1 inch eastward at the north end (right bank of All-American Canal) and a similar distance but in the opposite direction at the south end. The screws holding the keeper lugs failed on the west side of the bearing rollers at the right abutment and on the east side of the rollers at the left abutment. No inspection has yet been made of the water seals and a slight leak is indicated at the upstream (north) end. Some settlement of the piers or abutments is indicated, but no check has yet been made.

"At the Ash Temporary Flume, the two north bents were shifted, but repairs were quickly made.

"From Imperial Dam to the Araz Overchute, there was no indication of disturbance at any of the structures. At Pilot Knob Check and Wasteway, small cracks between concrete and backfill appeared. At Drops 1, 2, 3, and 4, this same condition exists, cracks increasing in size, with settlement of backfill increasing, at each structure downstream. At Drop 4 settlement of backfill was as much as 6 inches and a few small cracks were traced in the canal banks. Short circuits have been run indicating that Bench Marks along the right of way line near the structure have settled 0.14'. At all of the crop structures, joints in bridge decks showed movement had displaced the joint filler.

"Many structures across the Imperial Valley showed settlement of backfill, movement in joints, and slight permanent displacement; but very little change took place which will be unsightly or require repair except as described above.

" . . . Except for slight cracks in fills about structures, there is no indication of damage to canal banks upstream from the East Highline Turnout. From this point on across the valley, all fills showed considerable cracking, particularly where the water table was close to the original ground surface. Between Stations 3150 and 3170, both banks show small longitudinal cracks, but nothing which will require repair. At Station 3183 about 400 feet of the south bank was cracked .... The fills approaching the Alamo River Crossing showed numerous small cracks on the day following the heavy shock, but the fill, being dry, apparently absorbed the shocks better than fills which were moist.

"The most serious condition exists below Drop No. 5 where a lake has been allowed to form just south of the border in Mexico. This lake acted as a settling basin for the Ash Canal and has been used as such for about four years. The water table under the canal banks was high and water was standing 10 feet deep in the All-American Canal ... the heavy 'dobe banks on this saturated foundation were shaken apart. One short section of canal bank on the north side which was built of more sandy material sluffed in contrast to the cracking of the heavier material .... It is estimated that 50,000 to 80,000 cubic yards have been displaced in this section of canal; the south bank being more seriously damaged, repairs will be difficult because of proximity of the International Boundary." Clark, T. A., 1940, pp. 4, 11, 14, 17, and 21.

Repair Time: 5 to 10 days for the All American and Yules Canals.

Costs: All-American Canal -- $2,683. Repair costs of canals and structures of the Imperial Irrigation District in California approximated $27,604 (costs do not include repairs of buildings and miscellaneous items). Total repair cost for the damages to the irrigation systems of the Imperial Irrigation District and Mexico which resulted from the earthquake of May 18, 1940, was $265,080. Imperial Irrigation District, 1940 and 1941.

96. YULE CANAL, Imperial County, 10 miles from epicenter of Imperial Valley earthquake of May 18, 1940. Geologic Formation: Unconsolidated alluvium, saturated, thick section. Imperial fault.

"The fracture which marks the shift of the earth's surface crossed the Yule No. 3 Turnout between the headwall and outlet. The outlet transition structure was moved northward about 2.5 feet; the gate structure was moved westward about 6.5 feet and northward about 2.5 feet ...." The north-south horizontal offset across Yule Lateral No. 2 amounted to approximately 13 feet. Clark, 1940, pp. 4, 11, 14, 17, and 21.

97. HOLTVILLE AND ASH CANALS, Imperial County, 10 miles from epicenter of Imperial Valley earthquake of May 18, 1940. Geologic Formation: Unconsolidated alluvium, saturated thick section. Imperial fault.

"Damage to irrigation canals was so widespread that it would be impossible to list it in detail. Perhaps the greatest damage to canal structures was in the region just west of Holtville and south of Holtville to the Mexican border. Breaks occurred almost the entire length of the Ash Canal from Holtville south to the border. About 7 miles of bank of the Holtville Main Drain was damaged." Ulrich, January 1941, pp. 16, 24.

98. TAMARACK CANAL, Brawley, Imperial County, 50 miles from epicenter of Verruga earthquake of June 4, 1940. Geologic Formation: Very soft alluvium. Fault unknown.

"Continued temblors ... were blamed for ripping a 50-ft. hole in the side of the Tamarack canal, approximately eight miles southwest of Brawley and flooded portions of a four-square mile area." UC, 1940-1943, Clipping from Brawley California News, June 5, 1940.

99. RIVER CHANNEL, Mojave River near Midway, San Bernardino County, 1 mile from epicenter of Manix earthquake of April 10, 1947, Intensity VII. Geologic Formation: Alluvium. Manix fault.

"Numerous cracks noticed on both sides of the channel, largest about 3 inches wide. Water in the river rose 2 to 3 inches after the main shock." USC&GS, "U. S. Earthquakes", 1947, p. 18.

100. ALL AMERICAN CANAL, about 10 miles north of Mexican border, Imperial County, 112 miles from epicenter of Desert Hot Springs earthquake of December 4, 1948. Geologic Formation: Alluvium. Fault unknown, possibly Mission Creek fault.

"On December 4, 1948, an earthquake shock of intensity as low as VI MM, opened one old crack in the Coachella branch of the All-American Canal." Ambraseys, p. 343.

101. VAIL CANAL AND IRRIGATION DITCHES, Calipatria, Imperial County, within 5 miles of epicenter of Calipatria earthquake of July 29, 1950, Intensity VIII. Geologic Formation: Unconsolidated alluvium, saturated thick section. Fault unknown.

"... irrigation ditch banks and embankments sloughed and the ground settled and cracked along the Vail Canal." Ambraseys, p. 343.

"Numerous sand boils were formed, irrigation ditch banks sloughed, and ground settled and cracked 1 to 2 miles southwest of Calipatria. Several concrete stand-pipes broke and a small railroad bridge shifted 6 to 8 inches. At North End Dam, old sheet piling broke as the levee settled." USC&GS, "U. S. Earthquakes", 1950, p. 10.

"The irrigation district damage will amount to around $15,000, according to [B. A.] Weiss," executive engineer. Engineering News-Record, August 17, 1950, p. 32.

102. MAIN CANAL, Trifolium, Imperial County, 5 miles from epicenter of Superstition earthquake of January 23, 1951. Geologic Formation: Very soft alluvium. Superstition Hills fault.

"The Imperial Valley Irrigation District reported ... cracks in Westside Main (N-S), vicinity of Trifolium; cracks in canal banks at head of Lateral 13 of Westside Main ..." USC&GS, "Abstracts", MSA-69, p. 4.

103. THISTLE CANAL, Westmorland, Imperial County, 5 miles from epicenter of Superstition earthquake of January 23, 1951, Intensity VII. Geologic Formation: Very soft alluvium. Superstition Hills fault.

"The Imperial Valley Irrigation District reported ... settlement on Thistle [Canal], Lateral 8, south of gate 12. 100' settled 1', running NW-SE [along the canal] ..." USC&GS, "Abstracts", MSA-69, p. 4.

104. CANALS, 10 miles northeast of Brawley, Imperial County, within 25 miles from epicenter of Brawley earthquake of December 5, 1951, Intensity VII. Unknown fault.

"Cracks and bank damage to canals." USC&GS, "U. S. Earthquakes", 1951, p. 16.

105. KERN RIVER CANAL, Bakersfield area, Kern County, about 15 to 25 miles north of epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Unconsolidated alluvium (fans, flood plain and basin deposits), thick section saturated, White Wolf fault.

"The effect . . . upon the water section of the canal was to cause waves several feet in height, which broke on the top of the canal bank. In receding, these waves brought all loose debris into the canal section and it accumulated on the structure next downstream to an extent which, in some places, caused bank overflow.

"Damage to the canal section was evidenced by logitudinal cracks in embankments above the water line, apparently due to slump of saturated material." Hemborg, p. 236.

"Many miles of earth irrigation canals and also concrete lines canals were reported to have sustained minor damage in the form of sluffing of their banks, but none were known to have had a major break.

"Water levels in some wells rose markedly after the main shock. This could be partly attributed to the cessation of pumping due to power failures but possibly was primarily due to consolidation of the soil. The California Division of Water Resources reported one 100-foot well became artesian for two days after the shock." Steinbrugge and Moran, 1954, p. 300.

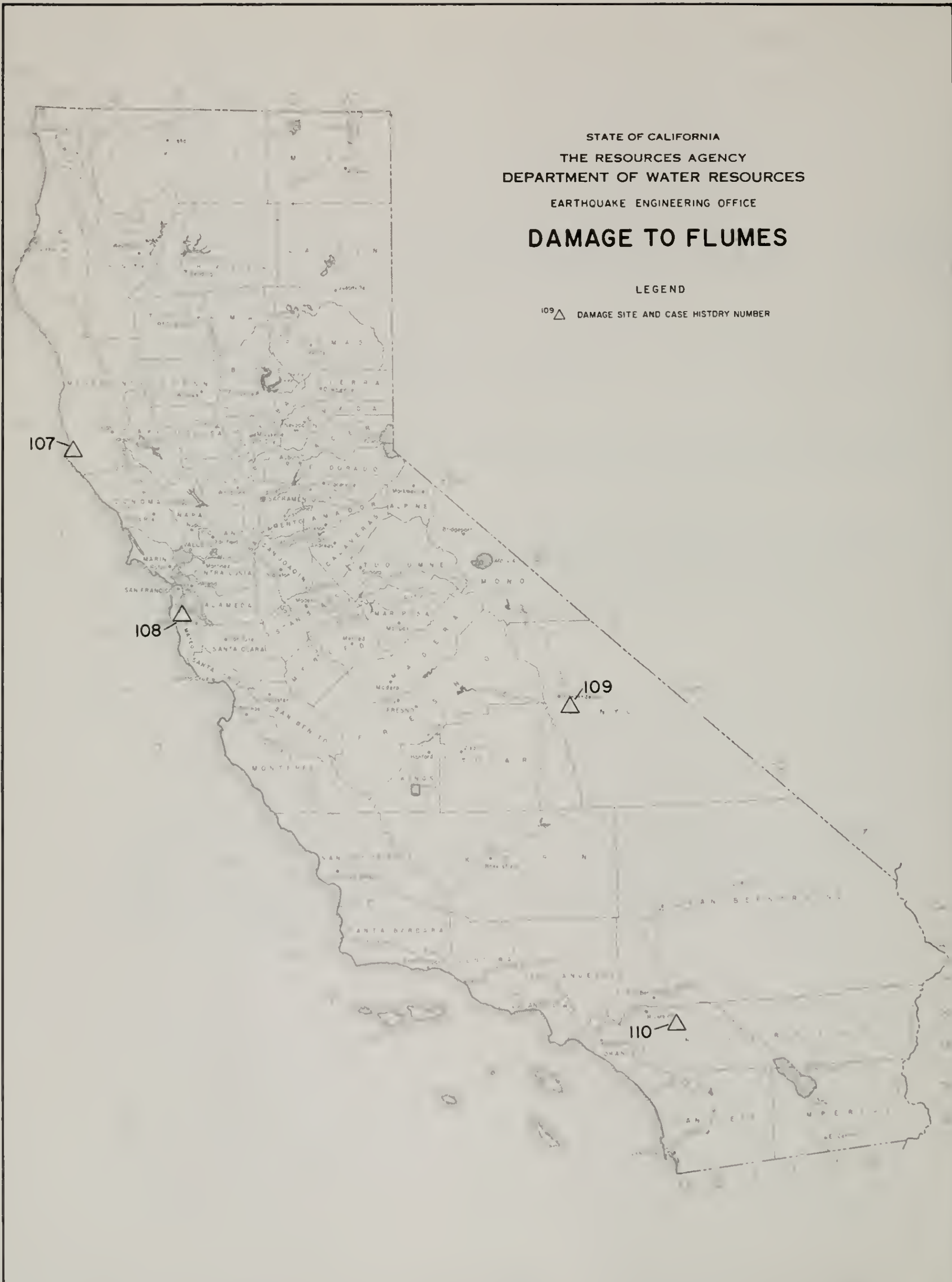
106. TOKAY AND THISTLE CANALS, Imperial Valley, Imperial County, probably 6 miles from epicenter of Imperial earthquake of June 13, 1953. Geologic Formation: Unconsolidated alluvium. Fault unknown.

"Press reported that the Imperial Valley Irrigation District suffered about $600 damage to the Thistle Lateral Canal (3 miles south of Westmorland), where one of the canal structures was damaged and a half mile of canal bank cracked. Tokay Canal near the Dahm Ranch was cracked and there was considerable settlement of the ground there." USC&GS, "Abstracts", MSA-78, p. 11.

FLUMES

(Cases 107-110)

FIGURE 10


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
EARTHQUAKE ENGINEERING OFFICE
DAMAGE TO FLUMES
LEGEND
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107. FLUME, Fort Bragg, Mendocino County, 70 miles from epicenter of San Francisco earthquake of April 18, 1906. Geologic Formation: No information--alluvium or possibly Franciscan formation. San Andreas fault.

"Along the Garcia River, the flumes of the L. E. White Lumber Company were reduced to kindling over long distances. Where they crost the river, suspended from steel cables, the end supports of the latter failed and let the flume drop down to the river bed." Lawson, p. 177.

108. FLUME, Pilarcitos Canyon, San Mateo County, 44 miles from epicenter of San Francisco earthquake of April 18, 1906. Geologic Formation: Probably residual rocky soils derived from underlying granitic and Franciscan formation bedrock. San Andreas fault.

"In Pilarcitos Canyon, the stone dam of the artificial lake was uninjured and the flume down the canyon sprung only a few leaks ...." Lawson, p. 253.

In Lawson's Atlas, the unnamed stone dam and its artificial lake appear in the canyon about two miles southeast of Pilarcitos Lake. Schussler also fails to name this dam (p. 79) but seems to tie it to the Locks Creek pipeline (see Case 84).

109. FLUME, Los Angeles Aqueduct, 40 miles south of Independence, Inyo County, distance from epicenter of Owens Valley earthquake of July 6, 1917, unknown. Geologic Formation: Unconsolidated alluvium. Fault unknown.

The earthquake "caused a break 160 feet long in the concrete flume of the Los Angeles aqueduct at a point between Haiwee reservoir and Owens Lake, in Inyo County .... the damage was temporarily repaired by bridging break with steel pipe. Since that time the flume has been rebuilt and reinforced. The water supply in Los Angeles was not cut off, because the break occurred above the Haiwee reservoir, which has a capacity sufficient for the storage of several weeks' supply of water for the city ...." Mulholland, p. 18. Palmer, p. 9.

110. FLUME, Blackburn Ranch, near San Jacinto, Riverside County, assumed nearby epicenter of San Jacinto earthquake of April 21, 1918. Geologic Formation: Probably alluvium. San Jacinto fault.

"At the Blackburn ranch the owner said that a concrete flume 2,000 feet long was broken, on an average, every six feet." Townley, p. 49.

CATEGORY IV

DISTRIBUTION LINES

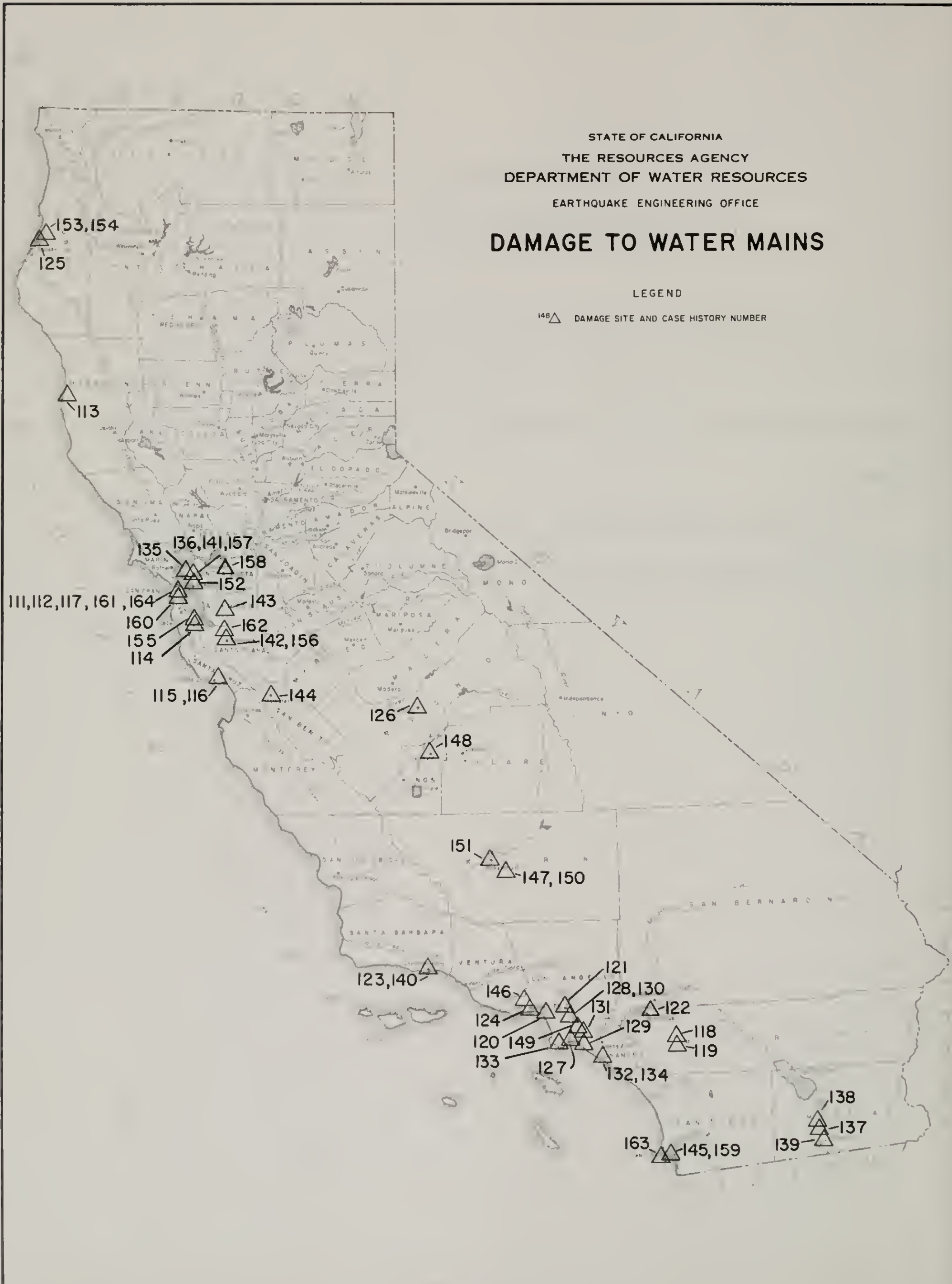
(Cases 111-211)

CATEGORY IV

DISTRIBUTION LINES

The following Cases concerning distribution line damage will be further divided into two categories. The first relating to city main distribution pipes, the second to service connections from the mains to individual consumers.

The careful reader interested in any aspect of urban water systems should scan also Major Water Conduits, Category III.


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
EARTHQUAKE ENGINEERING OFFICE
DAMAGE TO WATER MAINS
LEGEND
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WATER MAINS

(Cases 111-164)

111. WATER MAINS, San Francisco, San Francisco County, about 24 miles northeast of epicenter of Hayward earthquake of October 21, 1868. Geologic Formation: Alluvium, filled ground, and rock. Hayward fault.

"From the meagerness of reports it is certain that no great loss was occasioned by the parting of water mains .... In several parts of the city the water-pipes broke underground and caused some loss of water but the water company soon had all repairs made." Lawson, Vol. 1, p. 438.

The following six Cases concerning damage to water mains are related to the San Francisco earthquake of April 18, 1906, San Andreas fault.

112. WATER MAINS, San Francisco, San Francisco County, 32 miles southeast of epicenter. Geologic Formation: Unconsolidated alluvium, dune sand, marshland, filled ground, and solid ground (Franciscan formation).

"The city pipe distributing system was ... twisted off, especially in places where the ground, over which the streets had been constructed, had been poorly and loosely filled over old deep swamps and soft marshes. There were also a number of breaks in the streets that passed with deep loose fills over former ravines ....

"In solid ground there was very little trouble and but very few breaks. A number of the breaks noted ... as being on solid ground were caused by the use of dynamite and other explosives, employed in blowing down buildings.

"In the above sunken streets the city sewers, as well as other conduits, such as gas pipes, electric light conduits, etc., suffered the same as the water pipes, in that they were also similarly ruptured by the sinking and violent oscillations of the ground.

"On July 18, [1906--three months after the earthquake] there had been discovered and repaired 300 breaks in the street [water] pipe system, of which number 276 were in and immediately adjoining the burnt district, while in the entire balance of the city, viz., in the unburnt district, only 24 breaks have been found and repaired." Schussler, p. 33.

113. WATER MAINS, Fort Bragg, Mendocino County, 110 miles from epicenter. Geologic Formation: Sandy loam.

"The water mains were disconnected and the entire town might have been wiped out but for the timely assistance of the steamer 'Higgins' in the harbor." Lawson, Vol. 1, p. 173.

114. WATER MAINS, near Stanford University and in Portola, San Mateo County, 65 miles from epicenter. Geologic Formation: Mildly consolidated Tertiary marine sediments and alluvium.

Near the north bank of San Francisquito Creek--"In Portola brick chimneys were all down and water pipes were broken. ... the 12-inch cast-iron pipe of the Stanford University watermain, buried about 3 feet deep, was cracked, allowing the water to spurt 20 feet into the air." Lawson, Vol. 1, p. 263.

115. WATER MAIN, west of Santa Cruz, Santa Cruz County, 55 miles from epicenter. Geologic Formation: Alluvium.

"On the road 0.5 miles west of the dairy [Wilder Dairy, on the Santa Cruz-Pescadero road, 2 miles west of Santa Cruz near Meder Creek], the force of the shock broke an 8-inch water main." Lawson, Vol. 1, p. 270.

116. WATER MAIN, Santa Cruz, Santa Cruz County, 70 miles from epicenter. Geologic Formation: Tertiary marine terrace deposits overlying Tertiary rock units.

"A six-inch water main, running east and west across the ... [San Lorenzo River at a covered bridge] was broken at each end of the bridge and moved 5.5 inches eastward." Lawson, Vol. 1, p. 271.

117. WATER MAIN, Lake Merced, San Francisco, San Francisco County, 32 miles from epicenter. Geologic Formation: Sand dune.

"Upon following around the north end of the lake to the road that runs to the Life Saving Station, a line of terracotta pipe, about 8 inches in diameter was found. There was no large displacement in this pipe, although it had been cracked at many points." Lawson, p. 251.

118. WATER MAINS, San Jacinto, Riverside County, 3 miles from epicenter of San Jacinto earthquake of April 21, 1918. Geologic Formation: Alluvium. San Jacinto fault.

"... all water mains were destroyed by the quake." UC, Vol. 1, 1915-30, pp. 35-39.

119. WATER MAINS, Hemet, Riverside County, 1 mile from the epicenter of the San Jacinto earthquake of April 21, 1918. Geologic Formation: Alluvium. San Jacinto fault.

"... and all water mains were destroyed by the quake." UC, Vol. 1, 1915-1930, pp. 35-39.

120. WATER MAINS, Inglewood, Los Angeles County, approximately 7 miles from epicenter of Inglewood earthquake of June 21, 1920. Geologic Formation: Alluvium. Unknown fault, possibly Newport-Inglewood fault zone.

"The water mains and plant of the Inglewood Water Company were damaged, but the pipes were quickly repaired and new machinery installed." Taber, p. 131.

121. WATER MAINS, Los Angeles, Los Angeles County, 10-15 miles from epicenter of Los Angeles earthquake of July 16, 1920, Intensity VI. Geologic Formation: Alluvium. Fault unknown.

"Reports from several sources indicate that the city water mains have been affected by the shocks. The water supply in several buildings is reported to have failed.

"A water main was reported broken in Hill Street, between First and Second Streets." UC, Vol. 1, 1915-30, p. 46.

122. WATER MAIN, Riverside, Riverside County, distance from epicenter of San Bernardino Valley earthquake of July 22, 1923, unknown. Geologic Formation: Alluvium. Fault unknown.

" . . . at a house near Hollow Hill Farm, a chimney was destroyed and the concrete water pipe from Riverside municipal wells, was broken." Laughlin, p. 106.

123. WATER MAINS, Santa Barbara, Santa Barbara County, approximately 6 to 8 miles east of epicenter of Santa Barbara earthquake of June 29, 1925. Geologic Formation: Unconsolidated alluvium, semi-swamp lands, and older, slightly compacted, terrace sediments. Fault unknown, offshore.

" . . . damage to the distribution system . . . [was] confined to seven breaks in mains. There were numerous breaks in small lines and in service pipe . . . .

"Damage to the distribution system was repaired within 3 hours after the earthquake as indicated by the record on the chart of water pressure in the mains.

" . . . At 6:42 [a. m. (major shock)]the pen-point showed a violent movement, which indicated that the pressure was raised from 140 pounds to 175 pounds. At this time the mains were broken by the shock, and the pressure gauge indicated that the mains became empty in 10 minutes, the pressure, of course, being reduced to zero at this point. The pressure gauge also indicated that, as the mains were repaired, or by-passed, through the closing of the broken sections, the pressure gradually increased, and at 9:30 a. m. pressure had been restored to 125 pounds." Nunn, p. 314.

124. WATER MAIN, Santa Monica, Los Angeles County, 9 miles to epicenter of Santa Monica Bay earthquake of August 30, 1930. Unknown fault. Geologic Formation: Alluvium.

"A water main at Twenty-sixth Street and Montana Avenue broke and water spouted high over the streets." UC, Vol. II, 1930-34, p. 6, Clipping from Los Angeles Times, August 31, 1930.

125. WATER MAINS, Samoa, Humboldt County, 17 miles to epicenter of Eureka earthquake of June 6, 1932. Geologic Formation: Very soft alluvium. Unknown fault, offshore.

"... water mains were broken." Wood and Heck, p. 34.

126. WATER PIPE, Fresno, Fresno County, 170 miles to epicenter of Cedar Mountain-Nevada earthquake of December 20, 1932, Intensity IV. Geologic Formation: Alluvium. Cedar Mountain fault.

"One broken water main in downtown building ...." USC&GS, "Abstracts", Vol. 1-4, 1929-1934.

The following 7 Cases concerning damage to water mains are related to the Long Beach earthquake of March 10, 1933, Newport-Inglewood fault.

127. WATER MAINS (Concrete, cast iron and steel), Long Beach, Los Angeles County, 18 miles from epicenter. Geologic Formation: Unconsolidated alluvium, tidal flats, filled ground, and Pleistocene marine deposits, including Palos Verdes sand, San Pedro sand, and unnamed marine terrace deposits.

"The damage to these mains consisted of a 30-inch hub gate valve broken by the terrific compressive force which required its removal from the line; broken pipe and joints of 24-inch pipe which required replacement; the shearing off of a 30-inch pipe where the main joined a concrete cistern; broken pipe and joints of 42-inch pipe where the main joined a concrete cistern, and one 42-inch joint where steel and concrete pipes were joined.

"Cast iron mains ... the system contains 367.5 miles of cast iron mains ranging in sizes from 2- to 30-inch. A survey shows that 130 breaks occurred in mains .... An analysis of the location of the breaks shows that 52 percent of them occurred in the southeast area of the city where the land has been built up by a dredged fill on tide flats; 38 percent occurred in sections where the soil is of a naturally deposited silt with the ground water near the surface; and 10 percent occurred in hard adobe soil.

"Steel mains. The system contains 21.8 miles of steel pipe in sizes of 2 to 16 inches in which 135 breaks occurred. All of these breaks were in one district where the pipe had reached a condition where replacement was already necessary.

"Services. A survey of over 10,454 cast iron service laterals showed that only two breaks occurred in them between the main and the tee at the curb. All other breaks in cast iron services were either brass nipples or malleable fittings at the tee. A total number of 85 service breaks occurred in the entire system, 10 of which were in silty soil in North Long Beach and 75 in the Belmont Shore-Naples area where the soil is dredge-filled on tide flats." Porter, pp. 771-773.

128. WATER MAINS, South Gate, Los Angeles County, approximately 25 miles northwest of epicenter. Geologic Formation: Unconsolidated, saturated alluvium, thick section.

"There was a total of 247 leaks repaired which were chargeable to the earthquakes ....

"The leaks in the steel mains were of many varieties. Many minor leaks were due to the usual run of rust spots or pit holes which would have broken out sooner or later .... In the riveted steel pipe there were numerous split longitudinal seams, as well as sheared rivet heads.

"The small system of Hollydale near South Gate probably suffered more than any other. In one area three blocks wide there were 24 leaks in which the mains were either pulled apart of telescoped, in some instances as much as 6 inches. In one location the main had first telescoped and then backed away nearly 6 inches. These mains were of lap weld steel pipe with welded field joints." Harnish, p. 777.

129. WATER MAINS, American States Water Service, Huntington Beach, Orange County, approximately 4 miles northeast of epicenter. Geologic Formation: Not stated, probably Pleistocene marine terrace deposits and unconsolidated alluvium.

"Only one serious break occurred in large pipe and this was in a 14-inch transmission line of steel pipe weighing 30.2 pounds to the foot at Huntington Beach. This line was broken cleanly through a field weld and the pipe was pulled apart about 6 inches, one end being also about 6 inches above the other. Inspection showed the weld to be of very good workmanship and it is a coincidence that three steel oil lines, running parallel to the water main, had broken at exactly the same point . . . . " Harnish, p. 778.

Repair time: Approximately 24 to 48 hours for 14-inch transmission line.

130. WATER MAINS, Lynwood, Los Angeles County, approximately 17 miles northwest of epicenter. Geologic Formation: Alluvium and Pleistocene marine terrace deposits consisting of sand, silt, and clay.

"The [water distribution] . . . system consists of approximately 45 miles of mains of which approximately 30 percent is cast iron, 15 percent wood stave and 55 percent riveted steel . . . . In all, some 150 leaks and breaks were repaired . . . .

"Of the 14 miles of cast iron piping there was no damage with the exception of two small leaks at joints . . . . All other breaks occurred in the older wood stave and riveted steel lines . . . . " Bateman, p. 779.
Repair time: Large breaks were repaired within a period of three days.

131. WATER MAINS, Dominguez Water Company, Los Angeles and Orange Counties, approximately 17 miles northeast of epicenter. Geologic Formation: Deep alluvial deposits of sand, gravel, silt and clay, saturated.

" . . . 22 miles of wood pipe was not damaged . . . . The bad breaks [in concrete pipes] occurred . . . at the intersection of Wilmington and Carson Aves. The condition of the . . . [water] lines, . . . [and other structures] indicated that the earth had suffered a terrific grinding movement . . . . " Tallon, p. 783.

Repair time: Repairs were completed in about 48 hours.

132. WATER MAINS, Laguna Beach, Orange County, 20 miles from epicenter. Geologic Formation: Pleistocene marine terrace deposits.

"Leaks in water and gas mains." USC&GS, "U. S. Earthquakes", 1933, p. 12.

133. WATER MAINS, San Pedro, Los Angeles County, 20 miles from epicenter. Geologic Formation: Pleistocene marine terrace depqsits.

"Water mains ... broken." USC&GS, "U. S. Earthquakes", 1933, p. 12.

134. WATER MAIN, Laguna Beach, Orange County, 53 miles to epicenter of Aguanga earthquake of November 3, 1935. Geologic Formation: Probably alluvium. Agua-Caliente fault.

"Water main broken . . . ." USC&GS, "U. S. Earthquakes", 1935, p. 37.

135. WATER MAIN, Richmond, Contra Costa County, 6 miles from epicenter of Berkeley earthquake of March 8, 1937. Geologic Formation: Very soft alluvium. Probably Hayward fault.

"In Richmond, at the Ford Motor Co. plant (about 6 miles from the epicenter), a 6 inch cast iron water main was reported broken at a joint beneath reinforced concrete flooring." USC&GS, MSA-12, 1936, p. 17.

136. WATER MAIN, Berkeley, Alameda County, 0 miles from epicenter of Berkeley earthquake of March 8, 1937. Geologic Formation: Alluvium. Probably Hayward fault.

" . . . only one water main, in front of 916 Cragmont Avenue, was reported broken." UC, Clipping from Oakland Tribune, March 8, 1937.

137. WATER MAINS AND SEWER LINES, Imperial, Imperial County, 10 miles from epicenter of Imperial Valley earthquake of May 18, 1940. Geologic Formation: Very soft alluvium. Imperial fault.

"Apparently there was not a great amount of damage to the water mains and the sewage system in Imperial, although a number of breaks did occur.

"City water tank collapsed . . . and there were severe breaks in water mains underground." USC&GS, "Abstracts", MSA-26, 1940, pp. 13, 16.

138. WATER MAINS, Brawley, Imperial County, approximately 20 miles northwest of epicenter of Imperial Valley earthquake of May 18, 1940. Geologic Formation: Unconsolidated alluvium, saturated, thick section. Imperial fault.

"There were a large number of breaks in the city water mains and water was shut off in hundreds of homes because of broken plumbing. The damage to sewers was uncertain as a large amount of such damage is not immediately apparent." USC&GS, "Abstracts", MSA-26, 1940, p. 13.

139. WATER MAINS, El Centro, Imperial County, approximately 8 miles northwest of epicenter of Imperial Valley earthquake of May 18, 1940. Geologic Formation: Unconsolidated alluvium, saturated thick section. Imperial fault.

"There were few breaks in the water mains, but practically no damage to the water plant or sewer lines." Ulrich, p. 29.

140. WATER MAINS, Santa Barbara, Santa Barbara County, 10 miles from epicenter of Santa Barbara earthquake of June 30, 1941. Geologic Formation: Alluvium. Unknown fault, offshore.

"Four water mains were severed . . . ." Wood, p. 259.

141. WATER MAINS, Berkeley, Alameda County, 40 miles from epicenter of Mount Hamilton area earthquake of October 25, 1943. Probably

Calaveras fault.

"Water mains in the slide areas near Keith Avenue and at Arch and Spruce Sts. were reported damaged . . . . " UC, 1943-48, Berkeley Gazette, October 26, 1943.

142. WATER MAIN, San Jose, Santa Clara County, 7 miles from epicenter of San Jose earthquake of August 27, 1945. Geologic Formation: Very soft alluvium. Unknown fault.

"Water . . . was reported seeping through cracked pavement on Eighth Street, between San Antonio and San Fernando Sts., indicating a broken water main." USC&GS, "Abstracts" MSA-47, 1945, p. 9.

143. WATER MAIN, Pleasanton, Alameda County, 20 miles from epicenter of Santa Clara earthquake of April 25, 1946. Geologic Formation: Very soft alluvium. Unknown fault.

"Water line on main street was broken." USC&GS, "U. S. Earthquakes", 1946, p. 13.

144. WATER MAINS, Hollister, San Benito County, 0 miles from epicenter of Hollister earthquake of August 10, 1947, Intensity VI. Geologic Formation: Alluvium. Unknown fault.

"One water main leading to a residence was broken." USC&GS, "U. S. Earthquakes", 1947, p. 25.

145. WATER MAIN, San Diego, San Diego County, 96 miles from epicenter of Desert Hot Springs earthquake of December 4, 1948. Geologic Formation: Very soft alluvium. Unknown fault, possibly Mission Creek.

"One water main burst . . . . " USC&GS, "U. S. Earthquakes", 1948, p. 22.

146. WATER MAIN, Westwood, Los Angeles County, 128 miles from epicenter of Desert Hot Springs earthquake of December 4, 1948, Intensity VI. Geologic Formation: Very soft alluvium. Unknown fault, possibly Mission Creek.

"Water main on the UCLA campus broke ... was temporary installation partly at surface and partly in soft fill." USC&GS, "U. S. Earthquakes", 1948, p. 23.

147. WATER MAINS, Arvin, Kern County, 20 miles from epicenter of Kern County earthquake of July 21, 1952, Intensity VIII. White Wolf fault.

"Press reported 3 city water mains broke." USC&GS, "U. S. Earthquakes", 1952, p. 18.

148. WATER MAINS, Hanford, Kings County, 100 miles from epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Very soft alluvium. White Wolf fault.

" ... few minor leaks in water mains ...." USC&GS, "U. S. Earthquakes", 1952, p. 22.

149. WATER MAIN, Fullerton, Orange County, 105 miles from epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Very soft alluvium. White Wolf fault.

"Press reported gas and city water main broken. Four inch water main, running east-west, on hill part of town broken." USC&GS, "U. S. Earthquakes", 1952, p. 26.

150. WATER MAINS, Arvin, Kern County, 17 miles from epicenter of Tejon Ranch earthquake of July 22, 1952. Geologic Formation: Very soft alluvium. Unknown fault, possibly White Wolf fault.

"Gas and water mains were broken . . . ." USC&GS, "U. S. Earthquakes", 1952, p. 35.

151. WATER MAINS, Bakersfield, Kern County, 5 miles from epicenter of Bakersfield earthquake of August 22, 1952, Intensity VIII. Geologic Formation: Very soft alluvium. Unknown fault, possibly White Wolf fault.

"One 4-inch, cast-iron waterline, buried 3 feet, cracked in 18-19th Street alley and one 8-inch and one 12-inch line had small cracks." USC&GS, "U. S. Earthquakes", 1952, p. 37.

152. WATER MAIN, Oakland, Alameda County, 10 miles from epicenter of San Leandro earthquake of December 16, 1954. Geologic Formation: Very soft alluvium. Unknown fault.

" . . . water main broke." USC&GS, "Abstracts", MSA-84, p. 45.

153. WATER MAINS, Arcata, Humboldt County, 10 miles from epicenter of Eureka earthquake of December 21, 1954. Geologic Formation: Alluvium. Unknown fault.

"Some water main breaks were reported in Arcata . . . ." USC&GS, "U. S. Earthquakes", 1956, p. 45.

154. WATER MAINS, Eureka, Humboldt County, about 5 miles from epicenter of Eureka earthquake of December 21, 1954. Geologic Formation: Alluvium. Unknown fault.

" . . . Eureka water distribution system was broken in a number of places." Steinbrugge and Moran, April 1957, p. 138.

155. WATER MAIN, Menlo Park, San Mateo County, 24 miles from epicenter of San Jose earthquake of September 4, 1955. Geologic

Formation: Alluvium. Unknown fault.

" . . . police reported water began to seep up from a cracked water main at Partridge Avenue between El Camino Real and University Drive." UC, 1954-55, Clipping from San Mateo Times and News Leader, September 5, 1955.

156. WATER MAINS, San Jose, Santa Clara County, 6 miles from epicenter of San Jose earthquake of September 4, 1955. Geologic Formation: Alluvium. Unknown fault.

"Only minor damage to the San Jose Water Works system resulted from Sunday night's earthquake . . . none of the large transmission lines were affected . . . . A deep well pumping station on 12th Street produced a small amount of sand the next morning . . . a six-inch cast iron main at Mt. Hamilton and Anderson Road was split. It was repaired and back in service within six hours . . . . A small break in a three-inch cast iron main at Minnesota and Washington Sts. . . . a small break . . . in an eight-inch main at Bascom Avenue and O'Connor Drive." UC, 1954-1955, Clipping from Los Gatos Times-Observer, September 8, 1955.

157. WATER MAIN, Berkeley, Alameda County, 8 miles from epicenter of Concord earthquake of October 23, 1955. Geologic Formation: Alluvium. Unknown fault, probably Calaveras or Sunol fault.

"Fourteen inch water main broke, flooding a 4-block area." USC&GS, "U. S. Earthquakes", 1955, p. 25.

158. WATER MAINS, Concord, Contra Costa County, about 15 miles from epicenter of Concord earthquake of October 23, 1955, Intensity VII. Geologic Formation: Alluvium. Unknown fault.

"Several water mains broke." USC&GS, "U. S. Earthquakes", 1955, p. 25.

159. WATER MAIN, San Diego, San Diego County, approximately 100 miles NW of epicenter of Baja California, Mexico, earthquake of February 9,

1956. Geologic Formation: Marine terrace deposits. San Miguel fault.

In San Diego " . . . one water main, an overhead 5-inch pipe on Broadway Pier, broke; one water pipe broke on 6th floor of the downtown Land Title Building . . . . " USC&GS, "Abstracts", MSA-89, p. 20.

160. WATER MAINS, Daly City, Westlake Palisades, San Mateo County, approximately 1 to 2 miles northeast of epicenter of Daly City earthquake of March 22, 1957. Geologic Formation: Merced formation; (upper Pliocene)--in this area the material is 2/3 sand and 1/3 silt and clay. Formation is uncemented, friable, and easily excavated in most areas. San Andreas fault.

"The damage to the Daly City water system was confined to the Westlake Palisades area. Three water lines broke: an east-west 6-inch transite line on south side of Seacliff Avenue, in which the pipe telescoped, indicating ground shortening; a 2-inch east-west galvanized line on north side of Seacliff Avenue, which cracked through the threads, with indications of compressive forces; and a third similar to the 2-inch line on Seacliff Avenue. The foregoing damage is interesting because of its relation to nearby ground-surface effects and dwelling damage." Steinbrugge, Bush and Zacker, p. 101.

161. WATER MAINS, Southwestern part of San Francisco, San Francisco County, approximately 2 to 3 miles northwest of epicenter of Daly City earthquake of March 22, 1957. Geologic Formation: Colma formation (Pleistocene terrace deposits; chiefly friable sand with a little silt and clay). San Andreas fault.

"The San Francisco distributing system had four leaks in steel mains, all of which appeared to be corrosion-weakened pipes. Two leaks were in 30-inch mains, one in a 3-inch main, and one in a main for which the size was not specified. All of these leaks were in mains located in the southwestern part of the city, close to the more heavily shaken areas. Also, three air valve leaks indicated a surge of water in the large mains . . . .

"At the Lake Merced Pump Station in San Francisco, a filled area settled 4 to 6 inches, severing a 12-inch pipe from the station.

"A total of a hundred-odd services were broken; these were mainly old galvanized services; but a few copper services pulled apart at the meters. These breaks were scattered through the city, although there was some concentration in the southwestern part of the city . . . ." Steinbrugge, Bush and Zacker, p. 103.

" . . . 173 boiler steam lines fractured or broken; 97 broken sewer lines; 422 fractured, broken or bent gas supply lines . . . ." USC&GS, MSA-93, 1957, p. 20.

162. WATER MAIN, Milpitas, Santa Clara County, 8 miles from epicenter of San Jose earthquake of October 30, 1958. Geologic Formation: Very soft alluvium. Unknown fault.

"Water main cracked." USC&GS, "U. S. Earthquakes", 1958, p. 21.

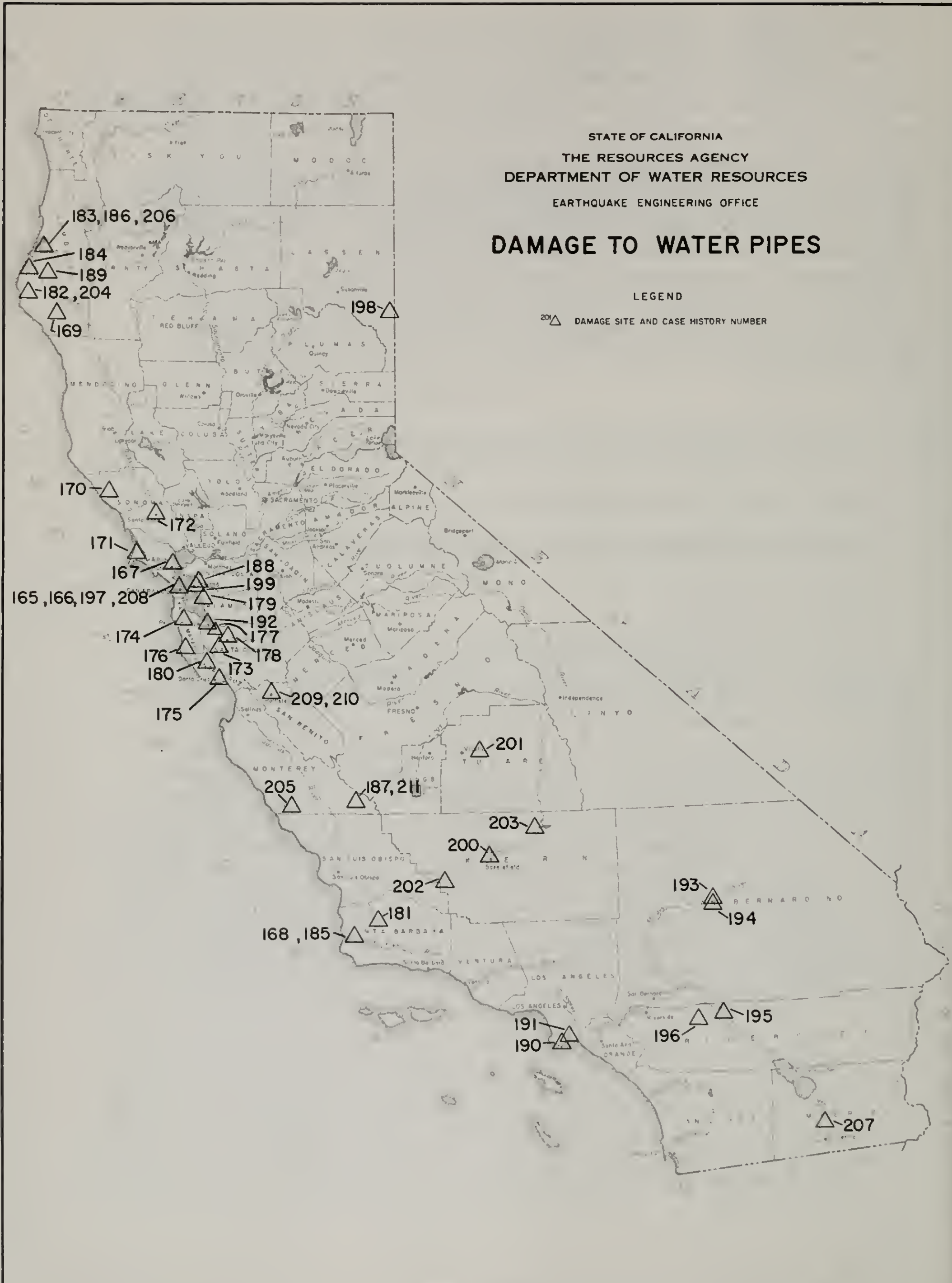
163. WATER MAINS, Fort Rosecrans, Point Loma, San Diego County, approximately 85 miles northeast of epicenter in Baja California, Mexico, of Baja California earthquake of November 30, 1958. Geologic Formation: Cretaceous shales and sandstone, dip slope. Unknown fault.

" . . . Lt. Brown felt it at Fort Rosecrans and the next day discovered a broken water main on the east hill-slope of the Point. There were numerous deep, open ground cracks; a major crack parallel to the contours passed through the site of the pipe break. The pipe ran directly upslope. On December 5 an odor of gas was noted and he found a two-inch tension break in a gas line northeast of the water line break. There are ground cracks in the vicinity of this break also and one of them passed through the site of the break. It was subsequently discovered that 2-1/2 million cubic feet of gas had escaped, indicating that the break had been open for some days, quite possibly since November 30. I toured the area of damage with Lt. Brown and saw extensive tension cracking high on the hill slope and small compression ridges along the asphalt roadway at the foot of the slope. The cracks swing in a generally arcuate form up the hillside and back down to the roadway, enclosing an area of some acres located between Ballast Point and the U. S. Navy Fuel Facility. Movement has continued since November 30, displacement on the water main now amounting to two feet. The area is a dip-slope in Cretaceous shales and sandstones; according to Moore (NEL Technical Report) the dips in this area are 5^o to 10^o which is less than the slope of the land surface just above the road. Up the hill from the cracking is the National Cemetery which has recently been expanded and where there is extensive watering of grass. This is an almost perfect example of dip-slope landsliding as has occurred recently in the Los Angeles area. Lt. Brown's suggestion that the slide was touched off by the November 30 shock is reasonable. However, the basic cause is instability of the slope, and the effects of the watering in the cemetery should be investigated. It should be noted that movement occurred before any heavy rains had occurred. I would anticipate that the sliding will continue with the eventual result of carrying out the road and dumping several acres of Point Loma into the San Diego Harbor Channel entrance." USC&GS, "Abstracts", MSA-100, p. 23.

164. WATER MAINS AND WATER PIPES, San Francisco, San Francisco County, approximately 100 miles northwest of epicenter of Hollister earthquake of April 8, 1961. Geologic Formation: Alluvium. San Andreas fault.

"Press reported the city superintendent for the water department said the two breaks in pipelines were 'probably attributable to the earthquake as we had more than the normal number of breaks'. Major pipelines were not damaged. Pacific Gas and Electric Company reported no damage. The breaks in the two mains were on Ortega Street between 18th and 19th Avenues, and on Montana Street between Plymouth and Capitol Streets. The 8-inch water main under Montana Street broke and tore a crater about 10 by 15 feet in the street and sidewalk above. Approximately 50 homes in the vicinity were without water for several hours. The 6-inch main under Ortega Street served mostly commercial buildings. In addition there were breaks in 'service pipes' which cut another 20 homes from their water supply. It was reported that service breaks occurred mostly in the Portola Drive-Ocean Avenue area. Damage was estimated at about $5,000." USC&GS, "Abstracts", MSA-110, p. 18.

FIGURE 12


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
EARTHQUAKE ENGINEERING OFFICE
DAMAGE TO WATER PIPES
LEGEND
201 DAMAGE SITE AND CASE HISTORY NUMBER
183, 186, 206
184
189
182, 204
169
198
170
172
171
167
188
199
165, 166, 197, 208
179
192
174
177
178
176
173
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175
209, 210
201
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187, 211
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202
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168, 185
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MENDOCINO
GLENN
SONOMA
SOLANO
SACRAMENTO
EL DORADO
ALPINE
TUOLUMNE
MONO
MARIPOSA
MERCED
INYO
FRESNO
MONTEREY
SAN BENITO
SAN LUIS OBISPO
KERN
VENTURA
LOS ANGELES
RED BLUFF
VALLEJO

WATER PIPES

(Cases 165-211)

165. WATER PIPES, San Francisco, San Francisco County, 50 miles from epicenter of Santa Cruz Mountains earthquake of October 8, 1865. Geologic Formation: Alluvium. Possibly San Andreas fault.

"On the marshy lands in the vicinity of Howard and Seventh Streets, lamp posts, water pipes, and gas pipes were broken and thrown out of position." Holden, p. 66.

166. WATER PIPES, San Francisco, San Francisco County, 15 miles from epicenter of Hayward earthquake of October 21, 1868. Geologic Formation: Alluvium. Hayward fault.

"In several parts of the city, water pipes broke underground and caused some loss of water, but the water company soon had all repairs made." Lawson, p. 438.

167. WATER PIPES, San Rafael, Marin County, 45 miles from epicenter of Vacaville earthquake of April 19, 1892. Geologic Formation: Unconsolidated alluvium. Unknown fault.

"No serious damage was done here, but in numerous residences clocks were stopped, crockery thrown from shelves, and water pipes wrenched." Holden, p. 185.

168. WATER PIPES, Lompoc, Santa Barbara County, 96 miles from epicenter of Los Alamos earthquake of July 27, 1902. Geologic Formation: Alluvium. Unknown fault.

"At Lompoc buildings were damaged and pipes broken." Townley and Allen, p. 117.

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The following eleven cases concerning water pipe damage are related to the San Francisco earthquake of April 18, 1906, San Andreas fault.

169. WATER PIPES, Briceland, Humboldt County, 150 miles from epicenter. Geologic Formation: Solid sandstone and shale, bedrock near surface.

"The village suffered damage to the extent of $1500 due to the breaking of chimneys, water and gas pipes, household furniture, etc." Lawson, p. 170

170. WATER PIPE, Fort Ross, Sonoma County, 40 miles from epicenter.

Geologic Formation: Probably beach terrace deposits.

"... a steel water pipe was dislocated by the earth movement and found to be offset 8 feet, the southwest portion having moved northwesterly." Lawson, p. 64.

171. WATER PIPE, Inverness, Marin County, 10 miles from epicenter.

Geologic Formation: Probably alluvium.

"A water pipe following an east-west road on the mesa, and buried about one foot, was buckled at two points so as to be lifted above the ground. I saw no earth cracks near these points." Lawson, p. 194.

172. WATER PIPES, Santa Rosa, Sonoma County, 24 miles from epicenter.

Geologic Formation: Alluvium.

"A small water pipe on the southern part of the hill, running north and south, was pulled apart. A pipe on the northern part of the hill running east to west is reported ... as pulled apart about 4 inches." Lawson, p. 201.

173. WATER PIPES, Hidden Villa, Mountain View, Santa Clara County,

50 miles from epicenter. Geologic Formation: Alluvium.

"Big blocks of rock are said to have been shaken loose from the mountain and to have rolled down the slopes. One of these rolled into the chicken-house, and others broke the water-pipes at several places farther up the gorge." Lawson, p. 261.

174. WATER PIPES, Woodside, San Mateo County, 50 miles from epicenter.

Geologic Formation: Tertiary and Pleistocene sediments.

"The water pipe running from the house to the pump was bent in a curve toward the northwest, and where it entered the pump house the boards were broken on the southeast side of the pipe. The other pipe (also four inches in diameter) had the threads stript off at a joint, and the ends of the pipe pulled apart for a distance of 2.5 to 3 inches. The pipe was new and buried a few inches below the surface of the ground." Lawson, p. 263.

175. WATER PIPES, six miles southeast of Congress Springs, Santa Clara County, 75 miles from epicenter. Geologic Formation: Probably alluvium.

"The water pipes here were badly displaced and broken." Lawson, p. 267.

176. WATER PIPE, Bolsa Point, San Mateo County, 62 miles from epicenter. Geologic Formation: Cretaceous bedrock.

"It was reported here that along the ocean shore, construction work near Bolsa Point, a concrete pipe 24 inches in diameter and 6 inches thick, embedded in clay, had been cracked by the shock." Lawson, p. 274.

177. WATER PIPES, Wright Station, Santa Clara County, 75 miles from epicenter. Geologic Formation: Alluvium.

"Water pipes were broken and twisted, and filled with dirt." Lawson, p. 276.

178. WATER PIPE, San Jose, Santa Clara County, 55 miles from epicenter. Geologic Formation: Alluvium.

"On the farm of Mr. Fox, 3 miles north of San Jose, the water pipe of the artesian well was broken off 60 feet below the surface and carried by the heave of the land in a northwesterly direction 4 feet from its original position." Lawson, p. 286.

179. WATER PIPES AND SEWER PIPE, Alvarado, Alameda County, 40 miles from epicenter. Geologic Formation: Alluvium.

"A six inch cast iron water pipe, attached vertically to the main building [of the Alameda Sugar Company] broke transversely about 30 feet above the ground. In the engine room the vertical steam pipes cracked next to the flanges by the wracking motion of the ceilings thru which they extended. The shock appears to have had a north-south direction, according to the position of the breaks in these pipes .... A two inch water pipe, laid under the ground some 60 feet north of the creek and almost parallel with the same, shows indications of having been submitted first to tension, causing rupture of one of the joints, then to sudden compression, causing it to be jammed together with violence .... The sewer pipe leading west to the creek was detached from the house by a space of 22 inches .... In the roadway south of the mill, water oozed out in a number of places, without the production of visible cracks. The water pipes and hydrants in this vicinity were crusht in several places." Lawson, pp. 304, 305.

180. WATER PIPES, 4 miles northwest of Laurel, Santa Cruz County, 4 miles from epicenter of Laurel earthquake of November 8, 1914. Geologic Formation: Alluvium. Unknown fault.

" ... at the Montezuma School, about four miles northwest of Laurel and approximately on the fault line, two water pipes were broken." Stanford, p. 219.

181. WATER PIPES, Los Alamos, Santa Barbara County, 3 miles from epicenter of Los Alamos earthquake of January 11, 1915. Geologic Formation: Alluvium. Unknown fault.

"A few water pipes were pulled apart at unions, and water was splashed from open reservoirs and watering troughs." Beal, March 1915, p. 19.

182. WATER PIPES, Petrolia, Humboldt County, 18 miles from epicenter of Cape Mendocino earthquake of January 22, 1923. Geologic Formation: Alluvium, Unknown fault.

" ... water pipes were broken ...." Townley and Allen, p. 227.

183. WATER PIPES, Eureka, Humboldt County, 0 miles to epicenter of Humboldt Bay earthquake of August 20, 1927. Geologic Formation: Very soft alluvium. Unknown fault.

"Water pipes were broken in the Federal Building." Byerly, 1930, p. 213.

184. WATER PIPES, Ferndale, Humboldt County, 15 miles to epicenter of Humboldt Bay earthquake of August 20, 1927. Geologic Formation: Alluvium. Unknown fault.

"In Ferndale water pipes were twisted and broken." Byerly, 1930, p. 213.

185. WATER PIPES, Lompoc, Santa Barbara County, 60 miles east of epicenter of Point Arguello earthquake of November 4, 1927. Geologic Formation: Alluvium. Unknown offshore fault.

"In Lompoc . . . water lines throughout the city were springing breaks later today." UC, Clipping from Santa Maria Daily Times, November 4, 1927.

186. WATER PIPES, Eureka, Humboldt County, 17 miles to epicenter of Eureka earthquake of June 6, 1932. Geologic Formation: Alluvium. Unknown fault.

"Sprinkler system in Holmes Lumber Company let go because of vibration against wooden joists." USC&GS, "Abstracts", Vol. 1-4, p. 9.

187. WATER PIPES, Parkfield, Monterey County, 9 miles from epicenter of Parkfield earthquake of June 7, 1934. Geologic Formation: Alluvium. San Andreas fault.

" . . . and water pipes broken . . ." USC&GS, "Abstracts", MSA-2, p. 16.

188. WATER PIPES, Albany, Alameda County, 2 miles from epicenter of Berkeley earthquake of March 8, 1937. Geologic Formation: Alluvium. Probably Hayward fault.

"Several pipelines were broken . . . in Albany." UC, Clipping from Oakland Post-Enquirer, March 8, 1937.

189. WATER PIPES, Scotia, Humboldt County, 2 miles from epicenter of Scotia earthquake of October 22, 1940. Geologic Formation: Alluvium. Unknown fault.

"Three underground pipes were broken." USC&GS, "U. S. Earthquakes", 1940, p. 28.

190. WATER PIPES, Los Angeles Basin, Los Angeles County, 5 miles from epicenter of Torrance-Gardena earthquake of November 14, 1941. Geologic Formation: Very soft alluvium. Unknown fault.

" . . . pipelines appeared to be pulled loose in a north-south direction in an around Torrance, Gardena, Redondo Beach, Long Beach, and downtown Los Angeles." USC&GS, "U. S. Earthquakes", 1941, p. 17.

191. WATER PIPES, coastal area, Los Angeles County, 0 miles from epicenter of Torrance-Gardena earthquake of November 14, 1941, Geologic Formation: Very soft alluvium. Unknown fault.

" ... pipelines appeared to be pulled loose in a north-south direction in Lometa, San Pedro, and Wilmington." USC&GS, "U. S. Earthquakes", 1941, p. 17.

192. WATER PIPE, Sunnyvale, Santa Clara County, 20 miles from epicenter of Mount Hamilton earthquake of October 25, 1943. Geologic Formation: Very soft alluvium. Probably Calaveras fault.

"A broken water line at Joshua Hendy Iron Works plant in Sunnyvale ... " USC&GS, "Abstracts", MSA-40, p. 7.

193. WATER PIPE, Tankersley House, San Bernardino, 8 miles from epicenter of Manix earthquake of April 10, 1947. Geologic Formation: Probably alluvium. Manix fault.

"A two inch waterline was torn from the water tank." USC&GS, "U. S. Earthquakes", 1947, p. 18.

194. WATER PIPE, Wright Brothers Ranch, San Bernardino County, 8 miles from epicenter of Manix earthquake of April 10, 1947, Intensity VII. Geologic Formation: Probably alluvium. Manix fault.

"Water pipe developed leaks but no breaks. Cement bottom and sides of a swimming pool cracked." USC&GS, "U. S. Earthquakes", 1947, p. 18.

195. WATER PIPES, Desert Hot Springs, Riverside County, 7 miles from epicenter of Desert Hot Springs earthquake of December 4, 1948, Intensity VII. Geologic Formation: Alluvium. Unknown fault, possibly Mission Creek fault.

"Some small pipes in ground broken." USC&GS, "U. S. Earthquakes", 1948, p. 19.

196. WATER PIPE, Cabazon, Riverside County, 23 miles from epicenter of Desert Hot Springs earthquake of December 4, 1948, Intensity VII. Geologic Formation: Alluvium. Unknown fault, possibly Mission Creek fault.

"Three-quarter inch water pipe about 10 inches in the ground sprung leaks." USC&GS, "U. S. Earthquakes", 1948, p. 19.

197. WATER PIPES, San Francisco, San Francisco County, 74 miles from epicenter of Gilroy-Hollister earthquake of March 9, 1949, Intensity VI. Geologic Formation: Alluvium. Unknown fault.

"One waterpipe was broken ...." USC&GS, "U. S. Earthquakes", 1949, p. 11.

198. WATER PIPES, Herlong, Lassen County, 0 miles from epicenter of Herlong earthquake of December 14, 1950, Intensity VII. Geologic Formation: Alluvium. Fort Sage fault.

"Some underground pipe damage." USC&GS, "U. S. Earthquakes", 1950, p. 14.

199. WATER PIPE, Oakland, Alameda County, 10 miles from epicenter of Berkeley Hills earthquake of July 23, 1951, Intensity IV. Geologic Formation: Very soft alluvium. Unknown fault.

"Water pipe broke and flooded street." USC&GS, "U. S. Earthquakes", 1951, p. 11.

200. WATER PIPES, Bakersfield, Kern County, 24 miles from epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Very soft alluvium. White Wolf fault.

"Many consumers lines broken. These are house connections .... Probably 400/500 broken." USC&GS, "Abstracts", MSA-75, p. 28.

201. WATER PIPES, Exeter, Tulare County, 90 miles from epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Very soft alluvium. White Wolf fault.

"Minor leaks in pipelines." USC&GS, "U. S. Earthquakes", 1952, p. 21.

202. WATER PIPES, Taft, Kern County, 28 miles from epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Very soft alluvium. White Wolf fault.

"Four-inch waterline reported broken in SE 1/4, Sec. 36, T31S, R24E." USC&GS, "U. S. Earthquakes", 1952, p. 24.

203. WATER PIPE, Bodfish, Kern County, 50 miles from epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Rock. White Wolf fault.

"Broken water pipe was attributed to earthquake." USC&GS, "U. S. Earthquakes", 1952, p. 25.

204. WATER PIPES, Petrolia, Humboldt County, 12 miles from epicenter of Petrolia earthquake of September 22, 1952. Geologic Formation: Very soft alluvium. Unknown fault.

"Plumbing in upper story of one house twisted loose and water flooded home." USC&GS, "U. S. Earthquakes", 1952, p. 41.

205. WATER PIPES, Bryson, Monterey County, 4 miles from epicenter of Bryson earthquake of November 21, 1952, Intensity VII. Geologic Formation: Alluvium. Unknown fault.

"A threaded waterpipe joint in the ground pulled apart." USC&GS, "U. S. Earthquakes", 1952, p. 45.

206. WATER PIPES, Eureka, Humboldt County, 6 miles southwest of epicenter of Eureka earthquake of December 21, 1954. Intensity VII.

Geologic Formation: Approximately one-half of the 19 water pipeline breaks were located in areas of filled ground, and approximately one-half of the water pipeline breaks were located on older Quaternary slightly compacted alluvium. Unknown fault.

"The Eureka distribution system was broken in a number of places including 16 gas pipeline breaks and 19 water pipeline breaks ....

"Total cost of repairs to the water supply, storage, and distribution systems of Eureka was estimated by city officials to be at least '$44,000'. Of this total cost $7,500 was spent on the distribution systems." [Assumed to include both 16 gas pipeline breaks and 19 two-inch galvanized water pipeline breaks.] Steinbrugge and Moran, 1957, p. 138.

207. WATER PIPES, Brawley, Imperial County, 3 miles from epicenter of Brawley earthquake of December 16, 1955. Geologic Formation: Very soft alluvium. Unknown fault.

"One break occurred in an old section of the city's water lines undergoing repair and there were about 15 breaks in private lines believed to be partially corroded." USC&GS, "U. S. Earthquakes", 1955, p. 32.

208. SEWER PIPES, San Francisco, San Francisco County, 5 miles from epicenter of Daly City earthquake of March 22, 1957. Geologic Formation: Alluvium. San Andreas fault.

" ... sewer and gas lines ... broken. Extensive plumbing damage." USC&GS, "U. S. Earthquakes", 1957, p. 23.

209. WATER PIPES, Hollister, San Benito County, 5 miles from epicenter of Hollister earthquake of January 19, 1960, Intensity VI. Geologic Formation: Very soft alluvium. Unknown fault.

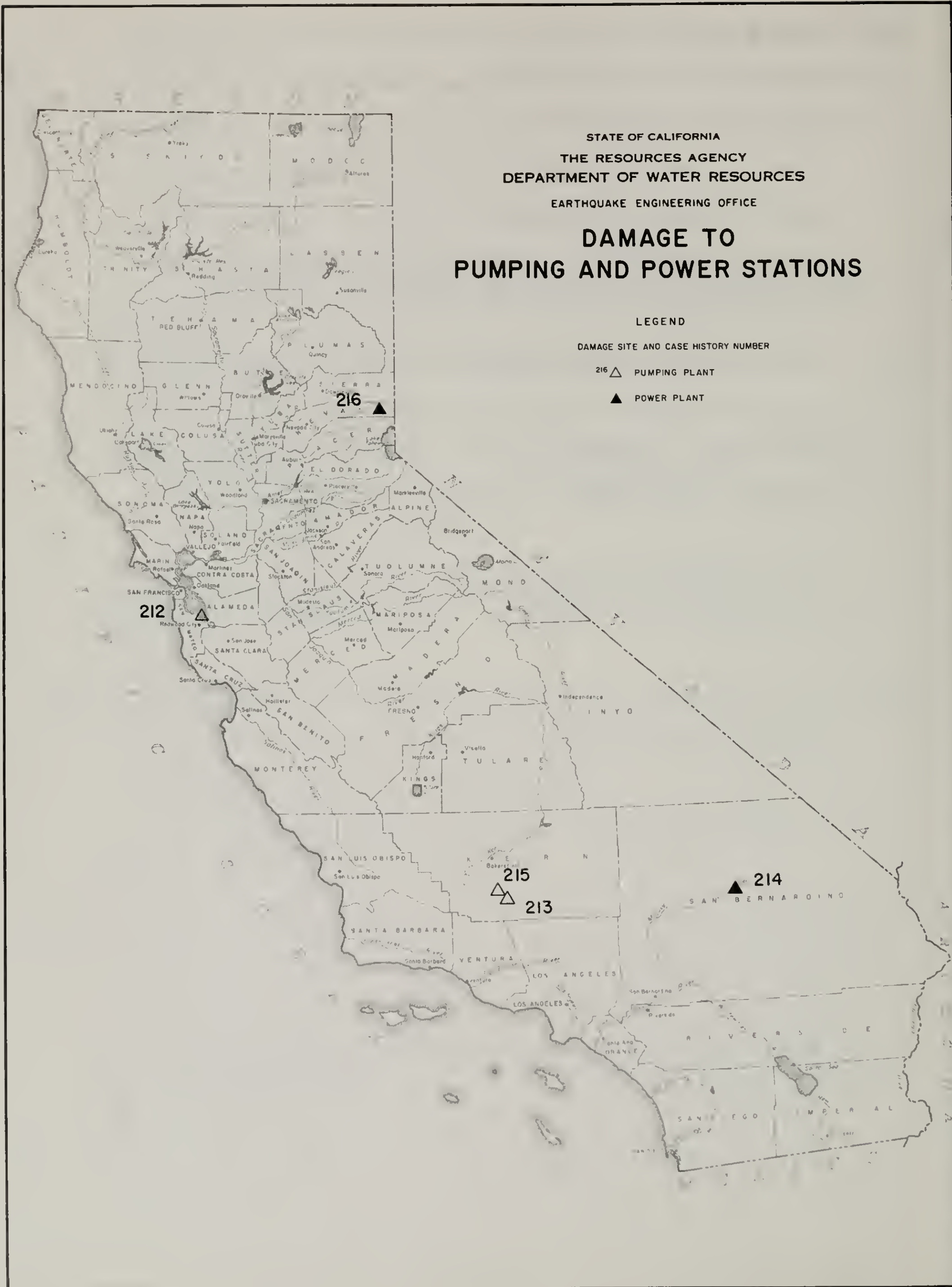
"A pipe broke between the boiler house and the drainage ditch [at the W. A. Taylor Winery]. This pipeline has broken before." USC&GS, "Abstracts", MSA-105, p. 4.

210. WATER PIPES, Hollister - Cienega District, San Benito County, about 8 to 10 miles north of epicenter of Hollister earthquake of April 8, 1961, Intensity VII. Geologic Formation: Unconsolidated alluvium, older Pleistocene alluvium, and undifferentiated Pliocene sediments. San Andreas fault.

"One-inch water pipe, buried at 45° to fault, broken ... Three-inch pipeline broken (almost parallel to fault) ..." USC&GS, "Abstracts", MSA-110, p. 8.

211. WATER PIPES, Parkfield Episcopal Church, Monterey County, 12 miles to epicenter of Parkfield earthquake of June 27, 1966, Intensity VII. Geologic Formation: Alluvium. San Andreas fault. "broken ... water pipes." The Daily Press, June 29, 1966.

FIGURE 13



STATE OF CALIFORNIA
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EARTHQUAKE ENGINEERING OFFICE
DAMAGE TO
PUMPING AND POWER STATIONS
LEGEND
DAMAGE SITE AND CASE HISTORY NUMBER
216 PUMPING PLANT
POWER PLANT
216
212
215
213
214
MENDOCINO
GLENN
BUTTE
PLUMAS
TEHAMA
LAKE
COLUSA
YOLO
SONOMA
NAPA
SOLANO
MARIN
CONTRA COSTA
SAN FRANCISCO
ALAMEDA
SANTA CLARA
SANTA CRUZ
SAN BENITO
MONTEREY
EL DORADO
ALPINE
TUOLUMNE
MONO
MARIPOSA
STANISLAUS
SAN JOAQUIN
MADERA
FRESNO
KINGS
TULARE
INYO
KERN
SAN LUIS OBISPO
SANTA BARBARA
VENTURA
LOS ANGELES
SAN BERNARDINO
RIVERSIDE
SAN DIEGO
IMPERIAL
SACRAMENTO

CATEGORY V

PUMPING AND POWER STATIONS

(Cases 212-216)

212. BELMONT PUMPING STATION, Belmont, San Mateo County, 40 miles from epicenter of San Francisco earthquake of April 18, 1906. Geologic Formation: Franciscan formation and alluvium and salt marsh. San Andreas fault.

"... at Belmont the flange of a steam valve serving one of five pumps was broken." Eckart, p. 193.

213. PUMPING PLANT, Grapevine, Kern County, 25 miles from epicenter of Maricopa earthquake of February 16, 1919. Geologic Formation: Alluvium. Unknown fault.

"Grapevine pump station, nine miles northwest of Lebec, where a concrete floor was cracked." Townley and Allen, p. 209.

214. ELECTRIC POWERPLANT, Newberry, San Bernardino County, 13 miles from epicenter of Manix earthquake of April 10, 1947. Geologic Formation: Very soft alluvium. Manix fault.

" ... an electric power plant was knocked off its foundation. Witnesses there reported that the ground rolled 'like a great ocean swell,' rocks rolled down mountains, and dust puffed up into the air during the earthquake." BSSA, 1947, Vol. 37, No. 2, p. 162.

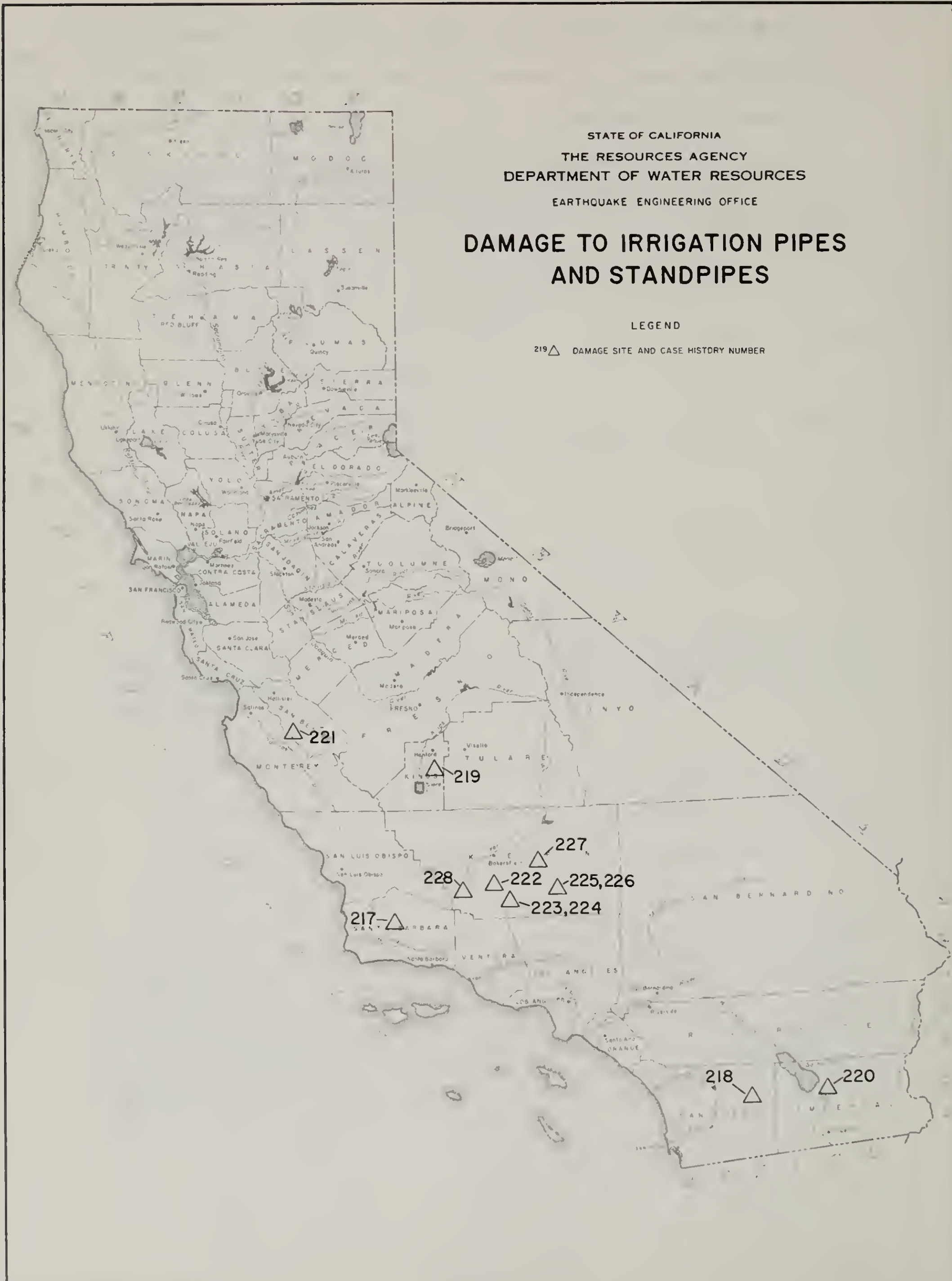
215. ROSE PUMPING STATION, 1.5 miles south of Wheeler Ridge, Kern County, 3 miles from epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Very soft alluvium. White Wolf fault.

"In the main machine installation, which contains the boilers and steam pumps, constructed of structural steel with corrugated steel sidings and roof, the connecting pipes and fittings between boilers and pumps were torn loose, the pressure to the pumps was lost, causing a temporary shut down of operations. The pump bases were slightly cracked, the heater tanks had shifted slightly, and there were cracks in the ground where the pipes enter. The chief engineer knew of no damage to the external structure housing the machinery." USC&GS, "Abstracts", MSA-75, p. 41.

216. FARAD POWERHOUSE, between Boca and Floriston, Nevada County, about 7 miles south of epicenter of Truckee earthquake of September 12, 1966. Fault unknown.

"Boulders tumbled from the cut slope above Interstate 80.... The unreinforced brick masonry wall of the Farad Powerhouse [below the highway] was penetrated by a twenty ton boulder." California Water Resources, p. 3.

FIGURE 14


STATE OF CALIFORNIA
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DEPARTMENT OF WATER RESOURCES
EARTHQUAKE ENGINEERING OFFICE
DAMAGE TO IRRIGATION PIPES AND STANDPIPES
LEGEND
219 △ DAMAGE SITE AND CASE HISTORY NUMBER
221
219
227
228
222
225,226
223,224
217
218
220
SAN FRANCISCO
SAN LUIS OBISPO
MONTEREY
TULARE
MONO
SANTA CLARA
ALAMEDA
CONTRA COSTA
EL DORADO
AMADOR
ALPINE
TUOLUMNE
MARIPOSA
SAN BERNARDINO

CATEGORY VI

IRRIGATION PIPES AND STANDPIPES

(Cases 217-229)

217. IRRIGATION PIPELINE, Zaca Lake, Santa Barbara County, 10 miles (not instrumentally determined) from epicenter of Los Alamos earthquake of January 11, 1915. Geologic Formation: Miocene marine sediments. Unknown fault.

"At Zaca Lake the shock broke all the connections on a 16-inch cement irrigating pipe 660 feet long, which was in a tunnel 42 feet underground." Beal, March 1915, p. 20.

218. IRRIGATION PIPELINE, Borrego, San Diego, 50 miles from epicenter of Imperial Valley earthquake of May 18, 1940. Geologic Formation: Very soft alluvium. Imperial fault.

"Damage slight to irrigation pipeline." USC&GS, MSA-26, 1940, p. 23.

219. IRRIGATION PIPES, Corcoran, Kings County, 122 miles from epicenter of Eureka Valley earthquake of February 11, 1949. Geologic Formation: Alluvium. Unknown fault.

"Cracked standpipes on 18" concrete water supply line." USC&GS, 1949, p. 9.

220. STANDPIPES (concrete), Calipatria, Imperial County, probably within 1 to 5 miles of epicenter of Calipatria earthquake of July 29, 1950. Geologic Formation: Unconsolidated alluvium, thick section, saturated. Unknown fault.

"In Calipatria concrete standpipes broke ...." Wood and Heck, p. 39.

221. IRRIGATION PIPES (concrete), Pinnacles, San Benito County, 5 miles from epicenter of Mulberry earthquake of July 29, 1951. Geologic Formation: Rock. Unknown fault.

"Slight damage to concrete pipes." USC&GS, "U. S. Earthquakes", 1951, p. 12.

222. IRRIGATION PIPES AND STANDPIPES (concrete), Kern County, approximately 18 miles north of epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Unconsolidated alluvium (fans, flood plain and basin deposits), saturated thick section. White Wolf fault.

"Extensive rupturing of concrete irrigation pipes resulted from the Arvin earthquake. The pipes lie at shallow depths, and were damaged by shifting, compaction and settlement in the alluvium ....

"Concrete standpipes were severely damaged. In general, ruptures occurred at the base of the standpipes. Metal standpipes anchored in concrete were occasionally toppled ...." Marliave, 1952, pp. 9-10.

"Concrete irrigation systems were damaged over large areas, but rarely destroyed. ... the pipe was usually tongue and groove, and was not reinforced. Breaks were found as close together as 3 feet to 6 feet in some areas. Vertical standpipes were generally damaged in the heaviest hit areas." Steinbrugge and Moran, pp. 299-300.

Repair Time: Repairs were initiated immediately, pipe layers and crews from all parts of California and neighboring states were called in.

223. IRRIGATION PIPES, Tejon Ranch (11 miles east of Wheeler Ridge on El Paso Creek), Kern County, 2 miles from epicenter of Kern County earthquake of July 21, 1952. White Wolf fault. Alluvium.

"... irrigation pipes ... damaged ...." USC&GS, "Abstracts", MSA-75, 1952, p. 20.

224. IRRIGATION PIPES, Glen Moody Ranch (south central Kern County), Kern County, 0 miles from epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Very soft alluvium. White Wolf fault.

"On the Glen Moody Ranch irrigation pipelines, which were buried 2 feet, were thrown to surface and broken, concrete pipes were severely cracked." USC&GS, MSA-75, 1952, p. 21.

225. IRRIGATION PIPES, Comanche Point Road, Kern County, 10 miles from epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Probably alluvium. White Wolf fault.

"1000' of concrete pipe cracked." USC&GS, "Abstracts", MSA-75, 1952, p. 32.

226. IRRIGATION PIPES, Tahachapi, Kern County, 30 miles from epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Very soft alluvium. White Wolf fault.

"Only pipes full of water cracked." USC&GS, 1952, p. 20.

227. IRRIGATION PIPES, Fairfax, Kern County, 27 miles from epicenter of Caliente earthquake of July 25, 1952. Geologic Formation: Very soft alluvium. Unknown fault, possibly White Wolf fault.

"Some pipeline damage and releveling." USC&GS, 1952, p. 35.

228. IRRIGATION PIPES, Maricopa Seed Farm (15 miles east of Maricopa), Kern County, 8 miles from epicenter of Wheeler Ridge earthquake of January 12, 1954. Geologic Formation: Alluvium. Unknown fault, possibly White Wolf fault.

" . . . some concrete pipe and steel-line breakage . . . ." USC&GS, "U. S. Earthquakes", 1954, p. 12.

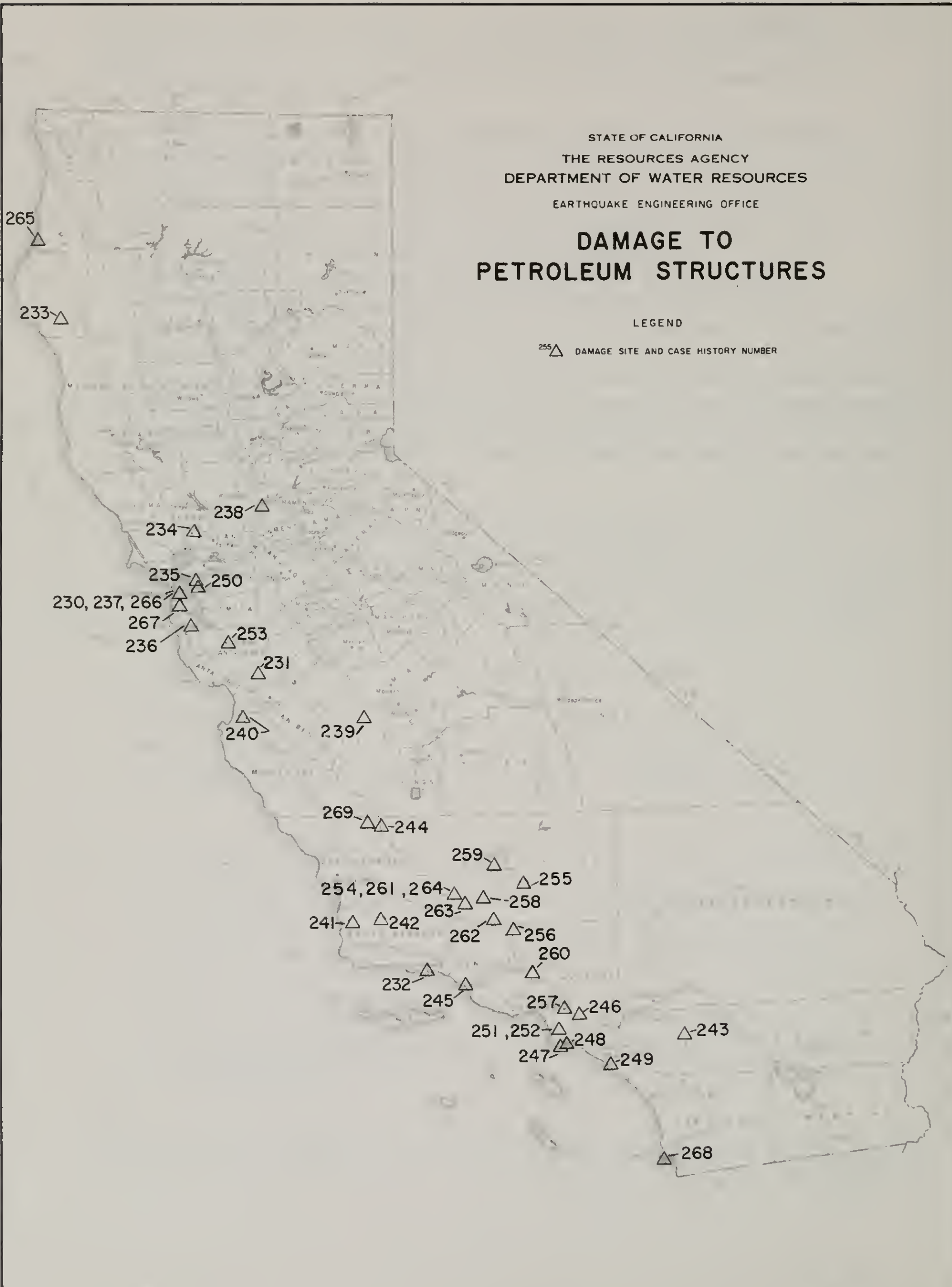
229. WEIRS*--Timbered weirs, Kern River; and check weirs, Kern Island Canal, Bakersfield, Kern County; approximately 22 miles north of epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Unconsolidated alluvium (fans, flood plain and basin deposits), saturated, thick section. White Wolf fault.

" ... five timbered diversion weirs located along the channel of the Kern River, each of which is several hundred feet in length, with the superstructure from 10 to 15 feet in height erected above a substructure consisting of 2-inch plank deck supported by anchor and sheet piling 16 feet in length. Only one of these weirs was damaged by the earthquake shock; it was buckled upward to a height of about 3 feet at the midpoint along approximately 50 feet of its transverse length. The deck separated from the piling and the stream flow ... passed beneath the deck ....

"Subsequent examination revealed that the upper part of the piling was 'punky' and it seems evident that the failure was caused by the deteriorated condition of the piling substructure rather than a weakness in design ...." Hemborg, p. 236.

*Because Case Number 229 refers to damage to weirs only, it is not shown on Figure 14.

FIGURE 15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EARTHQUAKE ENGINEERING OFFICE
DAMAGE TO PETROLEUM STRUCTURES
LEGEND
255 DAMAGE SITE AND CASE HISTORY NUMBER
265
233
238
234
235
250
230, 237, 266
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253
231
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254, 261, 264
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251, 252
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268

CATEGORY VII

PETROLEUM STRUCTURES

(Cases 230-269)

A close-up of the compressional buckle, the ruptured fuel tank, and the revetment at the foot of the landslide near the Alaska Native Hospital, Anchorage.

The dock area, a tank farm, and railroad facilities at Whittier were severly damaged by the surge-waves developed by underwater landslides in Passage Canal. The waves inundated the area of darkened ground, where the snow was soiled or removed by the waves.

230. GAS PIPES, San Francisco, San Francisco County, 50 miles from epicenter of Santa Cruz Mountains earthquake of October 8, 1865. Geologic Formation: Alluvium. Possibly San Andreas fault.

"On the marshy lands in the vicinity of Howard and Seventh Streets, lamp posts, water pipes, and gas pipes were broken and thrown out of position." Holden, p. 66.

231. GAS MAINS, Gilroy, Santa Clara County, about 8 miles from epicenter of Monterey Bay Region earthquake of April 24, 1890. Geologic Formation: Alluvium. Unknown fault, possibly San Andreas fault.

"The gas mains were disjointed, and there was some other damage." Townley and Allen, 1939, p. 81.

232. OIL AND WATER PIPELINES, Santa Barbara (Western Union Oil Company), Santa Barbara County, 10 miles from epicenter of Los Alamos earthquake of July 27, 1902. Geologic Formation: Sand dunes. Unknown fault.

"On the property of the Western Union Oil Co., two tanks containing 3,000 barrels of oil each were destroyed. Pipes for conducting oil and water were twisted and broken." Townley and Allen, 1939, p. 117.

The following eight Cases concerning damage to petroleum structures are related to the San Francisco earthquake, April 18, 1906, San Andreas fault.

233. GAS PIPES, Briceland, Humboldt County, 150 miles from epicenter. Geologic Formation: Solid sandstone and shale, bedrock near surface.

"The village suffered damage to the extent of $1,500 due to the breaking of chimneys, water and gas pipes, household furniture, etc." Lawson, Vol 1, p. 170.

234. GAS MAINS, Napa, Napa County, 33 miles from epicenter. Geologic Formation: Alluvium.

"The damage to street gas mains at Napa was very slight, only two leaks developing. The gas station was badly shaken up; about 10 feet of the end wall of the brick building was thrown down, falling on top of the boiler and breaking off the steam pipes. The gas-holders were badly shaken up. Water was displaced from the tanks, but only one guide wheel was shaken out of place." Lawson, Vol. 1, p. 211.

235. GAS PIPE, Oakland, Alameda County, 34 miles from epicenter.

"There were very few breaks in cast-iron gas mains. Two of these were caused by impact of heavy debris falling from buildings and poles. One was on Washington Street, where heavy blocks of sandstone fell from the third story and the roof, breaking the main 30 inches below the bituminous rock. Another was at the corner of Fourteenth Street and Broadway, where a transformer fell from a pole, striking the center of a short car rail and bending up both ends. A 3-inch cast iron main a short distance from this was broken at right angles. On the Twelfth Street Dam, a cast iron pipe was broken and displaced over a foot while the high pressure steel pipe paralleling it was practically undisturbed." Lawson, Vol. 1, p. 302.

236. GAS TANK, Redwood City, San Mateo County, 47 miles from epicenter. Geologic Formation: Alluvium.

"A 20,000-foot gas-holder in a redwood tank above ground was completely demolished by the earthquake." Lawson, p. 254.

237. GAS MAINS, San Francisco, San Francisco County, approximately 32 miles southeast of epicenter. Geologic Formation: Unconsolidated alluvium, dune sand, marshland, filled ground and solid ground (Franciscan formation).

"In solid ground there was very little trouble and but very few breaks. A number of the breaks noted . . . as being on solid ground were caused by the use of dynamite and other explosives, employed in blowing down buildings.

"In the above sunken streets the city sewers, as well as other conduits, such as gas pipes, electric light conduits, etc., suffered the same as the water pipes, in that they were also similarly ruptured by the sinking and violent oscillations of the ground.

During a three-month period, April 18 to July 18, 1906, ... "there had been discovered and repaired 300 breaks in the ... pipe system ... 276 were in and immediately adjoining the burnt district ... in the ... unburnt district, only 24 breaks have been found and repaired." Eckart, pp. 194-195.

238. GAS TANK, Sacramento, Sacramento County, about 75 miles east

of epicenter. Geologic Formation: Alluvium.

"The damage at the gas plant was very slight. The gas holders rocked to such an extent that considerable water was thrown out of the tanks, and the seals of the holder sections were partially emptied, allowing gas to escape." Lawson, p. 216.

239. OIL TANK, Mendota, Fresno County, 156 miles from epicenter.

Geologic Formation: Alluvium.

"At an oil-pumping station 10 miles south of Mendota, there were 10 large tanks ... of these the roofs (unsubstantially braced) of 6 caved in, and much oil was thrown over the sides." Lawson, p. 318.

240. OIL PIPELINE, Salinas River, Monterey County, 120 miles from

epicenter. Geologic Formation: Alluvium.

"An oil pipe which crost the bridge was twisted and buckled at the south end of the bridge, and when this was repaired the pipe was found to be shortened 7 feet. The pipeline extends from the San Joaquin Valley to the Bay of Monterey. A few hundred yards to the south of the bridge is a pumping station, and at this point some of the connections of the pipe were broken and displaced. The direction of the shortening of the bridge span and the pipe is roughly normal to the direction of the San Andreas Rift, on the other side of the Gavilan Range. Mr. S. A. Guiberson, superintendent of the line, reports that the pipe was broken in about 20 placed in the vicinity of the river, and that at some of these breaks the pipe was pulled apart." Lawson, Vol. 1, p. 296.

241. OIL PIPELINE, Harris, Santa Barbara County, 15 miles from epicenter of Los Alamos earthquake of January 11, 1915. Geologic Formation: Probably alluviated portion of valley. Fault unknown.

"At Harris the 8-inch pipeline of the Associated Oil Company from the Santa Maria field to Gaviota was broken, about 1,200 barrels of oil escaped." Beal, March 1915, p. 19.

242. OIL PIPELINE, Santa Rita, Santa Barbara County, 10 miles from epicenter of Los Alamos earthquake of January 11, 1915. Geologic Formation: Alluvium. Fault unknown.

"The same pipe [as in Case 241 above] was broken in two places near Santa Rita where the line runs southeast; in one of these breaks the pipe was apparently pulled apart at the union, and the southeast section pushed to the southwest and both sections pushed past each other, so that when found one lapped on the other four or five inches." Beal, March 1915, p. 19.

243. GAS MAINS, San Jacinto, Riverside County, 3 miles from epicenter of San Jacinto earthquake of April 21, 1918. Geologic Formation: Alluvium. San Jacinto fault.

" ... within ten minutes the breaking of the gas mains made it necessary to shut off the supply." UC, 1915, Vol. 1, p. 130.

Costs: Total damage from quake did not exceed $225,000 total of all damage in San Jacinto and Hemet.

244. OIL PIPELINES, Vicinity of Shandon and Antelope Valley, San Luis Obispo and Kern Counties, approximately 10 miles southeast of epicenter of Cholame Valley earthquake of March 10, 1922. Geologic Formation: Variable unconsolidated alluvium and Tertiary sediments. Probably San Andreas fault.

" ... oil pipelines broken between Shandon and Antelope ...." Wood and Heck, 1951, p. 32.

245. OIL PIPELINE, Ventura, Ventura County, 130 miles from epicenter of Point Arguello earthquake of November 4, 1927. Geologic Formation: Probably alluvium. Fault unknown, offshore.

"In Ventura a pipeline was broken." UC, 1915-1930, pp. 113-121.

246. OIL PIPELINES, Santa Fe Springs , Los Angeles County, 15 miles from epicenter of Whittier earthquake of July 8, 1929. Fault unknown.

"Oil operators at Santa Fe Springs reported that two producing oil wells in the eastern end of the field were stopped up by the tremor. Several oil lines in the field were reported broken." UC, 1915-1930, pp. 170-176.

247. OIL PIPELINE, Signal Hill, Los Angeles County, 5 miles from epicenter of Long Beach earthquake of March 10, 1933. Geologic Formation: Pleistocene marine sediments. Newport-Inglewood fault zone.

"Oil line broken." USC&GS, 1933, p. 11.

248. GAS MAINS, San Pedro, Los Angeles County, 20 miles from epicenter of Long Beach earthquake of March 10, 1933. Geologic Formation: Pleistocene marine terrace deposits. Newport-Inglewood fault zone.

"Numerous leaks in gas lines." USC&GS, 1933, p. 12.

249. GAS MAINS, Laguna Beach, Orange County, 20 miles from epicenter of Long Beach earthquake of March 10, 1933. Geologic Formation: Pleistocene marine terrace deposits. Newport-Inglewood fault zone.

"Leaks in ... gas mains." USC&GS, 1933, p. 12.

250. GAS PIPES, Berkeley, Alameda County, 4 miles from epicenter of Berkeley earthquake of March 8, 1937. Geologic Formation: Alluvium or Merritt sand. Fault unknown, probably Hayward fault.

"A number of gas lines were pulled apart or snapped off in the Cragmont Avenue and Keith Avenue section. In Berkeley and El Cerrito . . . in one store a window display of about $150 worth of choice liquors was thrown through a large window . . . . " UC, 1934-1937, Clipping from Oakland Tribune, March 8, 1937.

251. OIL AND GAS PIPES AND OIL TANKS, Torrance-Gardena area, Los Angeles County, 2 miles from epicenter of Torrance-Gardena earthquake of November 14, 1941. Geologic Formation: Very soft alluvium. Fault unknown.

"In the oil fields 2 tanks were demolished, 2 buckled badly, and a 6-inch pipeline broke in 4 additional places after having broken in 1 place during the October 21 earthquake; and an 8-inch natural gas pipe line burst. Fire was overted in all cases and most of the oil was recovered. Ground cracks were found in several cases near the broken oil line." USC&GS, "U. S. Earthquakes", 1941, p. 17.

252. OIL PIPELINE, Torrance-Gardena, Los Angeles County, 0 miles from epicenter of Torrance-Gardena earthquake of November 14, 1941. Geologic Formation: Very soft alluvium. Fault unknown.

"The swaying east-west tremblor . . . snapped oil and pipelines. In 1 liquor store, 15 thousand dollars' worth of stock was thrown to the cement floor and ruined." USC&GS, "U. S. Earthquakes", 1941, p. 17.

253. GAS MAIN, San Jose, Santa Clara County, 14 miles west of epicenter of Mount Hamilton area earthquake of October 25, 1943. Geologic Formation: Thick alluvium. Fault unknown, probably Calaveras fault.

" . . . at San Jose . . . a small gas main snapped in the Security building at First and San Fernando Streets." UC, 1943-48, Clipping from San Francisco News, October 26, 1943.

254. OIL PIPELINES, Maricopa area, Kern County, 2 to 4 miles north of epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Unconsolidated alluvium. White Wolf fault.

"Steel pipelines used in conveying petroleum were severed by landslides caused by the earthquake in the vicinity of Grapevine near Highway 99. Lateral displacement of alluvium in the area north of Highway 166 caused breaks in other oil lines. Several breaks occurred ... [in an area about a mile north of Wheeler Ridge]. Rupture of lines appeared to take place at points of weakness, as all breaks do not necessarily appear to have occurred in areas of particularly sharp movement. A cumulative compression of stretching effect caused ruptures, especially where the lines curved. These steel lines averaged five-sixteenth inch thick and ranged in diameter from 6 to 10 inches. The line to one General Petroleum pumping station, located about seven miles west of Highway 99 on Highway 166, bends gently to the north approximately 1-1/2 miles north of the station. The pipe at the bend was separated 18 inches. One-half mile to the north, a four-foot section of an oil line curving gently to the west was first buckled sharply to the west then straightened out before breaking six feet further north. In the same vicinity, two pipes on opposite sides of a road striking north-south suffered the opposite kind of action. The line on the east side telescoped approximately 36 inches, while that on the west side pulled apart approximately 55 inches. These lines were about 30 feet apart at points of rupture ...." Marliave, 1952, p. 10.

"The General Petroleum Corporation ... Emidio Pipe Line Station was probably the most severely shaken and pipe movements at this location in excess of five inches were noted. The following is a summary of pipeline breakage in the vicinity of Emidio Pipe Line Station, with distance from Emidio:

1.375 miles east: Pulled apart, then telescoped.
1.4 miles east: Pulled apart, then telescoped.
6.75 miles west: Line pulled out of collar.
.28 miles north: Line crinkled and ruptured.
.72 miles north: Pulled apart.
.76 miles north: Pulled apart, then telescoped.
1.04 miles north: Weld broke.
1.5 miles north: Pulled apart, then telescoped 42"."

Steinbrugge and Moran, 1954, p. 270.

255. OIL PIPELINES, Emidio, Kern County, 3 miles from epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Very soft alluvium. White Wolf fault.

"Severe damage to General Petroleum Corporation's pipelines. Breaks occurred on 8 and 10 inch lines. One 10 inch pipe telescoped 42 inches." USC&GS, "Abstracts", MSA-75, 1952, p. 19.

256. GASOLINE PIPELINE, Gorman, Los Angeles County, 16 miles from epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Very soft alluvium. White Wolf fault.

" ... a 10-inch gasoline pipeline severed. Gasoline cascaded down cliff." USC&GS, "Abstracts", MSA-75, 1952, p. 23.

257. GAS PIPE, Los Angeles, Los Angeles County, 80 miles from epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Very soft alluvium. White Wolf fault.

"68 earthquake operated gas shutoff valves in schools of the L. A. School District were operated. Hanging space heaters broke gas lines in industrial installation. Excess flow valves operated." USC&GS, "U. S. Earthquakes", 1956, p. 22.

258. OIL TANK, Tajon Ranch, Kern County, 10 to 15 miles from epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Alluvium. White Wolf fault.

" ... one of a battery of three 1,500-barrel [oil] tanks in the Tajon Ranch area ... collapsed .... " Johnson, p. 222.

259. BUTANE TANKS, near Bakersfield, Kern County, 14 miles from epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Alluvium. White Wolf fault.

At Paloma Cycling Plant 16 miles southwest of Bakersfield, "The shock of the earthquake caused two of the large spherical butane storage tanks to collapse, thereby rupturing lead-in lines and releasing quantities of highly volatile material." Johnson, p. 222.

260. GAS PIPELINE, Newhall, Los Angeles County, 45 miles from epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Very soft alluvium. White Wolf fault.

"Press reported a 12 inch gas line broken near the city limits." USC&GS, "U. S. Earthquakes", 1952, p. 22.

261. GAS PIPELINES, Emidio, Kern County, approximately 2 to 4 miles north of epicenter of Wheeler Ridge earthquake of January 12, 1954. Geologic Formation: Unconsolidated alluvium. Fault unknown, possibly White Wolf fault.

"... Southern California Gas and also Richfield Oil Company had ... pipeline damage ... in this area". Steinbrugge and Moran, 1954, p. 270.

262. GAS PIPELINE, Ridge Route between Los Angeles and Taft, 25 miles from epicenter of Wheeler Ridge earthquake of January 12, 1954. Geologic Formation: Alluvium. Fault unknown, possibly White Wolf fault.

" ... 12 inch gas pipeline broke." USC&GS, 1954, p. 12.

263. OIL PIPELINE, Paloma Oil Field, Kern County, 16 miles from epicenter of Wheeler Ridge earthquake of January 12, 1954. Geologic Formation: Alluvium. Fault unknown, possibly White Wolf fault.

" ... pipeline cracked at the Paloma oil field." USC&GS, "U. S. Earthquakes", 1954, p. 12.

264. GAS PIPELINE, Maricopa Flats, Kern County, 15 miles from epicenter of Wheeler Ridge earthquake of January 12, 1954. Geologic Formation: Alluvium. Fault unknown, possibly White Wolf fault.

"... gas pipelines damaged ...." USC&GS, 1954, p. 12.

265. GAS PIPES, Eureka, Humboldt County, 12 miles southwest of epicenter of Eureka earthquake of December 21, 1954. Geologic Formation: Filled ground and older Quaternary, slightly compacted alluvium. Fault unknown.

"The Eureka distribution system was broken in a number of places including 16 gas pipeline breaks and 19 water pipeline breaks." Steinbrugge and Moran, April 1957, pp. 138-139.

266. GAS PIPES, San Francisco, San Francisco County, 5 miles from epicenter of Daly City earthquake of March 22, 1957. Geologic Formation: Alluvium. Unknown fault.

"... gas lines ... broken." USC&GS, "U. S. Earthquakes", 1957, p. 23.

267. GAS MAIN, San Bruno, San Mateo County, 5 miles from epicenter of Daly City earthquake of March 22, 1957. Geologic Formation: Very soft alluvium. San Andreas fault.

"Gas main broke in Rollingwood tract ... plumbing broken." USC&GS, "U. S. Earthquakes", 1957, p. 22.

268. GAS MAIN, Fort Rosecrans, Point Loma, San Diego County, approximately 150 miles northeast of epicenter in Baja California, Mexico, of Baja California earthquake of November 30, 1958. Geologic Formation: Cretacious shales and sandstones, dip slope. Fault unknown.

" ... Lt. Brown felt it at Fort Rosecrans and the next day discovered a broken water main on the east hill-slope of the Point. There were numerous deep, open ground cracks; a major crack parallel to the contours passed through the site of the pipe break. The pipe ran directly upslope. On December 5 an odor of gas was noted and he found a two-inch tension break in a gas line northeast of the water line break. There are ground cracks in the vicinity of this break also and one of them passed through the site of the break. It was subsequently discovered that 2-1/2 million cubic feet of gas had escaped, indicating that the break had been open for some days, quite possibly since November 30. I toured the area of damage with Lt. Brown and saw extensive tension cracking high on the hill slope and small compression ridges along the asphalt roadway at the foot of the slope. The cracks swing in a generally arcuate form up the hillside and back down to the roadway, enclosing an area of some acres located between Ballast Point and the U. S. Navy Fuel Facility. Movement has continued since November 30, displacement on the water main now amounting to two feet. The area is a dip-slope in Cretaceous shales and sandstones; according to Moore (NEL Technical Report) the dips in this area are 5° to 10° which is less than the slope of the land surface just above the road. Up the hill from the cracking is the National Cemetery which has recently been expanded and where there is extensive watering of grass. This is an almost perfect example of dip-slope landsliding as has occurred recently in the Los Angeles area. Lt. Brown's suggestion that the slide was touched off by the November 30 shock is reasonable. However, the basic cause is instability of the slope, and the effects of the watering in the cemetery should be investigated. It should be noted that movement occurred before any heavy rains had occurred. I would anticipate that the sliding will continue with the eventual result of carrying out the road and dumping several acres of Point Loma into the San Diego harbor channel entrance." USC&GS, MSA-100, 1958, p. 23.

269. OIL PIPELINE, Highway 46, (1) mile east of Cholame, San Luis Obispo County, within 35 miles of epicenter of Parkfield earthquake of June 27, 1966, Intensity VII. Geologic Formation: Paso Robles. San Andreas fault.

" ... broke a Union Oil Co. pipeline along roadside." The Daily Press, June 29, 1966.

STATE OF CALIFORNIA

THE RESOURCES AGENCY

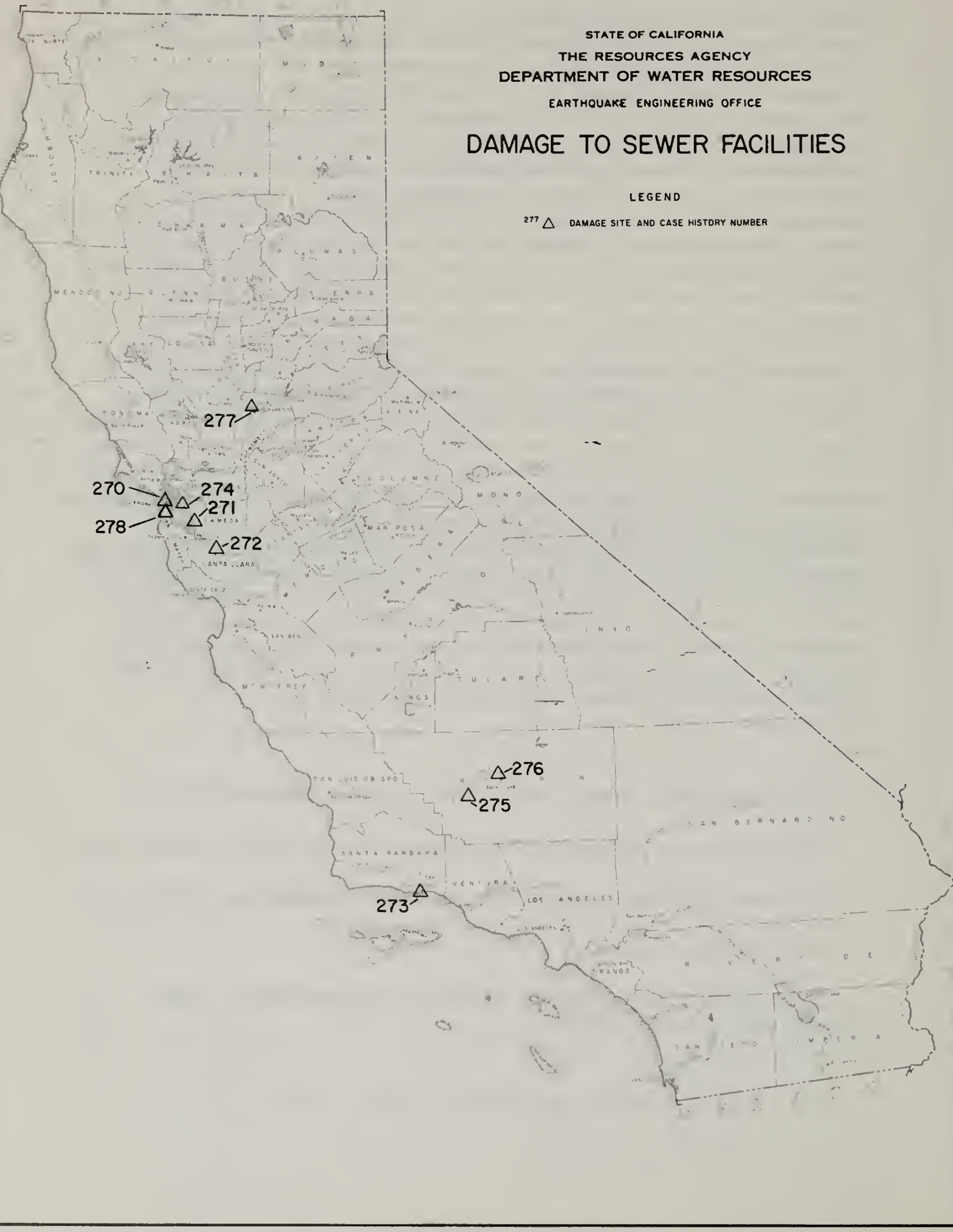
DEPARTMENT OF WATER RESOURCES

EARTHQUAKE ENGINEERING OFFICE

DAMAGE TO SEWER FACILITIES

LEGEND

277 △ DAMAGE SITE AND CASE HISTORY NUMBER



CATEGORY VIII

SEWERAGE FACILITIES

(Cases 270-278)

270. SEWERS, City of San Francisco, San Francisco County, approximately 32 miles southeast of epicenter of San Francisco earthquake of April 18, 1906. Geologic Formation: Unconsolidated alluvium dune sand, marshland, filled ground, and solid ground (Franciscan formation). San Andreas fault.

"In the above sunken streets the city sewers, as well as other conduits, such as gas pipes, electric light conduits, etc., suffered the same as the water pipes, in that they were also similarly ruptured by the sinking and violent oscillations of the ground." Eckart, 1937, p. 194.

271. WATER PIPES AND SEWER LINES, Alvarado, Alameda County, 40 miles from epicenter of San Francisco earthquake of April 18, 1906. Geologic Formation: Alluvium. San Andreas fault.

"The sewer pipe leading west to the creek was detached from the house by a space of 22 inches ... In the roadway south of the mill, water oozed out in a number of places without the production of visible cracks." Lawson, A. C., et al, 1908, Vol. 1, p. 305.

272. SEWER PIPE, San Jose, Santa Clara County, 8 miles from epicenter of San Jose earthquake of September 9, 1920. Geologic Formation: Very soft alluvium. Fault unknown.

"... a sewer pipe was cracked...." Townley and Allen, 1939, p. 217.

273. TRUNK-LINE SEWERS AND SEWER OUTFALL, City of Santa Barbara Santa Barbara County, approximately 6 to 10 miles north of epicenter of Santa Barbara earthquake of June 29, 1925. Geologic Formation: Unconsolidated alluvium, semi-swamp lands, and older, slightly compacted terrace sediments. Fault unknown, offshore.

"....A trunk line sewer of monolithic reinforced concrete pipe 33 inches in diameter, emptying at the treatment plant and leading back into the city, was cracked at various points. Two trunk-line sewers eighteen inches in diameter, of vitrified pipe were completely destroyed, ninety percent of the pipe being broken. The outfall sewer from the treatment plant to the ocean is a 44-inch reinforced concrete pipeline, constructed of pipe 12 feet in length.... It was this particular line, laid in sand over blue clay, that indicated a variation in elevation after the shock. Regardless of the fact that this line showed a violent movement, and that the Elastite joints were all squeezed out, not a single pipe was broken. The section continued out into the ocean, carried on capped piling, [but] did not show variation of elevation, although the joints were damaged and had to be recaulked. The lesson to be learned is that there is a much more violent movement in sand or swamp lands than in reasonably solid earthy and that vitrified pipe is worthless for sewer construction under the conditions mentioned." Nunn, 1925, pp. 314-315.

274. SEWER PIPE, Kensington Park, Alameda County; local, probably less than a mile from epicenter of Berkeley earthquake of March 8, 1937. Geologic Formation: Very soft alluvium. Fault unknown, probably Hayward fault.

"... Kensington Park where considerable damage was done to ... sewers." USC&GS, "Abstracts", MSA-12, 1937, p. 16.

275. SEWER PIPE, Fellows, Kern County, 37 miles from epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Very soft alluvium. White Wolf fault.

"House shifted northeast on foundation 3/8" and sewer connections broke at ground level on southwest side of house. Production tanks sloshed contents out on N-S sides." USC&GS, "U. S. Earthquakes", 1952, p. 21.

276. SEWER PIPE, Kern River Powerhouse, Kern County, 32 miles from epicenter of Kern County earthquake of July 21, 1952. Geologic Formation: Alluvium. White Wolf fault.

"At Kern River Powerhouse, about 10 miles northeast of Bakersfield, at the bottom of the Kern Canyon, boulders fell from both sides of the steep canyon walls, breaking ... sewers." USC&GS, 1952, p. 18.

277. SEWAGE TREATMENT PLANT, Sacramento, Sacramento County, 185 miles from epicenter of Dixie Valley, Nevada, earthquake of December 16, 1954. Geologic Formation: Deep alluvium. Dixie Valley and Fairview Valley fault. Intensity VI.

"Damage also occurred at the Sacramento Sewage Treatment Plant and was due to the surging of contents in the five digestion tanks, which are reinforced concrete tanks 100 feet in diameter. There was water in two of them and sludge in the other three. Minor damage was found at each floating roof, most of it sustained by the tanks with the sludge. The amplitude of motion is not exactly known, as only visual nonrecording gages are on the tanks. However, the Eureka (California) earthquake of December 21, 1954, created a surge causing the tank contents to oscillate through a double amplitude of 2 to 3 feet without damage to the tank; this movement was observed on the visual gages by the plant operator on duty. It is therefore not unreasonable that, as claimed by the plant operators, a 4-foot double-amplitude motion caused the damage to the roofs on December 16, 1954. The floating tank tops rotated clockwise, causing them to pound against stops (roller guides) preventing rotation. The computed fundamental period for the contents of these tanks, with contents assumed as water, and neglecting the effect of the floating top, is about 6.4 seconds. The sludge probably increased the fundamental period slightly." Steinbrugge and Moran, BSSA, Vol. 47, October 1957, pp. 340-343.

278. SEWER PIPE, Daly City, San Francisco County, 2 miles from epicenter of Daly City earthquake of March 22, 1957. Geologic Formation: Soft, sandy, Merced formation. San Andreas fault.

"... 97 broken sewer lines...." USC&GS, "Abstracts", MSA-93, p. 20.

DAMAGE

ADJACENT TO CALIFORNIA

The following Cases describe damage resulting in Nevada, Arizona, and Baja California, Mexico, from the nine earthquakes whose epicenters are indicated on Figure 17.

FIGURE 17

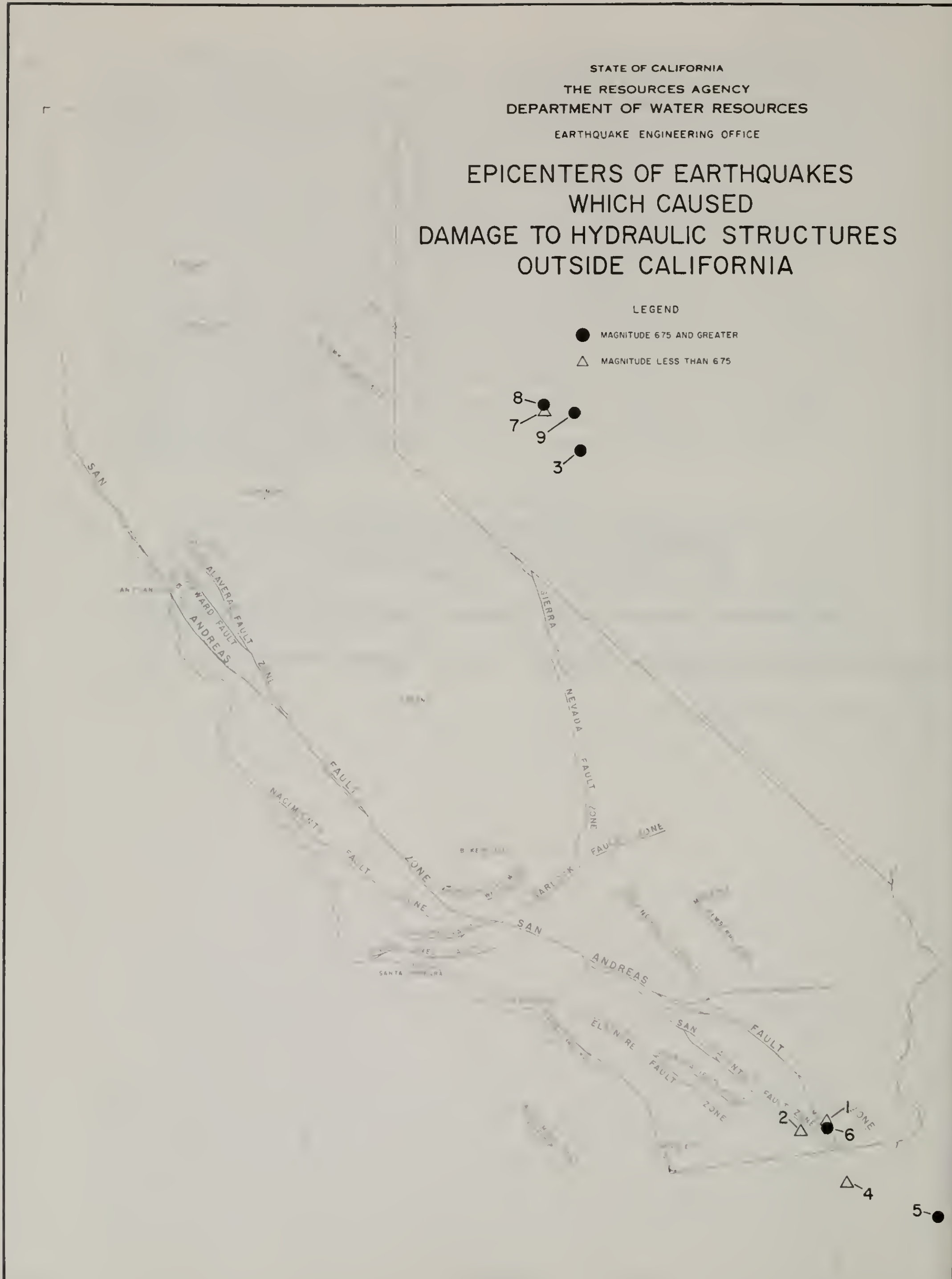

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
EARTHQUAKE ENGINEERING OFFICE
EPICENTERS OF EARTHQUAKES WHICH CAUSED DAMAGE TO HYDRAULIC STRUCTURES OUTSIDE CALIFORNIA
LEGEND
MAGNITUDE 6.75 AND GREATER
MAGNITUDE LESS THAN 6.75
8
7
9
3
SAN ANDREAS FAULT ZONE
SIERRA NEVADA FAULT ZONE
NACIMIENTO FAULT ZONE
SAN ANDREAS FAULT ZONE
ELSINORE FAULT ZONE
2
1
6
4
5

TABLE II

EARTHQUAKES DAMAGING TO
HYDRAULIC STRUCTURES ADJACENT TO CALIFORNIA

EXPLANATION:

Intensity - Maximum damage intensity at the epicenter in the Modified Mercalli Scale (I-XII)

Magnitude - Richter Scale (maximum observed is 8.75)
* -- Magnitude approximated from intensity information using conversion, page 353, Richter (1958)

Fault Displacement Description -
V -- Vertical movement
H -- Horizontal (strike slip) movement
L -- Length of rupture

Related Damage Cases - Numbers refer to numbered descriptions (Case numbers) in text

No.	Earthquake	Fault	Date	County	Epicenter	
					Lat. N.	Long. W.
1	El Centro-Calexico	Unknown, possibly south-eastward extension of San Jacinto	Jun. 22, 1915	Imperial	32.8°	115.5°
2	Imperial Valley (near Mexican border)	Unknown, possibly south-eastward extension of San Jacinto	Jan. 1, 1927	Imperial	32.5°	115.5°
3	Cedar Mountain Nevada	Cedar Mountain	Dec. 20, 1932		38.75°	118°
4	Laguna Salada District, Baja California, Mexico	Unknown, possibly San Jacinto	Dec. 30, 1934		32.25°	115.5°
5	Baja California Mexico	Unknown, probably southeast segment of San Jacinto	Dec. 31, 1934		32°	114.75°
6	Imperial Valley	Imperial	May 18, 1940	Imperial	32.7°	115.5°

Intensity	Magnitude	Fault Displacement Description	Related Damage Cases	References
VIII	6.25	(No rupture reported)	281	Allen, 1965, p. 769. Townley, 1939, pp. 180-181. Wood, 1966, pp. 12, 30-31.
VIII	5.75	(No rupture reported)	288	Townley, 1939, pp. 244-245. Wood, 1966, pp. 13, 33.
X	7.3	V-24" max; H-34" max. rt. hand offset; L-Individual displacements few hundred feet to 4 miles. Effects attributable to faulting were found in a belt 4 to 9 miles wide and 38 miles long trending about N21°W.	293, 294	Eppley, 1965, p. 64. Richter, 1958, pp. 469, 507-508. Wood, 1966, pp. 14, 20.
IX	6.5	(No rupture reported)	279, 296	Allen, 1965, pp. 767-769. Neumann, 1936, pp. 32-34. Wood, 1966, pp. 14, 35.
X	7.1	(No rupture reported) Surface rupture postulated based on interpretation of aerial photographs of the area taken in 1935 which show a distinct fault trace that has a much fresher appearance than that revealed in subsequent photography.	297	Allen, 1965, pp. 767-769. Neumann, 1936, pp. 34-36. Wood, 1966, pp. 14, 35.
X	7.1	V-4'; H-19'; L-40 miles approximately. Some indication that faulting in Mexico may have continued southward from areas of observed rupture, thus increasing length of rupture to in excess of 40 miles.	282, 289, 298, 299, 302, 303.	Allen, 1965, pp. 768-769. Neumann, 1942, pp. 20-24. Richter, 1958, pp. 488-494. Ulrich, 1941, pp. 16-24. Wood, 1966, pp. 14, 20-21.

No.	Earthquake	Fault	Date	County	Epicenter	
					Lat. N.	Long. W.
7	Fallon-Stillwater, Nevada	Fault system along eastern border of Rainbow Mountain	Jul. 6, 1954		39.4°	118.5°
8	Fallon-Stillwater, Nevada	Fault system along eastern border of Rainbow Mountain	Aug. 23, 1954		39.6°	118.5°
9	Dixie Valley, Nevada	Dixie Valley and Fairview Valley faults	Dec. 16, 1954		39.3°	118.2°

Intensity	Magnitude	Fault Displacement Description	Related Damage Cases	References
IX	6.6	V-1 to 12";H-none observed; L-approximately 11 miles. Vertical movement of the west side was up relative to the east side. Severe cracking, with no apparent displacement was also observed.	283, 284, 290, 300, 304.	Murphy, 1956, pp. 24-28. Richter, 1958, pp. 510-511. Wood, 1966, pp. 16, 41.
IX	6.8	V-30"; H-none observed; L-approximately 14 miles. The August 23 displacement was much more continuous than the July 6 movement. The west side of the fault was up relative to the east side.	285, 286, 291, 301.	Murphy, 1956, pp. 29-33. Richter, 1958, pp. 510-511. Wood, 1966, pp. 16, 41.
X	7.1	V-12'; H-12'; L-approximately 55 miles. Northern fault zone shows at least 7 feet of dip-slip and little or no strike-slip. The southern fault zone has up to 12 feet of vertical and horizontal movement.	280, 287, 292, 295.	Murphy, 1956, pp. 37-43. Richter, 1958, pp. 512-515. Wood, 1966, pp. 21-22.

279. WATER TANK, Cocopah, Baja California, about 150 miles from epicenter of Laguna Salada District earthquake of December 30, 1934, Intensity VIII. Fault unknown.

"An empty 65,000-gallon water tank was thrown sideways from its supporting columns and landed on its bottom outside the foundation area. Examination showed that one of the tie-rods was broken." USC&GS, "U. S. Earthquakes", 1934, p. 33.

280. WATER TANK, Mina, Nevada, 64 miles from epicenter of Dixie Valley earthquake of December 16, 1954. Geologic Formation: Alluvium. Dixie Valley and Fairview Valley faults.

"Water thrown 25 feet from 50-foot railroad water tank." USC&GS, "U. S. Earthquakes", 1954, p. 39.

281. VOLCANO LAKE DYKE, 25 miles south of Calexico, Baja California, 20 miles from epicenter of El Centro-Calexico earthquake of June 22, 1915. Geologic Formation: Very soft alluvium. Fault unknown, possibly southeast extension of San Jacinto fault.

"The Imperial Valley earthquake of June 22, 1915, was especially severe at and about Volcano Lake and the dyke was demolished .... The structure was inspected immediately after the earthquake and it was found to be completely destroyed with apparent spreading and fracturing of the main body of the dyke. ... Cracks 18 inches wide running along both upstream and downstream slopes were found to extend 5 feet into the body of the dyke." Ambraseys, p. 336.

282. VOLCANO LAKE DYKE, 25 miles south of Calexico, Baja California, 23 miles from epicenter of Imperial Valley earthquake of May 18, 1940. Geologic Formation: Very soft alluvium. Imperial fault.

"After these earthquakes [June 22, 1915, and November 20, 1915] the dyke was reconstructed to be demolished again by the Imperial Valley Earthquake of 1940." Ambraseys, p. 336.

283. COLEMAN DAM, one mile northwest of Fallon, Nevada, 15 miles from epicenter of Fallon-Stillwater, Nevada, earthquake of July 6, 1954. Rainbow Mountain fault.

" ... the structure was destroyed during the earthquake. This structure failed because of displacement and cracking of earth-fill abutments, which in turn permitted water to erode around the concrete portion, causing it to partially overturn, crack and settle. The earth abutments were completely washed out." Ambraseys, p. 350.

284. SAGUSPE DAM, about 5 miles northeast of Fallon, Nevada, 16 miles from epicenter of Fallon-Stillwater, Nevada, earthquake of July 6, 1954. Geologic Formation: Alluvium. Rainbow Mountain fault.

"Nothing authoritative was learnt about its seismic behavior except that it settled over a foot." Ambraseys, p. 350.

285. ROGERS DAM, 3 miles northeast of Lovelock, Nevada, 42 miles from epicenter of Fallon-Stillwater, Nevada, earthquake of August 23, 1954, Intensity VII. Geologic Formation: Alluvium. Rainbow Mountain fault.

"This dam was reported to have failed during the earthquake of August 23 in Fallon. ... The southeast part of the dam composed of earth fill gave way and a portion of the concrete structure was broken off and turned around into the stilling basin." Ambraseys, p. 350.

286. SAGUSPE DAM, about 5 miles northeast of Fallon, Nevada, 13 miles from epicenter of Fallon-Stillwater, Nevada, earthquake of August 23, 1954. Geologic Formation: Alluvium, Rainbow Mountain fault.

"The shock of August 23 opened up a crack in the dam which subsequently failed." Ambraseys, p. 350.

287. CARSON DIVERSION DAM, Fallon, Nevada, between 30 and 40 miles from epicenter of Dixie Valley earthquake of December 16, 1954. Geologic Formation: Alluvium. Dixie-Fairview Valley fault.

" ... a slight displacement occurred at the Carson Diversion Dam." USC&GS, "Abstracts", MSA-84, p. 20.

288. WATER MAINS, Mexicali and Calexico, Imperial County and Baja California, Mexico, within 5 miles of epicenter of Imperial Valley earthquake of January 1, 1927 (near Mexican border). Geologic Formation: Very soft alluvium. Fault unknown, possibly SE extension of San Jacinto fault.

"At Mexicali and Calexico water mains broken." Townley and Allen, p. 24.

289. WATER MAINS, Mexicali, Baja California, Mexico, 7 miles from epicenter of Imperial Valley earthquake of May 18, 1940. Geologic Formation: Very soft alluvium. Imperial fault.

"...water mains broken by the tremor ... in Mexicali ..." UC Earthquake Scrapbook, Vol. 5, 1940-43, Clipping from Los Angeles Times, May 19, 1940.

290. WATER MAINS, Naval Auxiliary Air Station (5 miles southeast of Fallon, Nevada, 10 miles from epicenter of Fallon-Stillwater, Nevada, earthquake of July 6, 1954. Geologic Formation: Alluvium. Rainbow Mountain fault. Intensity VIII - IX.

"Water main broke... Entire water system required extensive purging and removal of debris." USC&GS, "U. S. Earthquakes", 1954, p. 25.

291. WATER MAIN, Fallon, Nevada, 19 miles from epicenter of Fallon-Stillwater, Nevada, earthquake of August 23, 1954. Geologic Formation: Alluvium. Rainbow Mountain fault.

" ... a 4-inch water main broke in two places." USC&GS, "U. S. Earthquakes", 1954, p. 31.

292. WATER MAIN, Mina, Nevada, 64 miles from epicenter of Dixie Valley, Nevada, earthquake of December 16, 1954. Geologic Formation: Alluvium. Dixie Valley - Fairview Valley faults.

"Eight-inch water line broke." USC&GS, "U. S. Earthquakes", 1954, p. 39.

293. WATER PIPE, Garlach, Nevada, 140 miles from epicenter of Cedar Mountain, Nevada, earthquake of December 20, 1932. Geologic Formation: Probably alluvium. Cedar Mountain fault. "Broke one city water pipe." USC&GS, "Abstracts", Vol. 1-4,

294. WATER PIPE, Fallon, Nevada, 81 miles from epicenter of Cedar Mountain, Nevada, earthquake of December 20, 1932. Geologic Formation: Probably alluvium. Cedar Mountain fault. Intensity VI - VII.

"A piece of quarterinch boiler plate was cemented in around the pipe . . . [a] 5-foot length of 5-inch pipe was screwed into the main pipe to run water away from the well. This boiler plate was dented and bulged up like a dinner plate by rock blown up by the terrific force, some of the rocks almost puncturing the plate. The five-foot length of water pipe was blown entirely away from the main pipe." UC, Clipping from Fallon, Nevada "Standard", 1930-1934, p. 101.

295. WATER PIPE, Kaiser Mine 13 miles NW Gabbs, Nevada, approximately 24 miles from epicenter of Dixie Valley, Nevada earthquake of December 16, 1954. Geologic Formation: Alluvium. Dixie Valley and Fairview Valley faults.

"Two and a half inch water line broke." USC&GS, "U. S. Earthquakes", 1954, p. 39.

296. CANALS, Baja California, 20 to 25 miles from epicenter of Laguna Salada District earthquake of December 30, 1934. Geologic Formation: Alluvium. Unknown fault, possibly San Jacinto fault.

"The Solfatera levee in Mexico was reported to have been leveled by yesterday's earthquake, but it was not in use at the time." UC, 1934-37, Clipping from San Diego Tribune, December 31, 1934.

" ... the Alamo and Wardlow canals damaged." UC, 1934-37, Clipping from Alhambra Post Advocate, December 31, 1934.

297. CANALS, Baja California, 80 miles from epicenter of Baja California, Mexico, earthquake of December 31, 1934. Geologic Formation: Alluvium. Fault unknown, probably southeast most segment of San Jacinto fault.

" ... The Solfatera canal, taking off at Cudahy, spilled water over the flats when its banks crumbled." UC, 1934-37, Clipping from the Los Angeles Examiner, January 1, 1935.

" ... for a distance of twelve miles along the Alamo canal, which brings water from the Colorado River, ditch banks have been broken and split with crevices three feet wide and ten feet deep ...." UC, 1934-37, Clipping from Los Angeles Times, January 1, 1935.

" ... Wardlow canal [was] damaged." UC, 1934-37, Clipping from Anaheim News, January 1, 1935.

298. CANALS AND DRAINAGE CHANNELS of the Yuma Project in the Lower Colorado River area, Arizona, approximately 42 miles east of epicenter of Imperial Valley earthquake of May 18, 1940. Geologic Formation: Alluvium. Imperial fault.

"On the Yuma Project, an area extending approximately four miles north and south of Gadsden and eastward from the levee for about two miles was badly shaken. Damage was chiefly to canals and drainage channels .... It has not been determined whether there was any movement along a local fault line, but indications are that lurching, following movement along the fault in the Imperial Valley, caused the upheaval and subsidence in this area.

"Miles of drainage ditches were obstructed, the bottom of the channels being pushed up as high as normal ground surface or even above, in one instance water from the drain flowed out over adjacent land. In some places, this was accompanied by subsidence of the banks or wastebanks ...." Clark, p. 31.

Costs: A preliminary estimate was $15,000, but this estimate is conservative.

299. ALAMO AND SOLFATERA CANALS, Mexico, approximately 10 miles from epicenter of Imperial Valley earthquake of May 18, 1940.

Geologic Formation: Alluvium. Imperial fault.

"The Alamo Canal, main feeder for the entire system, had 8 major breaks between the Cudahy Check and Laurence Heading. Longitudinal cracking of the bank extended from Kilometer 38 to the Boundary and along the East Highline and the Ash Canals with resulting slides and smaller breaks.

"The Solfatera Canal was completely destroyed from Tortuoso Check to Kilometer 23, canal banks ten feet high appeared to have sunk vertically remaining only a foot or two above the bottom of the canal. The entire area adjacent to the canal was so flooded that a clear picture of the situation could not be obtained. It appeared, however, after the canal had been rebuilt, that lurching rather than a general subsidence was responsible for the conditions which resulted. Upstream from the Tortuoso Check, canal banks were cracked laterally, but no major breaks occurred." Clark, 1940, pp. 24, 27.

Repair time: 500 cfs was turned in after the fourth day and by the eighth day, 2,000 cfs was in the canal.

300. CANALS, DRAINS, CHECKS, DROPS, AND TURNOUTS, Lone Tree and Stillwater areas of the Newlands Reclamation Project, Nevada, approximately 16 miles west of epicenter of Fallon-Stillwater,

Nevada, earthquake of July 6, 1954. Geologic Formation: Alluvium, deep, saturated. Rainbow Mountain fault.

"Damage resulted in many localities of the Newlands Project, ranging from slight cracking in the lining of the Truckee Canal tunnels west of Wadsworth, Nevada, which may or may not have been caused by the earthquake, to extensive damage to the canal and drainage systems of the project, particularly in the Lone Tree and Stillwater areas .... Considerable damage was also inflicted on irrigation and drainage structures ....

"Numerous redwood box-type culverts partially or completely collapsed as a result of the earthquakes. Most of these were located along the drainage channels and at points where roads or irrigation ditches crossed the drains. Longitudinal cracking and sloughing occurred in many places along both drainage channels and irrigation canal banks.

"In the Lone Tree and Stillwater areas, canal banks settled from 1 to 3 feet at the same time the bottoms of the canals were raised from 1 to 2 feet, and in an extreme case the bottom of a drain ditch was forced up approximately 5 to 6 feet, by the heaving action of the earthquake.

"The earthquake damage to project facilities prevented delivery of irrigation water to approximately 80 percent of the lands under the project." Steinbrugge and Moran, 1956, pp. 26-31.

Emergency rehabilitation work was completed during a six-weeks' period following the earthquake. Costs: Summary of July 6, 1954, Earthquake Damage Newlands Project, Nevada, U. S. B. R. Report.

Feature	Temporary Emergency Repair Costs	Total Replacement Costs
Canals	$34,625	$36,740
Checks, drops, turn-outs and flumes	3,050	6,710
Clean and repair drains	32,730	39,645
Power system	4,000	4,000
Bridges and culverts	24,850	46,700

301. CANALS, DRAINS, CHECKS, AND CULVERTS, Newlands Reclamation Project, Nevada, approximately 16 miles west of epicenter of Fallon-Stillwater, Nevada, earthquake of August 23, 1954.

Geologic Formation: Alluvium, deep, saturated. Rainbow Mountain fault.

"The damage caused by this series of quakes occurred in the same general areas [as the July 6, 1954, quake]; however, some areas located a little further west sustained damage this time that were not affected by the July quake. The type of damage was practically the same as reported for the July 6 quake with reference to collapsed culverts, settlement and cracking of ditch and drain banks, canal and drain bottom upheavals and tilting and cracking of canal turnout and drop structures. In some instances the damage was more severe than that observed following the July quake. A large part of the emergency rehabilitation work that has been completed during the last six weeks was completely obliterated by this series of quakes.

"Two concrete drop structures were seriously damaged, one being rendered useless and requiring replacement ....

"The District took immediate action in an attempt to restore water service to the project lands. District and private equipment had begun rehabilitation work by the morning of August 24 ...." Steinbrugge and Moran, 1956, pp. 31-32.

Costs: Summary of August 23, 1954, Earthquake Damage, Newlands Project, Nevada, U. S. B. R. Report.

Feature	Temporary Emergency Repair Costs	Total Replacement Costs
Canals	$33,600	$33,800
Drains (clean and repair)	19,400	20,300
Structures (bridges, checks, flumes)	11,800	17,600
Culverts	5,900	5,900
Power system	5,000	5,000

302. FLUMES, Yuma Project in the Lower Colorado River area, Arizona, approximately 42 miles east of epicenter of Imperial Valley earthquake of May 18, 1940. Geologic Formation: Alluvium. Imperial fault.

"Bridges and flumes buckled, the piles apparently being shoved up by the repeated pitching of the earth. Preliminary estimate for repairs to this system was $15,000 ..." Clark, p. 31.

303. FLUMES, New River Flume, Baja California, Mexico, approximately 10 miles southeast of epicenter of Imperial Valley earthquake of May 18, 1940. Geologic Formation: Alluvium. Imperial fault.

"The New River flume on the West Side Main Canal, a timber structure 1400 feet long, was demolished...." Clark, p. 24.

Repair Time: "In excess of 10 days." Clark, p. 29.

304. FLUME, Stillwater, Nevada, approximately 24 miles northwest of epicenter of Fallon-Stillwater, Nevada, earthquake of July 6, 1954. Geologic Formation: Alluvium. Rainbow Mountain fault.

"Stillwater flume collapsed. Officials said that the ground shifted under supports of the 150-foot flume, which will have to be replaced." USC&GS, "Abstracts", MSA-83, p. 10.

SUMMARY OF DAMAGE

Twenty-two of the 82 earthquakes described in this document caused a large portion of the damage recorded in the Cases. In this group of 22 are several lesser magnitude quakes. However, even these caused considerable damage.

Damage in California extends from Eureka to Calexico and San Francisco east to Lake Tahoe. The damage described outside California occurred in Nevada, Arizona, and Baja California.

Foundation Materials and Relationship to Earthquake Damage

A large variety of geologic formations* comprises the foundation materials of the hydraulic structures in California damaged by earthquake activity.

Unconsolidated alluvium, generally saturated and thick, was the predominant material underlying the damaged hydraulic structures. These materials were mainly Quaternary alluvial fans, flood plain and basin deposits, dune sand, marshlands, tidal flats, and bay muds. Filled ground, having the same general unconsolidated nature and low strength characteristics as the unconsolidated alluvium, underlies many damaged hydraulic structures, particularly in the San Francisco Bay area. Slightly to moderately compacted sediments and older consolidated bedrock units comprise the foundation materials for a few damaged hydraulic structures. These materials include: Pleistocene and Pliocene continental and marine sedimentary deposits; consolidated Cretaceous sandstones and shales; granitic rocks of Mesozoic age; and the Franciscan formation of Mesozoic age, consisting of sandstone, shale, and some ultra-basic rocks.

*Refer to California Division of Mines and Geology State Geologic Maps, scale 1:250,000, for details as to formation names, ages, and general rock descriptions.

A review of case histories indicate that contrary to "popular" belief, earthquake hazard is not necessarily greatest close to faults. Observations, which are cited herein, indicate that structures built on alluvium commonly are subjected to much stronger shaking than are like structures on rock foundations from the same event--even when the structures on alluvium are many miles more distant from the earthquake source. The failures cited are almost entirely caused by more violent shaking of the structure, not foundation failure.

Dr. C. F. Richter, Professor of Seismology, California Institute of Technology, is quoted on this subject as follows:

> "Seismologists and geologists are frequently consulted by those planning to build, for residence or business purposes, as to the safety of a given site with respect to earthquakes. The first inquiry usually refers to the location of active faults. It has to be explained that, in the long run, in a region like California the differences between two locations depend less on their distances from faults than on the character of the ground. Any given point is sooner or later going to be shaken heavily--either by a great earthquake far away or a smaller one comparatively nearby. In either case, intensity is going to be higher, other things being equal, on unconsolidated ground than on firm rock." Richter, p. 384.

After the 1906 San Francisco earthquake on the San Andreas fault, the State Earthquake Investigation Commission was created to study the effects of that large earthquake. Damage was inspected throughout the state, and at that time it was noted that the nature of the materials underlying structures signigicantly influenced the degree of damage they sustained. For example, structures on deep alluvium many miles from the source of the earthquake were severely shaken. In regard to this fact, the Commission report states:

> " . . . . On emerging from mountainous districts into the deep alluvial plains of the San Joaquin Valley, the intensity of the shock increased, until at Los Banos it reached a maximum. A count of the chimneys showed 57 percent (17 out of 30) fallen . . .

"Now Los Banos, where the apparent intensity was highest,* is distant 40 miles from the nearest point on the San Andreas fault at San Juan, its southern end. It is nearly 34 miles in an air-line from Hollister, the nearest point to the westward having a similarly high apparent intensity. In the Coast Ranges between Hollister and Los Banos, the intensity was as low as V." Lawson, 1908.

The Commission also noted other instances in which structures at considerable distance from the faults on alluvial foundations sustained greater damage than similar structures close at hand but constructed on rock. The Commission concluded:

" . . . proximity to the fault was not the only factor determining the degree of intensity. The soft, more or less incoherent, and water-saturated alluvial formations of the valley-bottoms were much more severely shaken than the rocky slopes of the intervening ridges, and the structures upon them were consequently more commonly and more completely wrecked . . . ." Lawson, 1908.

More recent observations of the influence of foundations on the amplitude of earthquake vibrations were made by comparing records from pairs of seismographs, one being placed on alluvium and the other on an adjacent bedrock area. The report on these studies concludes:

"The old conclusion still holds: that, for finding the safest location for a building in a region where there are active faults, it is more important to look for sites on bedrock than for locations with a maximum distance from the faults. . . ." Gutenberg, B., 1957.

The State Earthquake Commission also reviewed effects of the earthquake of 1868 in which the Hayward fault ruptured from San Leandro to Warm Springs, a distance of about 20 miles. The Commission observed that the chief damage in San Francisco, as in 1906, occurred on fill along the margin of the bay shore, about 15 miles from the Hayward fault, and that little damage was sustained by structures on the rocky slopes.

*Maps prepared by the State Earthquake Investigation Commission indicate an intensity of IX on the Rossi-Forel scale.

Another report states:

> "The effects of the Tehachapi earthquake of July 21, 1952, add new evidence to substantiate the long-held belief that structural damage is greatest in areas underlain by thick unconsolidated sediments and least in areas underlain by rock. . . ." Schlocker, J., 1955.

Nature of Damage

Various types of earthquake damage were sustained by canals and pipelines, ranging from small breaks and leaks to complete destruction. Slumping, fissuring, sloughing, and offset of banks were typical of the damage to canals, ditches, and dams. Rupture, telescoping, pulling apart and bending were typical of the damage to pipes and pipelines. Sewers were cracked, ruptured, telescoped, or pulled apart. Storage tanks were usually toppled from generally inadequate supports. Variations of these major types of damage were extensive.

Repair Time

Very little information is available on time to repair earthquake damage to canals and pipelines and associated structures. Case histories published in the technical literature generally make no mention of this factor. Where repair times are mentioned, they are generally given in loose terms such as "quickly repaired", "immediately repaired", "soon repaired", etc. When repair times have been given they indicate that responsible public agencies and individuals, with the help of private industry, have surmounted obstacles and made necessary repairs in record time.

Costs

Very little information is available on costs to repair earthquake damage to canals and pipelines and related structures. As in repair time, case histories published in the technical literature generally make no mention of this factor.

Comprehensive repair costs are available in California for only two earthquakes: the May 18, 1940, Imperial Valley earthquake, Magnitude 7.1, and the December 21, 1954, Eureka earthquake, Magnitude 6.6. Cost to the Imperial Irrigation District to repair damage to their canal systems following the May 1940 earthquake was $365,080. Cost to the City of Eureka to repair damage to their water supply, storage, and distribution system following the December 1954 earthquake was $44,000. Of this total, $25,000 was spent in repairing one difficult pipeline break on a bridge crossing northeast of Eureka.

Several cases outside of California furnished valuable information on costs. The Newlands Project near Fallon, Nevada, was damaged by two earthquakes in 1954. Cost to repair the July 6 earthquake, Magnitude 6.6, was $133,795. Cost to repair the August 23 earthquake, Magnitude 6.8, was $82,600.

Distance Between Damaged Hydraulic Structures and Earthquake Epicenter

Distance between the earthquake epicenter and hydraulic structures damaged ranged from a few miles to 190 miles. Many structures were damaged in the general range of one to ten miles from the earthquake epicenter. In the case of larger earthquakes, many hydraulic structures were damaged in the range of 12 to 42 miles. Few structures were damaged at greater distances. In several cases hydraulic structures were severed by rupture along the fault.

Types of Structures Damaged

The types and numbers of hydraulic structures significantly damaged in California and vicinity from 1868 to 1964 include: 9 reservoirs, 44 water tanks, 22 dams, 5 aqueducts, 11 pipelines, 15 canals and ditches, 4 flumes, 54 water mains, 47 water pipes, 5 pumping and power stations, 12 irrigation pipes and standpipes, 1 weir, 40 petroleum product structures, 9 sewerage structures, and 1 dyke.

RECOMMENDATIONS

1. Earthquake damage reports should contain more thorough and detailed engineering and cost information than is presently available in the accessible literature.

2. To effect more adequate damage reporting for use in improving public water projects, the Department of Water Resources should conduct field inspection of earthquake damage to hydraulic structures within and outside the State of California. Reports should contain sufficient engineering detail for maximum utilization by all concerned. Inspection teams should be derived from appropriate Department specialists and consultants. The inspection party should include an experienced structural engineer to reconstruct insofar as possible the behavior of damaged structures and their components during the earthquake and to determine the nature and magnitudes of the stresses that caused failure. Designs should be analyzed in the light of these evaluations and improved criteria and engineering procedure recommended where it can be shown that feasible changes will lead to increased safety and reliability in the future.

3. The listing of damage from the literature should be completed to include earthquake damage from areas outside of California.

4. The consolidation of earthquake damage reports and upgrading of engineering content should be extended to other than hydraulic structures through cooperative programs with the Divisions of Architecture, Highways, and other agencies.

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