State of California
THE RESOURCES AGENCY

DEPARTMENT OF WATER RESOURCES

SEISMICITY HAZARDS IN THE SACRAMENTO-SAN JOAQUIN DELTA

CENTRAL DISTRICT
October 1980

C-105124

Cover Photo - County road along Salinas River south of Salinas, disrupted by slumping and lateral spreading during the 1906 San Francisco Earthquake (Photograph courtesy of K. A. Meserole, Menlo Park, California and provided by U. S. Geological Survey.)

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FOREWORD

Potential seismic activity is a vital safety element of the joint DWR-Corps of Engineers Sacramento-San Joaquin Delta Levee Study. Seismic hazards in the Delta are real; therefore, potential earthquakes in the Delta area affect all planning activity, and levee rehabilitation cannot be iniatiated without considering this element in future levee design and construction. This report addresses the present knowledge of earthquake hazards in the Delta to the extent we have been able to find it.

Information concerning the area, soil characteristics, geology, potential hazards, and identification of earthquakes and faults of the Sacramento-San Joaquin Delta was drawn from several studies conducted on the Delta.

A proposal for study to better define the soil liquefaction potential for earthquakes is contained in Appendix C. An outline for a detailed seismic study of the type necessary before final levee design is also presented in Appendix C.

Wayne MacRostie

Wayne MacRostie
Chief, Central District

C-105127

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Frederic R. Kelley . . . . California Division of Mines and Geology
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Chapter I. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

There is a long history of levee failures in the Delta that have resulted in extensive economic damage, but no failures of Delta levees are known to be directly attributable to earthquakes. Even so, two factors indicate a possible bleak picture for the future of the many Delta levees. First, no serious causative quakes have occurred on nearby major faults since the San Francisco earthquake of 1906. Second, the Delta levees of today are vastly different than those in the 1906 Delta, which had limited size and extent.

Even without consideration of another San Francisco earthquake, two recent seismic events, the Antioch earthquake of 1965 and the Greenville fault earthquake of 1980, emphasize the need to consider the seismic factor in levee rehabilitation design, especially where urban development exists or where urban water systems might be in jeopardy. While not an apparent Delta hazard in the past, liquefaction, settlement or other effects of causative earthquakes could seriously damage levees, especially as levees are built larger and higher to deal with continuing island subsidence.

The Sacramento-San Joaquin Delta is threatened by three major northwest trending active faults (the San Andreas, Hayward, and Calaveras) and minor faults close to or within the Delta, as shown on Figure 1.

The Midland fault, which crosses the Delta from north to south, is believed capable of causing a serious quake of perhaps Richter magnitude 7 (see Appendix E for Richter magnitude scale, modified Mercalli Intensity scale, etc.). However, there is little proven information concerning the Midland fault.

The local Green Valley fault zone must be considered semiactive. While no known earthquake has occurred due to this fault, an offset fence along the fault alignment indicates recent creep.

Another fault of potential danger to the southern and eastern Delta is the Tracy-Stockton fault. No surface expression of this fault has been mapped. Subsurface data indicate, however, that no appreciable movement has occurred on the Tracy-Stockton fault since mid-Pliocene time, perhaps three million years ago or more.

In 1972 evidence of an active fault (Antioch fault) was discovered in the Antioch area by the U. S. Geological Survey.[1] On September 10, 1965, this fault produced an earthquake of 4.9 Richter magnitude. Previously, no active faults were known to exist in the Delta.

More recently, on January 24, 1980, the Greenville fault, approximately 16 kilometres (10 miles) southwest of Clifton Court Forebay produced an earthquake of 5.5 Richter magnitude plus surface rupture. Aftershocks occurred for six days. On January 27, an earthquake of 5.8 Richter magnitude occurred at the southern end of this fault. Minor surface rupture occurred along the fault for at least 6 km, with both

[1] Burke and Helley, Basic Data Contribution #60, MF-533.

right-lateral strike-slip and some dip-slip motion with the northeast side up.[2]

Conclusions

Pertinent observations and conclusions are:

1. Since 1906 no strong earthquake has occurred close enough to the Delta to produce known damaging levels of ground shaking.

2. Knowledge about the earthquake response of the Delta levees is presently limited.

3. A geological hazard that is of great importance to the Delta is the adverse behavior of natural materials as expressed by land-sliding, creeping, subsidence, and liquefaction. Any of these behaviors could result in wide-spread loss of large areas of Delta levees, where substandard levees exist if initiated by a large earthquake.

4. Although a definite earthquake hazard exists in the Delta, no seismic evidence was found in this study that would preclude a major levee rehabilitation program from being carried out. A significant seismic safety factor, however, should be included in levee design.

Recommendations

1. Three programs should be carried forward to establish specific knowledge of Delta soil behavior[3] and are described in Appendix C.

   a. ABAG's Earthquake Hazard Mapping Program.

   b. Proposed UCD Earthquake Mapping Program.

   c. Proposed Delta Seismology Investigation Plan (rough outline).

2. The present Strong Motion Instrumentation Program in the Delta (discussed in Chapter V) be continued and expanded. Different kinds of levee materials should be selected to record their behavior during earthquakes.

3. Based on the above, an appropriate earthquake safety factor be included by the Corps in development of levee standards and design.

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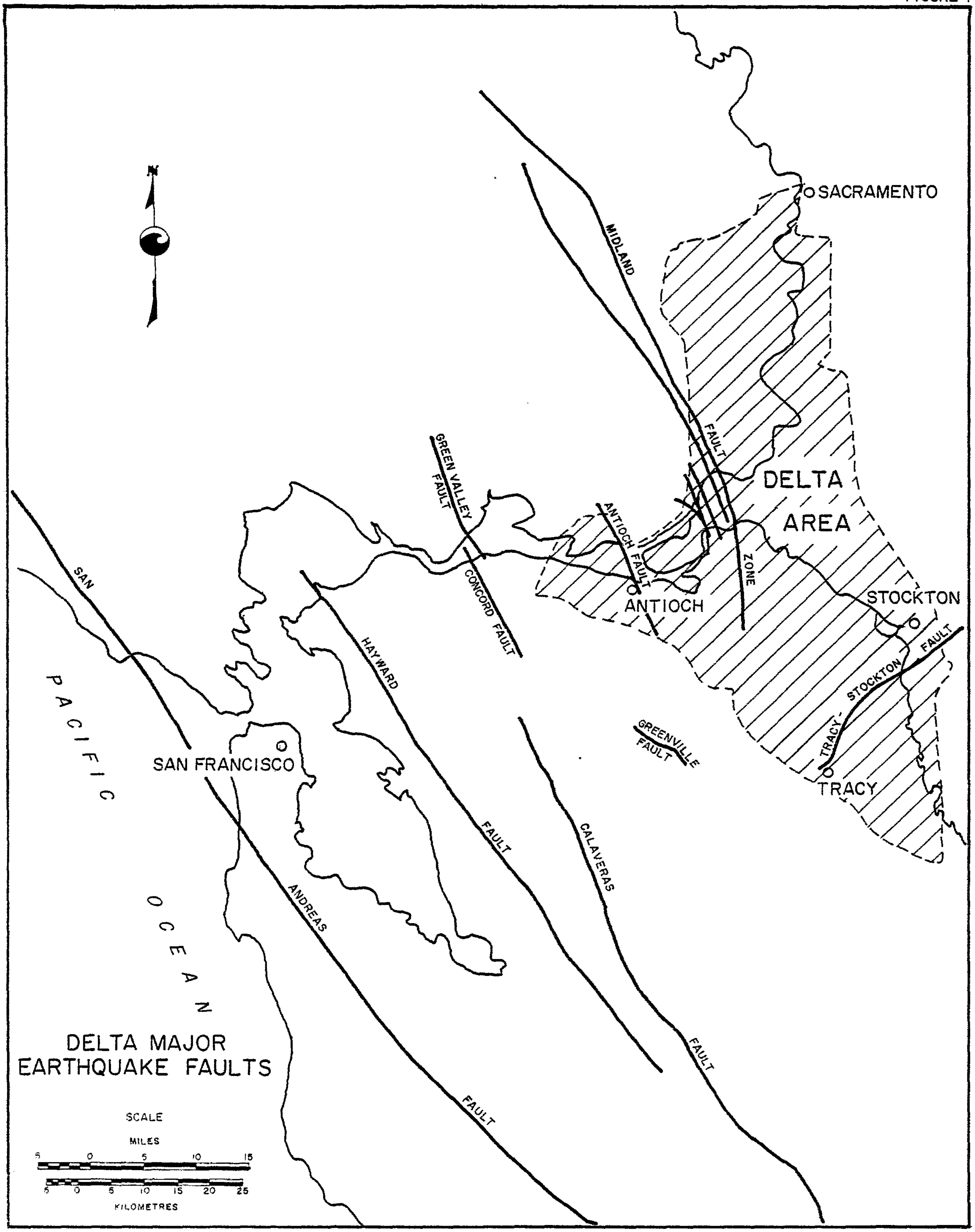
[2] Greenville Earthquake Sequence of January, 1980, California, by B. A. Bolt, T. W. McEvilly, and R. A. Uhrhammer, February, 1980.

[3] Present knowledge of properties and behavior of Delta soils, and their response to earthquake shaking should be increased before final levee design is completed for a program of future levee rehabilitation. A significant seismic safety factor should be included in levee design.

FIGURE 1



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Chapter II. OVERVIEW OF THE SACRAMENTO-SAN JOAQUIN DELTA

The Delta is situated along the confluence of the Sacramento and San Joaquin River system, where it occupies an area of more than 2 850 square kilometres (1,100 square miles) including over 1 100 kilometres (700 miles) of meandering, picturesque waterways. It is bordered by major population centers of the San Francisco Bay Area, Sacramento and Stockton (see Figure 2 for boundary of Delta). Portions of five counties -- Contra Costa, Sacramento, San Joaquin, Solano, and Yolo -- are within the area of the Delta.

The Delta encompasses 60 leveed islands and tracts. Most of these islands are reclaimed marsh land lying near sea level and up to 9.1 metres (30 feet) below sea level, and depend on levees to protect them against inundation. Thousands of hectares are protected by a network of artificial levees totaling about 1 770 kilometres (1,100 miles) in length.

The Delta is one of the most fertile agricultural areas in the United States, supporting a wide variety of crops. Some 91 percent of the Delta is zoned for agriculture. The types of crops grown include asparagus, pears, potatoes, celery and other truck crops. A grape and winery industry is also growing in the area.

The area contains important high quality natural gas-producing areas, supports one of the State's greatest fishery resources, and provides habitat for over 100 species of waterfowl and wildlife including important game and endangered species. Also, the Delta is one of California's major outdoor recreation areas. Its abundant water, fish, wildlife, cultural and historical resources offer a variety of recreational opportunities such as fishing, boating, hunting, picnicking, camping and sightseeing.

Two major roads, Highway 4 and 12, bisect the Delta. Highway 160 follows the meandering course of the Sacramento River and Highway 113 traverses north to south through Yolo and Solano Counties. Interstate 5 skirts the eastern side of the Delta. In addition, 9.2 metre (30-foot) deep ship channels to Sacramento and Stockton enable ocean-going vessels to berth at these two ports.

No major cities are located entirely within the Delta. Small incorporated cities within the Delta include Antioch, Pittsburg, Isleton, and Rio Vista, plus about 10 unincorporated towns and villages.

Geology

The Sacramento-San Joaquin Delta is part of the Central Valley geomorphic province, a northwest-trending structural basin filled with sedimentary deposits.

In the deepest part of the Delta, the basin contains over 9 000 metres (30,000 feet) of sediment and rocks ranging in age from Jurassic to Holocene. Well consolidated Jurassic, Cretaceous, and early Tertiary marine sedimentary rocks fill most of the basin. Nonmarine late Tertiary and Quaternary sedimentary deposits roughly 720 to 900 metres (2,400 to 3,000 feet) thick cover the older sedimentary rocks.

The Delta is typically covered by organic soil deposits. The organic soils are thickest in the western and central portions of the Delta, especially near the confluence of the Sacramento and San Joaquin Rivers. The Holocene deltaic deposits reach maximum thickness of approximately 19.7 metres (65 feet) beneath Sherman Island.

Organic soil deposits consist of peat, organic silt, and clays with low density, low shear strength and high moisture content. Usually, peat is on the surface and grades into silty peat and organic silt at depth. Dense silty sand or poorly graded, fine-grained sand is usually encountered below the organic horizon in the western and central Delta.

Mineral deltaic soils occur mostly along the Delta margin. Other inorganic soil and mixtures of mineral and organic soils occur in the Delta as channel and natural levee deposits. These soils are mostly sand and silt, though they often contain significant amounts of organics.

The ground water levels in the Delta are maintained at depths ranging from 0 to -3.1 metres (-10 feet) depending upon agricultural needs and the season of the year. They would rise quickly to the ground surface over most of the Delta area if they were not pumped by the farmers. In the central and western sections of the Delta, ground water in sands beneath the deltaic deposits may exist under artesian conditions.

Soil Hazard

The soils of the Delta are composed of peat, organic sediments, and alluvium, with organic peat soils by far the most common. However, the physical and chemical properties of peat soils -- their susceptibility to wind erosion, subsidence, and flammability -- create potential problems that threaten continued use of the area. The most persistent problems are erosion and subsidence. The peat areas of the islands subside at a rate up to 76 millimetres (3 inches) per year. Subsidence is mainly due to oxidation (about 80 percent), caused primarily by farming.

Levee Stability and Failure

Causes of levee failure, especially during high water, include: (1) sufficient seepage through or under the levee to cause a boil or blowout, (2) levee erosion by current or wave action, (3) levee overtopping by floodflows that exceed levee heights, and (4) structural failure due to underlying soil characteristics.

The problem of levee instability exists throughout most of the Delta, but is most critical in deep peat areas. As subsidence of the peat soils in the islands continues, the water pressure in the channel can become too great for the levees to withstand. A section of the levee may fail, with subsequent flooding of the island. Foundation failures due to subsidence may become more common, especially in the central Delta, due to low-bearing strength materials and seepage.

The number of levee failures could be substantially increased by seismic activity. Due to the unusual natural characteristics of the Delta interacting with marginal levees on reclaimed islands, a situation has been created in which during almost any level of wind and water flow situation, in theory, a major earthquake could destroy the deteriorating private levees.[4] Additional flooding might then result from a widespread "domino effect".

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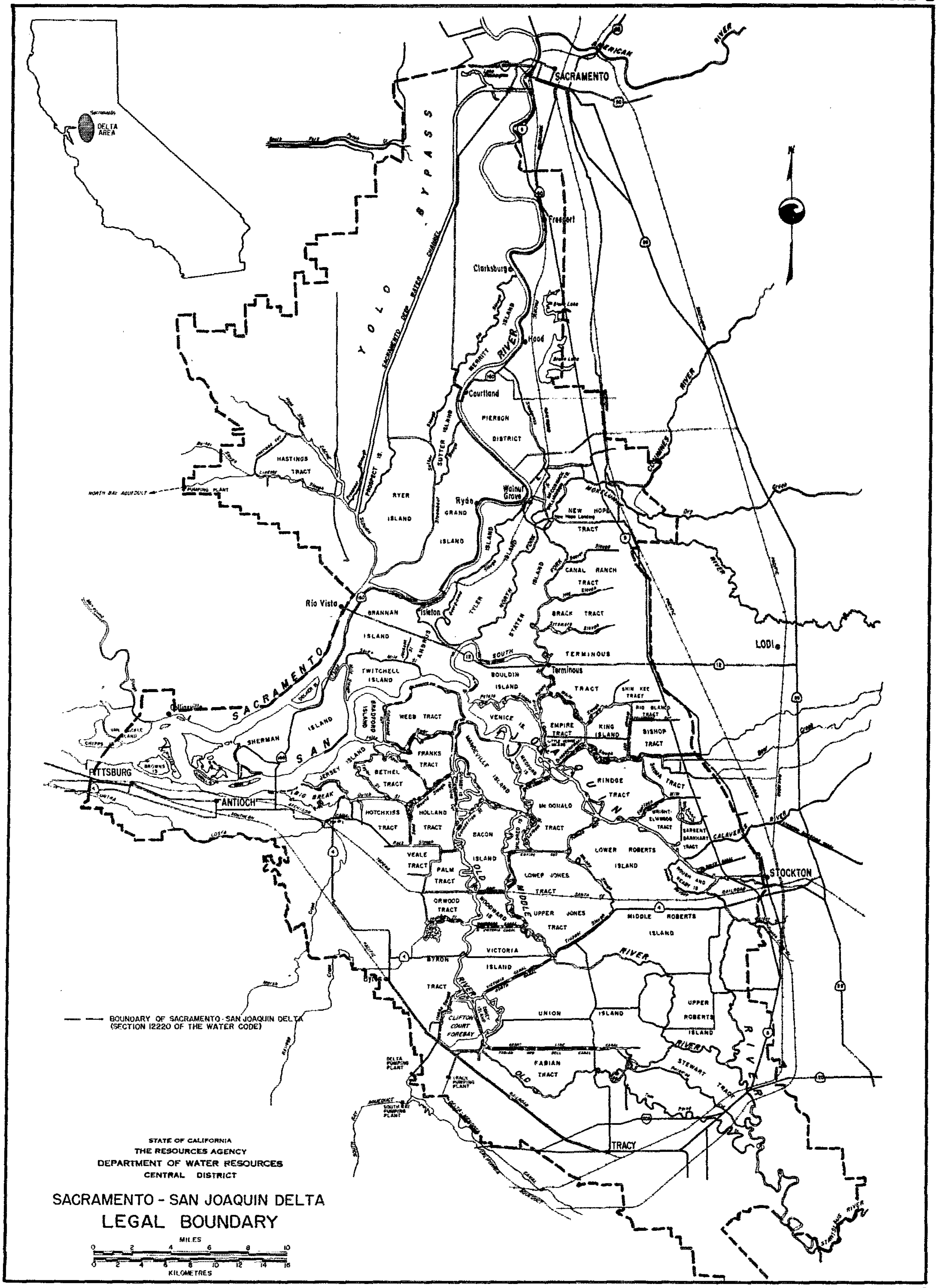
[4] See page 14 for definition of private and project levees.

FIGURE 2



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Main Street, Winters, CA, April 19 & 21, 1892; Midland Fault Earthquake (DWR 4030)

Chapter III. IDENTIFICATION OF EARTHQUAKES AND FAULTS

The Sacramento-San Joaquin Delta is subject to the effects of several faults close to or within its area. Among them the San Andreas fault, Hayward fault and Calaveras fault are the most active and are capable of inducing strong seismic shaking. Besides these, several other faults including Green Valley-Concord faults, Midland fault, Antioch fault, Tracy-Stockton fault, and Greenville fault may also affect the Delta. See Figure 1 for fault locations.

Table 1 chronologically outlines major past seismic activity that may have affected the Delta. Appendix A contains a detailed listing of historical seismic activity near the Delta.

San Andreas Fault Zone

The San Andreas fault is one of the longest and most active faults in the world. The surface trace of this great fault extends from a point off the Northern California coast to the lower reaches of the Gulf of California, a distance of over 1 000 kilometres (600 miles).

In California great earthquakes have occurred on the San Andreas fault, producing surface rupture between San Bernardino and Parkfield (1857) and between San Juan Bautista and Shelter Cove on the North Coast (1906). There is no reason to believe that such quakes will not occur again.

Hayward Fault

The Hayward fault zone comprises a northwest-trending zone of faults along the western front of the hills bordering the east side of San Francisco Bay. The fault zone can be traced nearly continuously northwest from the Warm Springs district in southern Alameda County to San Pablo Bay at Point Pinole in Contra Costa County. Southeast of San Francisco Bay Area, the Hayward fault is inferred to merge with the Calaveras fault.

A review of existing seismic records provides compelling evidence that the Hayward fault is seismically active. Movement on this fault caused two major earthquakes (1836 and 1868), each with an estimated Richter scale magnitude of about 6.7.[5] In addition, between January 1, 1969, and September 3, 1973, approximately 70 small earthquakes were recorded along this fault. Tectonic creep continues to damage buildings, tunnels and other structures that cross the narrow bands of active movement within the Hayward fault zone.[6]

Calaveras Fault

The Calaveras fault, approximately 160 kilometres (100 miles) long, borders the eastern flank of the Berkeley-Hayward Hills and extends to the southeast where it joins the San Andreas fault south of Hollister.

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[5] Division of Mines and Geology, Open File Report EFR 79-6 SAC.
[6] Geological Survey Circular 525, 1966.

Due to physiographic and geologic evidence and earthquake epicenters located along the trace of the fault, the Calaveras fault zone has long been considered active. The physiographic evidences include a fault-line valley, elevated stream terraces, sag ponds and other aligned, close depressions. Geologic field evidences include tectonic creep and surface rupture accompanying a historic earthquake. These factors, along with the present day seismicity of the fault, provide the evidence that the Calaveras fault is active.

Green Valley-Concord Fault

This fault zone, extending from Walnut Creek to west of Fairfield, exhibits displacement throughout most of its length within recent geologic time and there is evidence of some recent movement in the form of creep along the fault in the City of Concord.

Midland Fault

The Midland fault, which is buried under recent alluvium, extends north from Bethel Island in the Delta to the east of Lake Berryessa. The California Division of Mines and Geology (CDMG) suggests that the strong earthquake of 1892 centered near Vacaville was possibly originated on the Midland fault.[7] CDMG also considers the Midland fault capable of generating an earthquake as large as Richter magnitude 7.0.

Antioch Fault

The name Antioch fault is applied to a recently identified active zone of faulting that strikes N 30° W and passes through the City of Antioch. The total extent of the fault is not well known. To the south it is inferred to merge with the north-south striking Davis fault approximately 5 km (3 miles) southeast of Antioch. To the north the fault appears to cross the Sacramento and San Joaquin Rivers and form the western boundary of the Montezuma Hills in Solano County.[8]

The Antioch area is subject to relatively frequent earthquakes. For example, during the ten-year period 1962-1971, general purpose seismographs recorded nine earthquakes having Richter magnitude in the range 2.5 to 5.0 and more than twenty smaller earthquakes were centered near the vicinity of Antioch. Additionally, from January 1, 1969, to September 3, 1973, the National Center for Earthquake Reserach recorded more than 30 microseismic events in the vicinity of the Antioch fault.

Tracy-Stockton Fault

The Tracy-Stockton fault crosses San Joaquin County from the southwest near Tracy to the northeast near Linden, passing directly beneath Stockton. Subsurface data indicate that no appreciable movement has occurred on the Tracy-Stockton fault for three

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[7] Greensfelder, California Division of Mines and Geology.
[8] Reiche, 1950. "Rio Vista, California, Fault Scarp", (abs.) Geol. Soc. Amer. Bull., Vol. 61, p. 1529-30.

million years or more. However, there is evidence of activity near the easternmost subsurface sections of the fault. On April 10, 1881, an earthquake occurred near Linden having an estimated Modified Mercalli intensity of VII.[9]

Greenville Fault

The Greenville fault runs from the northern end of the Carnegie fault northwestward to the southern tip of Marsh Creek fault, and is about 17 kilometres (11 miles) long.

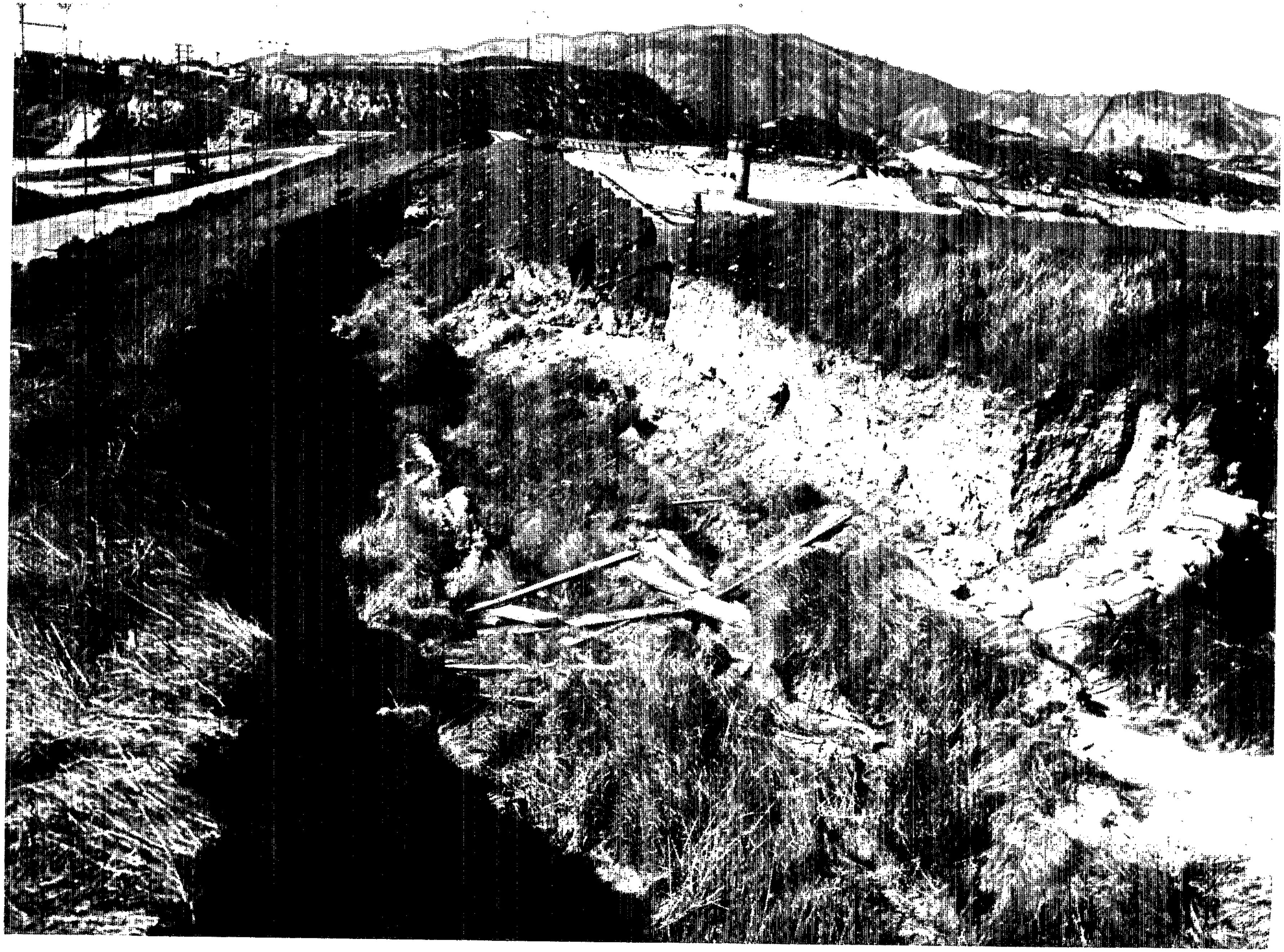
The latest earthquakes related to this fault occurred on January 24, 1980, and registered 5.5 on the Richter scale. Two days later, on January 26, 1980, another earthquake registering 5.8 on the Richter scale occurred, with the epicenter measured at 14 kilometres (9 miles) to the south of the first epicenter.

[9] San Joaquin County Safety/Seismic Safety Element, 1978.

TABLE 1

HISTORICAL SEISMIC ACTIVITY NEAR THE DELTA

Year	Date	Epicentral Area	Maximum Modified Mercali Intensity	Richter Magnitude
1836	June 10	San Francisco Bay (Hayward Fault)	IX-X	--
1838	June	San Francisco Bay (San Andreas Fault)	X	--
1861	July 3	Contra Costa, Alameda County (Calaveras Fault)	VIII	--
1868	Oct. 21	Hayward (Hayward Fault)	IX-X	--
1872	Apr. 3	Antioch	IX-X	--
1881	--	Linden (Tracy-Stockton Fault)	VII	--
1889	May 19	Antioch, Stockton	VI	--
1892	Apr. 19	Vacaville (Midland Fault?)	IX	--
1892	Apr. 21	Winters, Dixon	IX-X	6.0-6.9
1906	Apr. 18	San Francisco (San Andreas Fault)	XI	8.3
1916	Oct. 22	East Bay Area	--	--
1940	Sept. 19	Linden (Tracy-Stockton Fault)	--	4.0
1965	Sept. 10	Pittsburg (Antioch Fault?)	VI	4.9
1975	Aug. 1	Oroville	--	5.7
1980	Jan. 26	Greenville Fault	--	5.8



Scarps in embankment of Lower San Fernando Dam, San Fernando Valley earthquake, 1971. San Fernando photographs are included to illustrate damage similar to that expected on levees during earthquakes. (DWR 4118.)

Chapter IV. DELTA EARTHQUAKES -- THE POTENTIAL HAZARD

Since the 1906 San Francisco earthquake, the Delta levee system has been subjected to only mild seismic induced stresses. There has not been any reported failure of Delta levees due to seismic shaking. This may be attributed to the absence of large historic earthquakes in or near the Delta since 1906. The 5.8 Richter magnitude Greenville fault earthquake of 1980 is the largest known to have occurred in or near the Delta since 1906.

Prior to 1906, levees were for the most part either small or nonexistent. Today the Delta is comprised of numerous cohesionless, water saturated, unconsolidated levees at heights approaching 9.2 metres (30 feet). The largest levees may be susceptible to ground shaking failure. As further subsidence occurs, their susceptibility to such failures increases.

Most potential hazards to Delta levees are interrelated, and the occurrence of one phenomenon may in turn cause additional damaging phenomena. A significant earthquake could trigger soil instability that could cause a levee failure and subsequent flooding could inundate many of the Delta islands having substandard levees.

Earthquake Probability

Because few people lived in the undeveloped Delta in the 19th century, the damage potential of past earthquakes was limited. Between July 1861 and April 1906, the areas adjacent to Carquinez Strait-Suisun Bay exhibited the highest levels of seismicity in Central California. At least ten damaging earthquakes produced strong ground motion in eastern Contra Costa County. Maximum ground shaking of intensity VII+ on the Modified Mercalli scale was experienced during seven of those earthquakes.

In 1892 two severe earthquakes were centered east of Fairfield. Significant damage occurred in Winters, Dixon, Vacaville and Suisun, and some damage occurred as far away as Sacramento and Martinez. Although the fault responsible for these earthquakes is unknown, the only major fault mapped in the epicentral area is the Midland fault. The San Francisco office of the California Division of Mines and Geology (Kilbourne) has expressed special interest in proving the 1892 earthquake attributable to the Midland fault, but funds are not available for the necessary documentary procedure.

Since 1906 the largest earthquake near the Delta (Greenville fault) was in 1980 with a Richter magnitude of 5.8. Predictions of when, where, or how large the next large earthquake will strike the Delta, as many did prior to 1906, is dependent on the limited recorded history of earthquakes now available. Several estimates of earthquake probability for the Bay Area have been made by scientific organizations, and their results are roughly comparable.

The Technical Background Report of the Contra Costa County Seismic Safety Element of the General Plan contains available data and information that has been used to estimate earthquake probabilities for Contra Costa County. Table 2 shows approximate probability of occurrence of earthquakes on selected Bay Area faults and Table 3 presents estimated maximum parameters for known faults affecting Contra Costa County.

Information on earthquake characteristics of accelerations and derivations

TABLE 2

APPROXIMATE PROBABILITY OF OCCURRENCE OF
EARTHQUAKES ON SELECTED BAY AREA FAULTS
(50-Year Period)

Causative Fault	Magnitude	Approximate Probability of Occurrence (over a 50-year period)
San Andreas	7.0 - 8.0	Likely
	8.0 - 8.5	Intermediate
Hayward-Wildcat	6.0 - 7.0	Likely
	7.0 - 7.5	Intermediate
Calaveras	6.0 - 7.0	Intermediate
	7.0 - 7.5	Intermediate - Low
Concord	5.0 - 6.0	Likely
	6.0 - 7.0	Intermediate - Low

LIKELY: Greater than 50% probability of occurrence
INTERMEDIATE: 15 - 50% probability of occurrence
LOW: Less than 15% probability of occurrence

Source: Contra Costa County Planning Department Estimates, 1975

of strong ground shaking are necessary to the engineering design of structures. Criteria for Delta levee design should be no exception. Therefore, similar earthquake probabilities for the Delta should be estimated.

Seismic Hazard to Delta Levees

Levees within the statutory Delta boundary have been classified in this study into three categories: project, nonproject, and direct agreement levees. The project levees, comprising 15 percent of the total levee system, were either built, rebuilt, or adopted as federal flood control project levees. They are maintained by local districts to federal standards.

The nonproject levees, which make up 75 percent of the levees in the Delta, are generally in poor condition and need rehabilitation. They were privately constructed and are maintained either by the island landowners or local agencies. The cost of maintenance is funded entirely by the landowners who many times have to minimize maintenance work, which results in the maintenance rarely being accomplished to any set of uniform standards.

Direct agreement levees, comprising the remaining 10 percent of the levees are maintained by local districts to federal standards. They are either part of a navigation project or were rebuilt by the Federal Government after a flood disaster.

TABLE 3

ESTIMATED MAXIMUM PARAMETERS FOR KNOWN FAULTS AFFECTING CONTRA COSTA COUNTY

		San Andreas Fault	Hayward and Calaveras Faults	Concord and Green Valley Faults
Estimated Magnitude[1] (Richter Scale)		7 to 8.25	6 to 7.5	6 to 7
Estimated Fault Offset[2] (feet)		4 to 30	1 to 8	1 to 4
Estimated Duration Strong Shaking[3] (seconds)		24 to 37	5 to 30	5 to 24
Estimated Length of Tectonic Rupture[4] (miles)		40 to 300	5 to 70	5 to 25
Estimated Maximum Intensity[5] (M.M.)		VII to VIII	IX to X	VIII to IX
Estimated Peak Horizontal Accelerations in Bedrock[6] (g's)				
Distance from Causative Fault	at 5 miles	over .50	over .35	over .35
	at 10 miles	.35 to .50	.25 to .35	.25 to .35
	at 20 miles	.20 to .35	.10 to .30	.10 to .25
	at 30 miles	.10 to .25	.05 to .20	.05 to .15
	at 40 miles	.05 to .20	.05 to .15	less than .1
	at 50 miles	.05 to .15	less than .1	less than .1

EXPLANATION

Earthquake acceleration is expressed as a fraction of gravity (g). Thus an acceleration of .5g corresponds to an acceleration which is 50% of the value of gravity. At a distance of 10 miles from the San Andreas fault, earthquake accelerations in bedrock are expected to be between .35g and .5g. Local ground conditions and other factors could either increase or decrease expected accelerations.

NOTE: The estimated maximum parameters are intended as estimates of the maximum earthquake characteristics that appear capable of occurring given presently known seismological and geological conditions. It should be recognized that (1) the approximations which are presented are for comparative purposes only, (2) there are differences of opinion among professionals on the reliability of such estimates, and (3) the approximations which are presented are not intended as design criteria for structures.

Sources:

[1] Estimates based on historic seismicity of the fault (Townley and Allen, 1939), behavior of faults of similar length (Tocher, 1958; Lida, 1965; Albee and Smith, 1967; Bonilla, 1967; Bonilla and Buchanan, 1970), and, where available, geologic history of displacement.

[2] Estimates based on historic offset associated with earthquakes in a specified magnitude range (Bonilla, 1970a, 1970b; Wallace, 1970; Algermissen, et al, 1972).

[3] Estimates based on records of the duration of shaking of historic earthquakes (Greensfelder, 1973; Page, et al, 1972, p. 3).

[4] Estimates based on the geologic history of the fault and on the general relationship that exists between earthquake magnitude and the length of the associated tectonic rupture. (Bonilla, 1970a, 1970b; Wallace, 1970).

[5] Estimates based on records at the intensity of shaking associated with historic earthquakes. The empirical relationship between magnitude and maximum intensity if given by M = 1 + (2/3)1.

[6] Estimates based on accelerogram records of selected historic earthquake. (Grensfelder, 1973, Schnabel and Seed, 1972).

Compiled by the Contra Costa County Planning Department.

Much of the Delta is generally composed of organic peat material, which is ideal for agricultural purposes, but is poor foundation material for levees and structures. The peat has an average thickness of about 6 metres (20 feet) with a maximum depth of over 15 metres (50 feet). The organic soil is constantly decomposing and subsiding, compounding flood problems.

About 65 percent of the Delta levees are substandard and subject to overtopping or breaching. Poor strength of both natural soil and artificial embankments is compounded by continuous subsidence, thereby increasing water pressure on the levees. As subsidence continues, levee failure susceptibility increases. The flood threat is further intensified by the expansive, light, and sponge-like peat, composed of decaying organic matter that makes very poor dike construction material. Finely-grained sand lenses,[10] which are interbedded with and underlie the peat, are also susceptible to shaking and some of these sands have a high liquefaction potential.

The Delta levees, especially nonproject levees, are subject to cracking, settlement, slumping and then possible complete collapse by seismic shaking. A strengthened levee system, however, would have a much greater chance of surviving seismic activity. Many of the privately owned levees of the Delta are poorly constructed and are being subjected to substantial subsidence and erosion without proper remedial maintenance, which greatly increases the risk.

Available information strongly indicates that much of the levee system is susceptible to failure during a severe earthquake, and the potential hazard caused by earthquakes is greatest during periods of high water level in the Delta when levees are under higher stress. The flooding of Webb Tract and Holland Tract (both are nonproject levees) resulted from high water and local levee failure in early 1980 and exemplifies the hazardous conditions. Nonproject levees (and perhaps project levees) would not provide protection against a considerable seismic event. In short, the seismic stability of the Delta levee system is highly questionable.

Possible impacts upon Delta levees that could result from seismic ground shaking include:

- Liquefaction of levees or foundation soils.
- Compaction and settlement of levees or foundation soils.
- Lateral spreading of levees or foundation soils.
- Slumping of levees.
- Ground cracking of levees.
- Lurching of levees.
- Erosion or topping of levees by waves due to seiches.

Ground Shaking

The Delta is a floodplain underlain primarily by unconsolidated, water-saturated clay, silt, fine sand, and peat. This condition makes the area highly susceptible to damage by earthquake shaking. Moreover, prolonged shaking within the Delta could be particularly damaging because of the water-saturated condition of the loosely compacted soils.

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[10] Sand lenses exist throughout the Delta in varying degrees and they are most extensive in the southern and western Delta.

Amplification

Selective amplification of certain frequencies of earthquake waves occurs as the waves pass from bedrock into unconsolidated surface materials. The effect is to increase the intensity of certain frequencies, which is determined by a combination of soil conditions, depth to bedrock, and seismic factors.

Seiches

A seiche may be an earthquake-generated violent wave action (sloshing) within an enclosed or restricted body of water, such as a bay, lake, or reservoir. In the Delta, a seiche could potentially occur in Clifton Court Forebay or in Franks Tract, both of which are permanently flooded islands. Furthermore, a seiche may potentially occur on an island during temporary flooding. Delta lands flooded during 1980 are Holland, Webb, Upper Jones, Lower Jones and Deadhorse Tracts and Prospect Island.

Liquefaction[11]

The threat of liquefaction (the process of transforming any substance into a liquid) is greatest in areas where the depth to ground water is shallow and where the duration of shaking is sufficient for water to be released.

Liquefaction as a Function of Earthquake Magnitude

The unconsolidated and water saturated sediments (usually sands and silts) characteristic of the Delta are susceptible to liquefaction. Tables 4 and 5 and Figures 3 and 4 show the liquefaction potential of clay-free sands in the Delta and general seismic susceptibility of the Delta.

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[11] The definition of liquefaction, as stated in the Journal of the Geotechnical Engineering Division of September 1978 is: "Liquefaction - The act or process of transforming any substance into a liquid. In cohesionless soils, the transformation is from a solid state to a liquefied state as a consequence of increased pore pressure and reduced effective stress. Comments - Liquefaction is thus defined as a changing of state that is independent of the initiating disturbance that could be a static, vibratory, sea wave, or shock loading, or a change in ground-water pressure. The definition also is independent of deformation or ground failure movements that might follow the transformation. Liquefaction always produces a transient loss of shear resistance but does not always produce a longer-term reduction of shear strength. The committee recommends that use be discontinued of definitions that incorporate a modifier with the term liquefaction such as 'initial liquefaction', 'cyclic liquefaction', 'true liquefaction', etc. The tendency to subdue or drop such modifiers in routine usage has been a common source of confusion. Relayed terms include the following: Cyclic Strain Softening - A stress-strain behavior under cyclic loading conditions in which the ratio of strains to differential shear stresses increases with each stress or strain cycle. In saturated undrained cohesionless soils cycle strain softening is caused by increased pore-water pressure. Comments - Continued cyclic loading usually leads to increasing axial strains and increasing pore-water pressures, but does not necessarily lead to loss of ultimate shear strength if the material is diative."

In 1976 the Contra Costa County Planning Department developed a series of liquefaction potential maps, known as the Resource Mapping System (Administrative Map Overlay Series) in 1:24,000 scale for Contra Costa County. The map series is based upon inferred granularity, relative density, and probable ground water depth. The liquefaction potential or seismic susceptibility at an individual site cannot be interpreted from these maps. The maps indicate only the magnitude of the general Delta seismic potential hazard. (A mapping program to provide more information on liquefaction potential is proposed in Appendix C.)

Using the largest measured near-Delta earthquake of 5.8 magnitude (Greenville fault), we find the nearest Delta levees to be in the vicinity of Clifton Court Forebay, approximately 16 kilometers (10 miles) away. Seismic damage to the Delta levees was expected by many. Figure 5, which depicts earthquake magnitude versus maximum distance to significant liquefaction-induced ground failures, shows that an earthquake magnitude of greater than 6.0 would be necessary to induce liquefaction at Clifton Court Forebay. Les Youd of the USGS indicated in a personal communication that the curve might possibly be skewed upward for California. In either case, it would appear that a large earthquake (>RM6.0) necessary to affect the Delta, has not occurred since 1906.

Slide damage in embankment of Lower San Fernando Dam, San Fernando Valley Earthquake, 1971 (DWR 4109)

Table 4

ESTIMATED LIQUEFACTION POTENTIAL FACTORS FOR UNCONSOLIDATED SEDIMENTS, CONTRA COSTA COUNTY

Geologic Unit	Liquefaction Potential of Clay-Free Granular Layers	Occurrence and/or Distribution of Sands	Geologic Age	Depth of Water Table Below Surface	Remarks
Young Bay Sediments Unconsolidated silt and clay with admix abundant organic material, local peat, sand and gravel lenses or discontinuous beds.	Generally High	Clay-free sands are generally restricted to present and former stream channels. Locally beach or dune sands may be present.	Late Holocene*	0-5'	There is a general tendency for older, more deeply buried sands to be more compact than near surface deposits. Data show that approximately 75 percent of sands in younger bay sediments have a high liquefaction potential.
San Joaquin Delta Deposits Mainly unconsolidated peat, organic clay, silt and fine-grained sand; irregularly interstratified.	Generally High	Predominantly flood plain and marsh deposits. Includes channel sands and dune sands.	Late Holocene	0-5'	Loose, water saturated sands are present in most boring logs, and approximately 75 percent of the sands within 20 feet of the surface have a high liquefaction potential. Below a depth of 20 feet, sands have a much lesser but significant potential for liquefaction.
Stream Channel Material Mainly loose, well-sorted sand and gravel.	Generally High	This material is restricted to present and former stream channels.	Historic	5-25'	Largely restricted to material presently being transported during periods of normal runoff.

*As used in this table, Late Holocene is considered to represent the period of time that has elapsed since sea level attained its present position (approximately 5,000 years before present) and initiated with modern cycle of sedimentation.

NOTE: Information on the occurrence and character of surficial deposits is generalized from original source materials. This table is a guide for planning operations, not an indicator of ground conditions on individual sites.

Compiled by Contra Costa County Planning Department

Table 5

ESTIMATED SEISMIC SUSCEPTIBILITY FACTORS FOR GEOLOGIC UNITS CONTRA COSTA COUNTY*

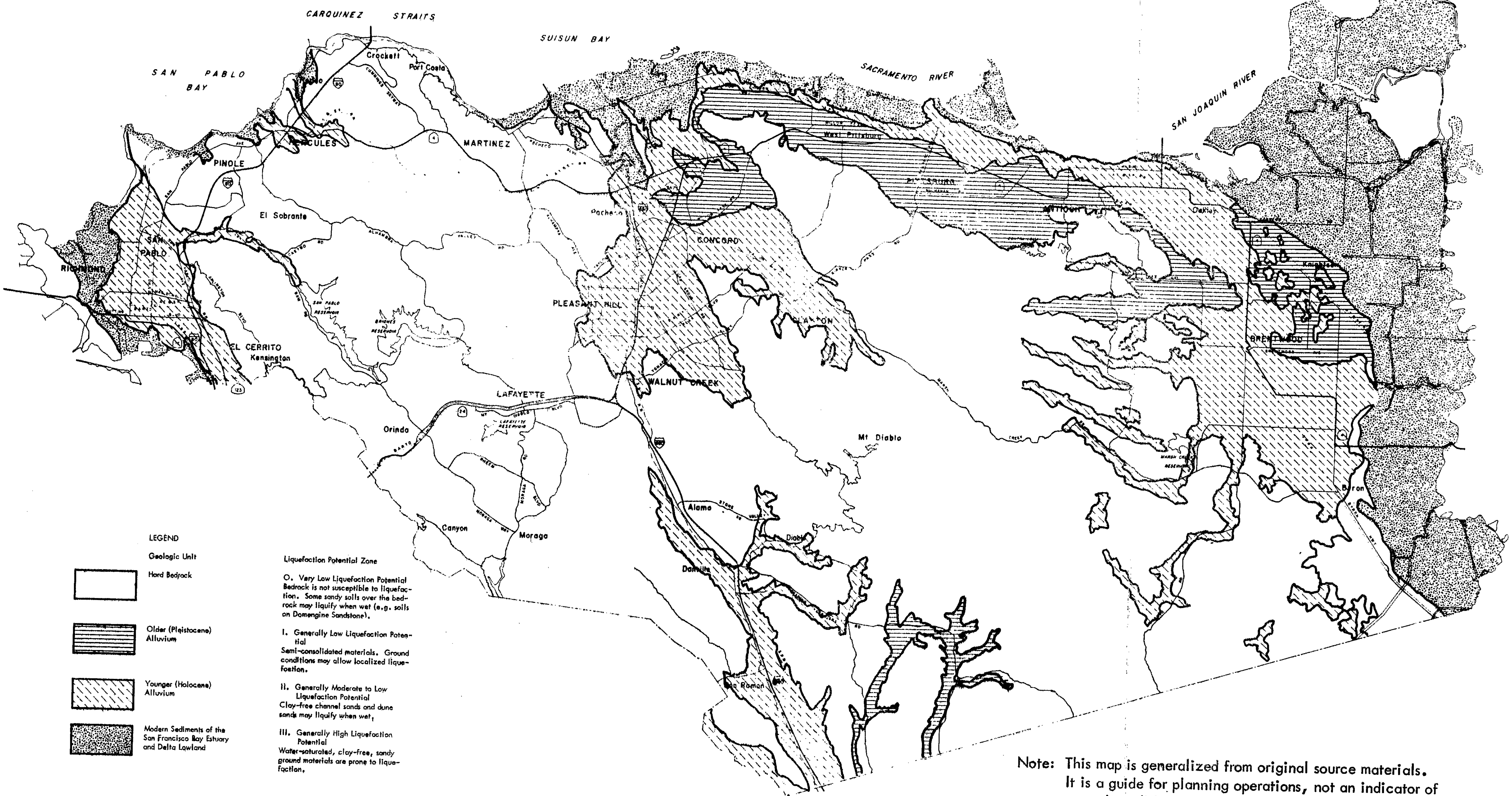
Lithology	Susceptibility Factor (Modified Mercalli Units)	Geologic Engineering Character	Remarks
Young Bay Mud (including non-engineered fill)		Silty, clayey, sandy mud; small sand lenses; massive structureless, soft and fluid at top, increasingly consolidated at depth; high water content, low shear strength; high compressibility; low bearing strength, moderately high sensitivity.	Seismic ground response studies indicate that weakly consolidated, water-saturated sediments amplify ground motion. Additionally, at the high stress levels that accompany damaging earthquakes, such areas typically experience ground failure, including differential subsidence, ground cracking, lurching, lateral spreading toward a free face, liquification, and compaction.
Less than 15' thick	2		
15 - 30' thick	2-1/2		
Greater than 30' thick	3-1/2		
Peat		Peat and associated organic silts and clay; underlain by normally loaded, water saturated fine grained clastics, peat approximately 50% combustible by weight; high water content; engineering properties comparable to young bay mud.	
Less than 15' thick	2		
15 - 30' thick	2-1/2		
Greater than 30' thick	3-1/2		
Quaternary Sediments		Shallow and deep slides. Includes debris slides, slump blocks, earth flows and rockfalls. Composition of slide deposits highly variable.	Stabilized, dry slides relatively safe; active and/or wet slides extremely hazardous, hazard greater on steep slopes, especially if local reflected waves arise.
Landslide deposits	1-1/2 - 3-1/2		

*The susceptibility factor is the estimated increase in Modified Mercalli Intensity, and all susceptibility factors are relative to the Franciscan Formation and igneous rocks.

Compiled by Contra Costa County Planning Department

FIGURE 3

ESTIMATED LIQUEFACTION POTENTIAL OF CLAY-FREE SANDS

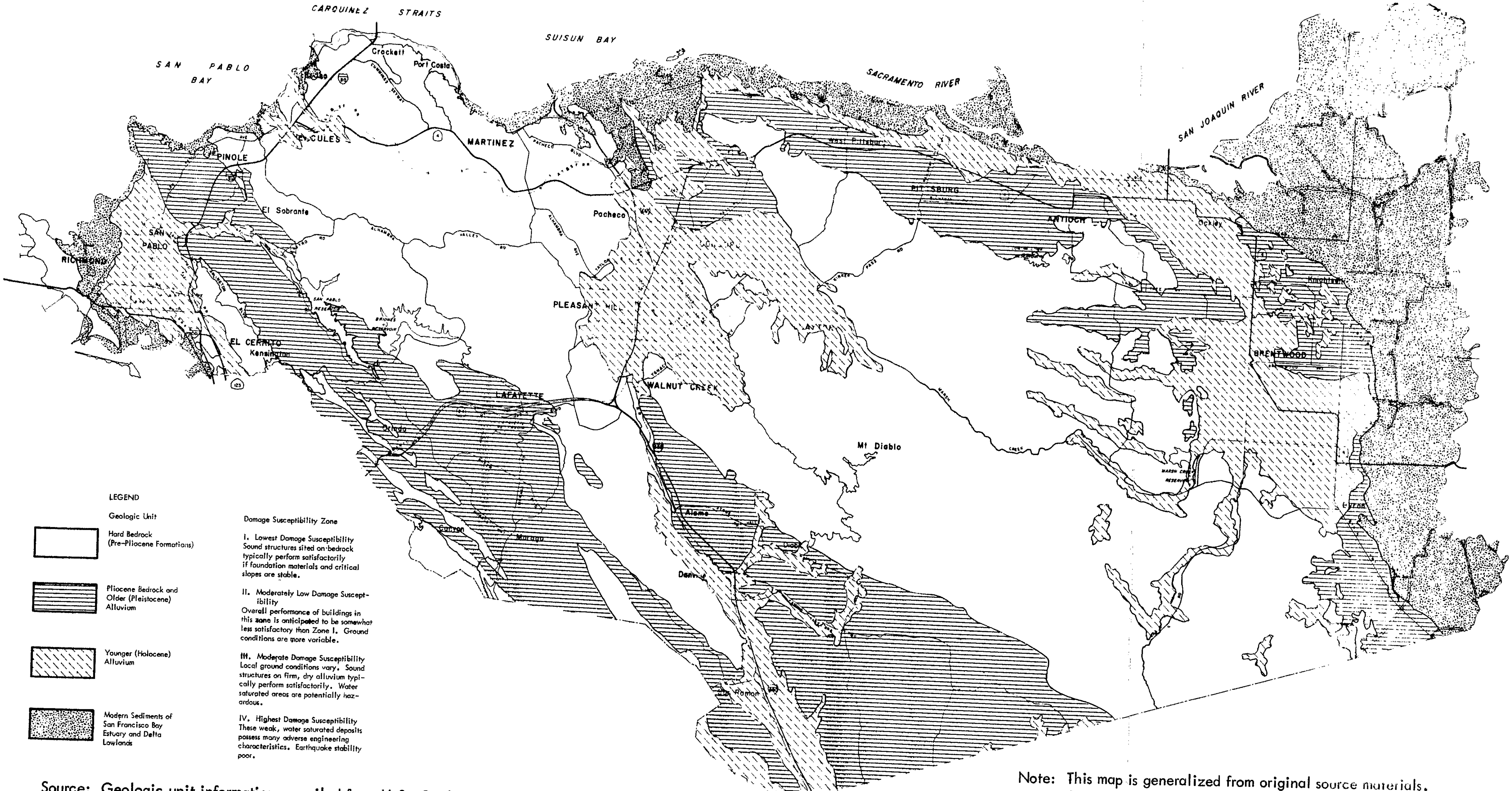


Note: This map is generalized from original source materials. It is a guide for planning operations, not an indicator of ground conditions on individual sites.

Source: Surficial deposit information compiled from U.S. Geological Survey and California Division of Mines and Geology Mapping. Liquefaction interpretation by the Contra Costa County Planning Department

Prepared by Contra Costa County Planning Department, December 1975.

FIGURE 4 SEISMIC SUSCEPTIBILITY



Source: Geologic unit information compiled from U.S. Geological Survey and California Division of Mines and Geology Mapping. Earthquake response interpretation by the Contra Costa County Planning Department

Note: This map is generalized from original source materials. It is a guide for planning operations, not an indicator of ground conditions on individual sites.

Prepared by Contra Costa County Planning Department,

Contra Costa County, California

C-105150

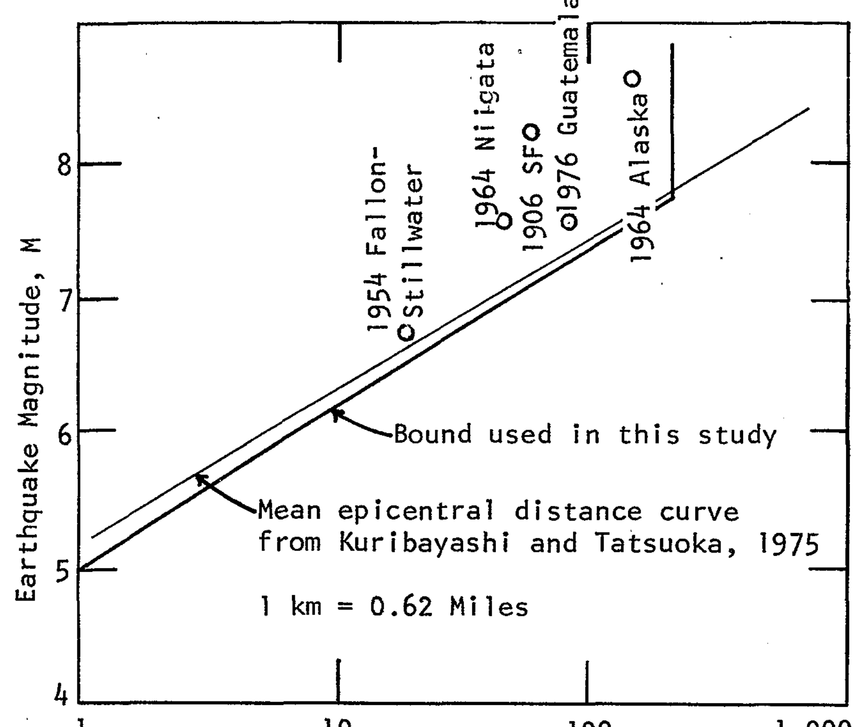
C—105150

FIGURE 5

DISTANCE FROM SEISMIC ENERGY SOURCE TO FURTHEST SIGNIFICANT LIQUEFACTION-INDUCED GROUND FAILURE TO FIVE PERTINENT EARTHQUAKES

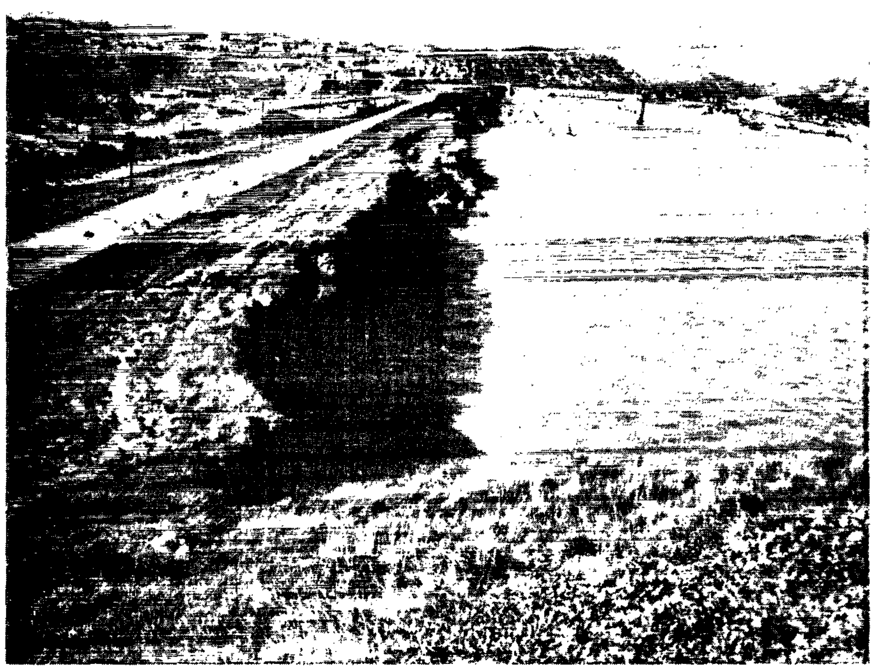
Earthquake	Magnitude	Assumed Source Zone	Distance* in miles	Location of furthest ground failure	Reference
1906 San Francisco	8.2	Ruptured fault	48	King City	Youd and Hoose
1954 Fallon-Stillwater	6.8	Ruptured fault	14	Lone Tree	Steinbrugge and Moran
1964 Alaska	8.6	Tectonic uplift	81	Glenn Ellen vicinity	Kachadoorian and Ferrians
1964 Niigata	7.5	Tectonic uplift area	44	Near Nagakoa	Kuribayashi and Tatsuoka
1976 Guatemala	7.5	Ruptured fault	56	Puerto Cortes, Honduras	Seena Hoose

From "Mapping Liquefaction-Induced Ground Failure Potential", Journal of the Geotechnical Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 104, No. GT4, April 1978, by T. Leslie Youd, M.ASCE and David M. Perkins.



EARTHQUAKE MAGNITUDE VERSUS MAXIMUM DISTANCE TO SIGNIFICANT LIQUEFACTION-INDUCED GROUND FAILURES

*Distance from source zone to furthest significant ground failure.



Failure along dam crest of Lower San Fernando Dam,
San Fernando Valley Earthquake, 1971 (DWR 4110 & 4118)

Chapter V. EARTHQUAKE HAZARD INVESTIGATIONS

This section presents available programs and proposed investigation programs that either evaluate Delta seismic hazards or (as in the case of ABAG's Earthquake Hazard Mapping Program) may possibly be adapted to this purpose.

Delta Accelerograph Installations

In cooperation with the Earthquake Engineering (EE) Section of DWR, Central District (CD) installed three SMA-1 instruments in the Delta proper in June 1980 (Figure 6). Three additional SMA-1s were placed in the Delta by request of Safety of Dams. No information had been obtained at the time of this writing.

The SMA-1 is a triaxial strong motion accelerograph housed in a light-tight, water-tight case aluminum base and cover. The SMA-1 records photo-optically on 70 mm film. The instrument remains in a standby condition until an earthquake causes the starter to activate the light source and film drive motor. Operation of the drive motor continues for as long as the starter detects the earthquake plus an additional time to record a single earthquake or a sequence of earthquakes and aftershocks lasting as long as 25 minutes (total time). At present, values for the Delta area are obtained only from association of available lists of strong motion accelerograms. Earthquakes can be studied to find a prototype accelerogram that estimates seismic response of structures on the site. Because of the lack of strong motion measurements on the diverse geological and soil structure of the Delta, there are no easy formulae that will yield hard and fast numerical values for Delta seismic parameters.

In summary, empirical deviations can give only approximations for ground accelerations; the existing uncertainties, therefore, emphasize the importance of the instrumentation network. The SMA-1 output is a time-history of ground acceleration at the instrument site. The acceleration traces can be digitized and processed to provide ground velocity and displacement time histories and the spectral content of these parameters.

Many installation sites and alternative sites for the instruments were suggested and numerous network designs are possible. The limited number of instruments available limited the possible coverage. Basically, the SMA-1s were installed on cohesionless soils roughly representing the north, east, south and west area of the Delta. Exact placement of the accelerographs was determined by the availability of stable-secure structures with accessibility, power, and entry permission when required.

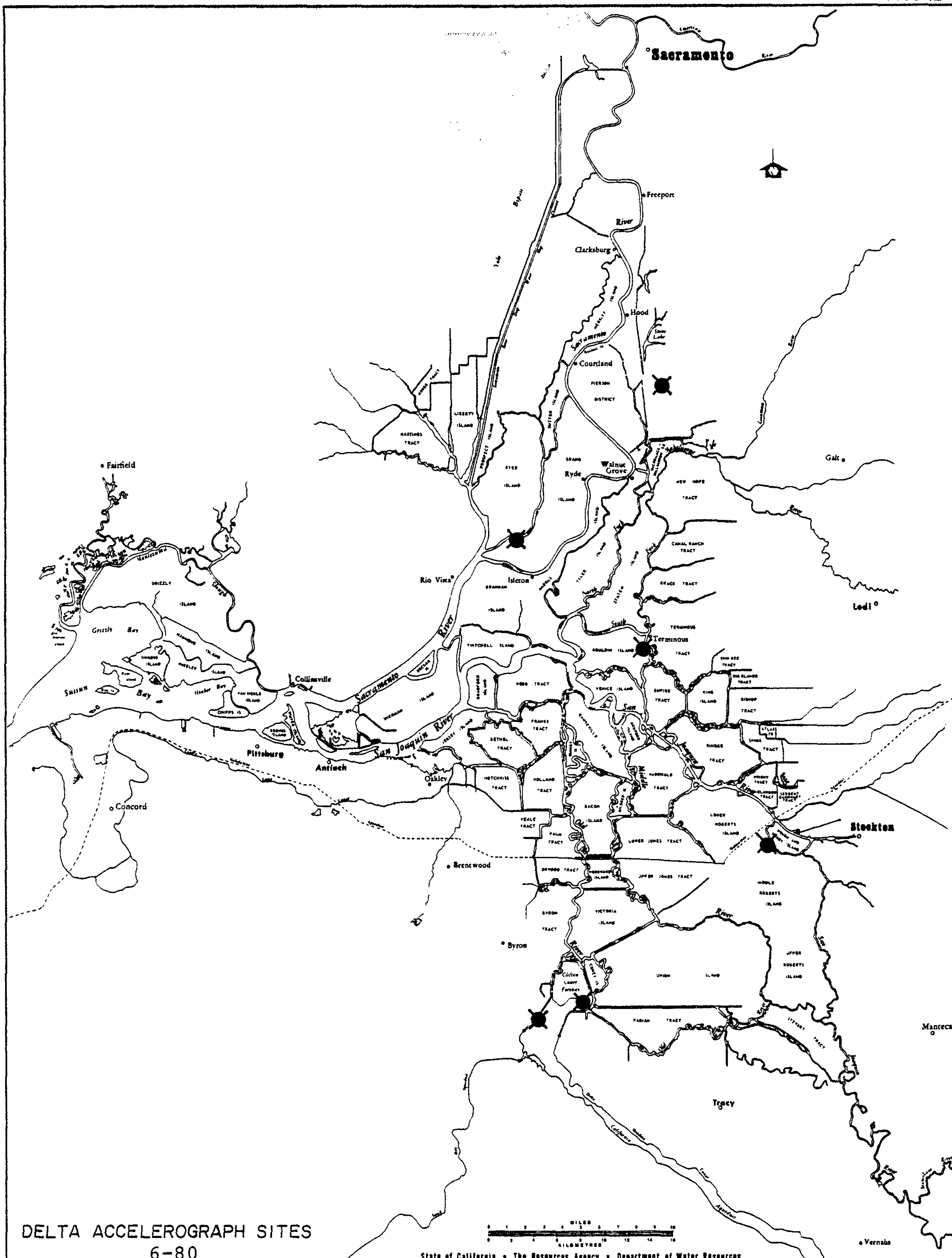
The SMA-1s were installed at the following locations (see map, Figure 6).

1. Bouldin Island - east side; installed in warehouse structure approximately 8 kilometres (5 miles) south of Highway 12.

2. Grand Island - southwest side; located in pumphouse on Steamboat Slough near the confluence of the Sacramento River.

3. Rough and Ready Island - west end; pumphouse on Burns Cut.

4. Clifton Court Forebay - south levee of forebay; west of intake gates.



DELTA ACCELEROGRAPH SITES
6-80

C-105154

C-105154

5. Delta Pumping Plant - located on intake canal approximately 1 kilometre (1/2 mile) upstream of pumps.

6. Snodgrass Slough - installed in small electrical structure along Peripheral Canal alignment approximately 3 kilometres (2 miles) west of I-5 and 2 kilometres (1 mile) south of Lambert Road.

Soils at the various sites are primarily stream channel deposits consisting of unconsolidated gravel, sand, silt and clay covering the channels, floodplains and natural levees of existing and ancestral streams from the Quaternary and Holocene periods.

More detailed information should be sought for further studies on the response of the levees. Soil logs, published geologic cross sections and shallow refraction surveys would be helpful, but they are either vague or nonexistent. Information obtained from an accelerograph would be enhanced by core logs showing the soil profile directly beneath the accelerograph station.

Since it will require a sizeable earthquake (approximately RM 3.5) at the immediate site to trigger the instruments at 1 percent, it is not possible to predict when any useful information may come from the placement of these instruments. Also, the EE has reported that given an emergency situation (i.e., Oroville Dam earthquake) these instruments may be withdrawn for emergency use.

ABAG's Earthquake Hazard Mapping Program

Started in February 1979 in a program funded by USGS, ABAG established a series of computer-based map files showing various basic data maps related to earthquakes. The system has produced several maps illustrating various earthquake hazards based upon a synthesis of the basic data. A guide to ABAG's earthquake hazard mapping capability includes (1) basic data map files, (2) hazard map files, and (3) applications for map files. Details of the program capabilities are presented in Appendix C.

Proposed University of California at Davis Earthquake Mapping Program

Little information is available on the effects of earthquakes on organic peat soils. It is not known if the Delta levee system is in total or in part a potentially hazardous seismic zone. We, therefore, need to identify any Delta critical zones. A composite of studies and opinions from various agencies[12] generally indicates a very significant and definite importance to conducting a seismic study on the Delta levees. The primary concern as related by these agencies is levee susceptibility to earthquake-induced liquefaction and consequent levee failure.

Levee failure from liquefaction or other earthquake-related failures would cause life loss, inundation, loss of crops, transportation systems disruption, and great environmental and economic losses.

Potential liquefaction related hazards and the concensus of various agencies regarding the importance of liquefaction potential dictate the necessity of conducting a further evaluation of Delta levee liquefaction potential. A proposed plan outlined for an initial Delta levee liquefaction potential study is presented in Appendix C.

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[12] ABAG, DAPSC, DMG, USGS, DWR, Delta county planning departments, consultants, and others.

Proposed Delta Seismology Investigation

The general knowledge that the Delta levees have liquefaction potential is not sufficient for evaluation of the actual liquefaction potential at an individual site. Site specific geotechnical investigations are required to make such an assessment. A brief and basic outline of a proposed Delta Seismicity Investigation Plan is presented in Appendix C.

Flow failure along shoreline of Lake Merced triggered by the 1957 Daly City earthquake. Photograph previously published in Bonilla 1960, p. 22; with caption "Damage to roadway by landslides along south arm of Lake Merced. View looking northwest". (Photograph by M. G. Bonilla and provided by U. S. Geological Survey.)

APPENDIX A

HISTORICAL SEISMIC ACTIVITY IN THE DELTA

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HISTORICAL SEISMIC ACTIVITY IN THE DELTA

The purpose of this section is to identify and clarify the types of known ground failures associated with earthquakes in the Delta. Earthquake damage of the past has been principally due to lateral spreads, differential settlements, and ground cracks. Liquefaction has been the direct cause of most lowland failures. Though numerous sources were researched for possible events, the most complete source for the following abridged listing of events is the Historic Ground Failures in Northern California Associated with Earthquakes - Geological Survey Professional Paper 993 (T.L. Youd and S.N. Hoose, USGS, 1978).

KEY TO ACCURACY OF FAILURE SITES TO BE LOCATED

A — A site that can be accurately relocated.

B — A site that can be relocated to within a few kilometres and probably could be located more accurately with further investigation.

C — A site where the information is insufficient to allow precise location.

KEY TO GROUND FAILURES

 Hillside landslides including rotational slumps, block slides, debris avalanches, and rock falls.

 Streambank landslides including rotational slumps and soil falls.

 Lateral spread.

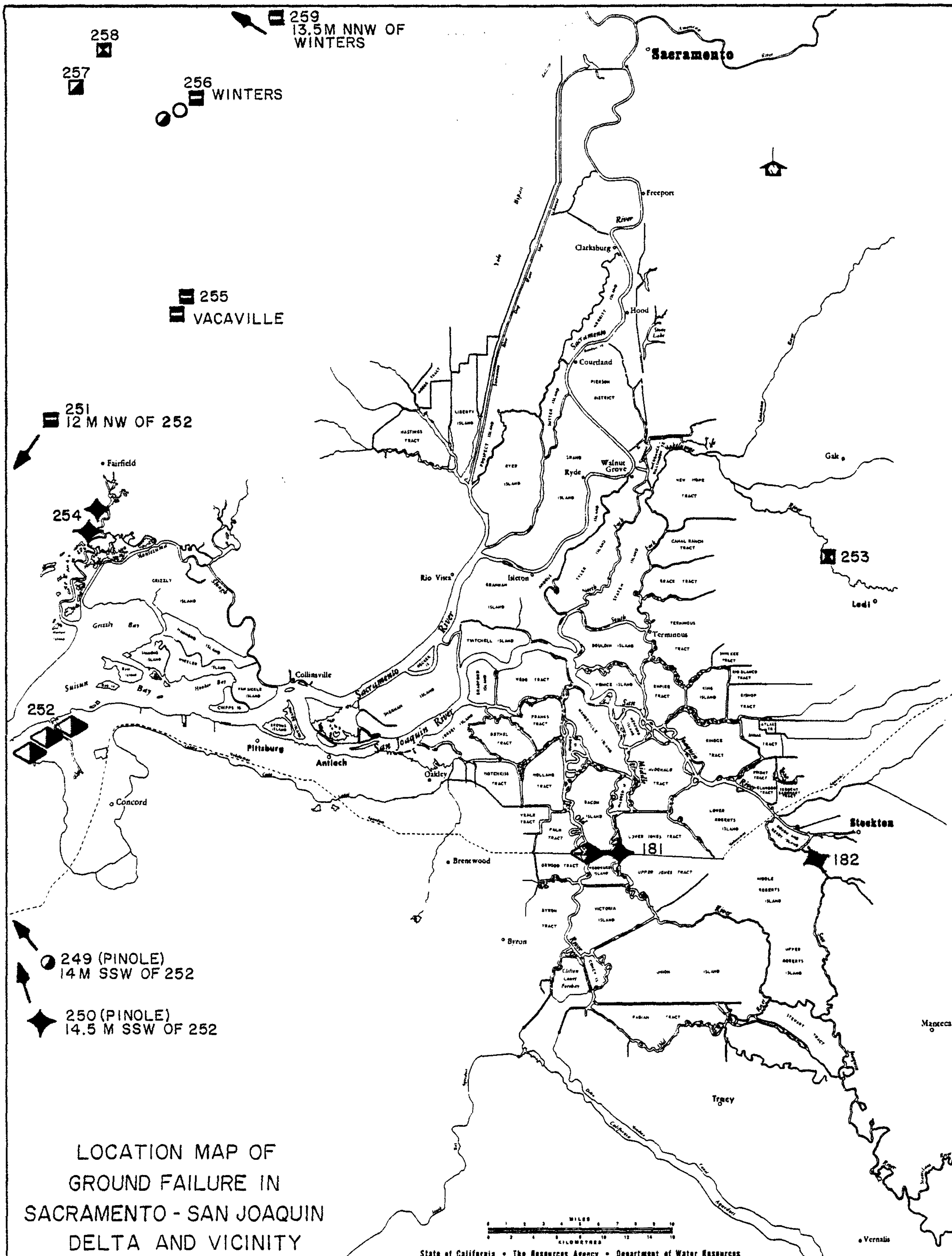
 Ground settlement.

 Ground cracks not clearly associated with landslides, lateral spreads, settlement or primary fault movements.

 Disturbed wells.

 Sand boils.

 Miscellaneous effects.



259
13.5 M NNW OF
WINTERS
258
257
256
WINTERS
255
VACAVILLE
251
12 M NW OF 252
254
252
253
181
182
249 (PINOLE)
14 M SSW OF 252
250 (PINOLE)
14.5 M SSW OF 252
Sacramento
Freeport
Clarksburg
Hood
Courtland
Walnut Grove
Ryde
Rio Vista
Isleton
Terminous
Collinsville
Pittsburg
Antioch
Oakley
Concord
Brentwood
Byron
Stockton
Lodi
Galt
Manteca
Tracy
Vernalis
Fairfield
Grizzly Bay
Suisun Bay
Sacramento River
San Joaquin River
LOCATION MAP OF
GROUND FAILURE IN
SACRAMENTO - SAN JOAQUIN
DELTA AND VICINITY
MILES
KILOMETRES
State of California • The Resources Agency • Department of Water Resources

C—105159

LOCATION: 181

YEAR: 1906

FAILURE TYPE: ✦ ◁▶

ACCURACY: A

REFERENCE: Salinas Daily Index, 1906
Latest earthquake news, the Santa Fe's Condition
Salinas, California. April 20, 1906
V. 19, No. 124, P. 3

QUOTATION: The big bridge at Middle River between Point Richmond and Stockton sank three feet and was twisted out of line.

LOCATION: 182

YEAR: 1906

FAILURE TYPE: ✦

ACCURACY: B

REFERENCE:

1. The Evening Post, railroad tracks sunk.
   New York, N.Y., April 18, 1906.
   V. 105, P. 1.

2. New York Tribune, 1906
   Ruin and death widespread
   New York, N.Y., April 19, 1906
   V. 66, No. 21.704, P. 1

QUOTATION:

1. Santa Fe Bridge Over the San Joaquin Settles. Stockton, California, April 18. A sharp earthquake shock was felt here at 5:15 o'clock this morning. The Santa Fe Bridge over the San Joaquin River settled several inches.

2. Stockton, California, April 18, -- ... The Santa Fe Bridge, over the San Joaquin River, settled several inches.

C-105160

LOCATION: 249

YEAR: 1906

FAILURE TYPE: 

ACCURACY: C

REFERENCE: Jorden, D.C., ed. 1907
The California Earthquake of 1906
San Francisco, A.M. Robertson
360 pages, P. 33

QUOTATION: At Sobrante, in Contra Costa County, east of San Francisco Bay there are large slumps or cracks in the earth.

LOCATION: 250

YEAR: 1906

FAILURE TYPE: 

ACCURACY: C

REFERENCE: Salinas Daily Index, 1906c
Latest Earthquake News; The Santa Fe's Condition:
Salinas, California, April 20, 1906
V. 19, No. 124, P. 3

QUOTATION: The Santa Fe's Condition . . . . The railway bridges and railyards at Pinole sank two feet.

LOCATION: 251

YEAR:
1. 1906
2. 1898

FAILURE TYPE:
1. 
2. 

ACCURACY:
1. B
2. B

REFERENCE:
1. Lawson, A.C. and others, 1908
The California Earthquake of April 18, 1906;
Report of the California State Earthquake
Investigation Commission: Carnegi Institute,
Washington. Pub. 87, V. 1 and Atlas.
451 P., P. 212

C-105161

LOCATION: 251 (Continued)

2. Townley, S.D., and Allen, M.W., 1939
Descriptive Catalog of Earthquakes of Pacific Coast of the United States 1769-1928.
Seismol. Society America Bull., V. 29, No. 1, P. 21-252, P. 105.

QUOTATION:

1. Mare Island -- The earthquake was much less severe than that of 1898, which wrecked many of the government buildings in the navy yard. None of the government buildings were wrecked this time, nor was the damage at all serious except in the case of two or three new buildings recently erected on the "made" land near the waterfront. Here ground was thrown into violent undulations, and buildings were so twisted that about $2,000 worth of repairs had to be made. On this soft ground the brick walls were cracked . . . . In the case of the older buildings resting on hard ground, no cracks were formed, nor any injury reported.

2. 1898, March 30. 11:45 p.m., VIII, Mare Island, San Pablo Bay. This earthquake wrought such damage at Mare Island Navy Yard that it may properly be known as the Mare Island earthquake . . . . Admiral H. W. Lyon, U.S.N., has furnished the following information: " . . . . the violence of shock was greater than any shock previously experienced on this island, as far as can be learned from the oldest inhabitants.

"A detailed account of the damages done is set forth in a report to the commandant, dated April 5, 1898."

LOCATION: 252

YEAR: 1906

FAILURE TYPE: 

ACCURACY: B

REFERENCE: Lawson, A.C. and others, 1908
The California Earthquake of April 18, 1906;
Report of the California State Earthquake Investigation Commission: Carnegie Institute, Washington. Pub. 87, V. 1 and Atlas, 451 P., P. 310

LOCATION: 252 (Continued)

QUOTATION: The railroad track east of Martinez, near Bull's Head Old Works, was thrown 3 inches out of alignment to the north. Many cracks occurred in the embankment on both sides of the track. A series of five small transverse waves were found in the embankment about 0.5 miles west of Peyton Station. The distance between crests was about 10 to 15 feet; amplitude estimated at 3 inches. This embankment lies in flat marshy land. A small railroad bridge near Avon Station was thrown 4 inches toward the east abutment, but it had been repaired at the time of the visit.

LOCATION: 253

YEAR:
1. 1857
2. 1906

FAILURE TYPE:
1. 
2. 

ACCURACY:
1. C
2. C

REFERENCE:
1. Sacramento Age, 1857
Designs of the Earthquake.
Sacramento, California, January 10, 1857

2. San Francisco Chronicle, 1906
River Changed by Trembler.
San Francisco, California, May 1, 1906
V. 88, No. 106, P. 1

QUOTATION:
1. We have information of severe effects of the earthquake along the line of the lower Stockton Road. Below Benson's Ferry the waters of the Mokelumne River much swelled by recent rains were thrown over the banks, leaving the bed of the stream almost bare. Hoses were shaken violently, destroying articles of glassware and overturning furniture. Limbs were broken off from trees and the trees in some instances settled down two.or three feet into the ground. The inhabitants of that section were terror stricken, whilst dumb brutes appeared to be paralyzed.

2. Stockton, April 30 . . . . It was discovered today that in the vicinity of Woodbridge the Mokelumne River has fallen 12 feet, the bed of the river having dropped from the effects of the recent earthquake.

LOCATION: 253 (Continued)

This stream had been carrying a lot of water when it was noticed that the river was steadily falling, contrary to all precedent. The people could hardly believe their eyes. They watched the river recede for a day and made an investigation, with the result that the bed was found to be almost 12 feet lower than before.

As the waterway has been steadily filling up each year with silt from the upper portion of the river, farmers along that stream are highly pleased with the change, since it can carry far more water than heretofore, and not endanger their lands on either side of it.

Another incident of the earthquake is the drying up of Tracy Lake, in the northwestern part of San Joaquin County. Ever since the earthquake the water has been decreasing at a rapid rate, and at present it is almost on a level with the Mokelumne River.

Whether or not there is a crack in its bed, or an underground passage connecting the lake with the river, is not known, but at the rate the lake has been falling it will soon be as low as the river. The benefit in both instances will be appreciated by farmers.

LOCATION: 254

YEAR: 1906

REFERENCE:

1. Duryea, E., Jr. and others, 1907
The Effects of the San Francisco Earthquake of April 18, 1906 on Engineering Construction. American Society of Civil Engineers Trans. V. 59, Paper No. 1056, P. 208-329.

2. Ransome, F. L., 1906
The Probable Cause of the San Francisco Earthquake. National Geographic Magazine. V. 17, No. 5, P. 280-296.

3. Davison, C., 1906
The San Francisco Earthquake of April 18. Scientific American Supp. No. 1586, P. 25416 May 26, 1906.

LOCATION: 254 (Continued)

4. Engineering News, 1906
The San Francisco Disaster, 1906
Earthquake and Fire Ruin in the Bay Counties, Calif.
Engineering News, V. 55, No. 17, P. 478-480.

5. The Evening Post
Railroad Tracks Sunk: New York, N.Y.
April 18, 1906, V. 105, P. 1
Shock Felt at Stockton: New York, N. Y.
April 18, 1906, V. 105, P. 1.

6. The Evening Bee
Sacramento Suffers No Real Damage From the Effect of the Shock.
Sacramento, California, April 18, 1906, V. 99, No. 16,359, P. 4.

7. Los Angeles Daily Times
Stirring Incidents of the Cataclysm - Quake Works Havoc in Adjacent Towns.
Los Angeles, California, April 19, 1906, V. 25, P. 14.

8. Public Ledger, 1906
Over Mile of Track Sunk
Philadelphia, Penn., V. 141, No. 26, P. 4.

9. New York Tribune, 1906
Ruin and Death Widespread
New York, N.Y., April 19, 1906, V. 66, No. 21.704, P. 1.

QUOTATION:

1. Failure Type: ✦

Accuracy: C

At one point on the marsh between Benecia and Suisun, on the Southern Pacific, the settlement was 11 feet; at another point, 5 feet. These were nearly vertical.

2. Failure Type: ✦

Accuracy: C

On the north shore of Suisun Bay part of the tract of the Southern Pacific, laid on marsh, subsided several feet.

3. Failure Type: ✦

Accuracy: C

Three miles of railway have sunk out of sight between Suisun and Benecia.

LOCATION: 254 (Continued)

4. Failure Type: ✦

Accuracy: C

Farther east (of Oakland and Berkeley) the Southern Pacific Company suffered much disturbance of its railway lines... a section of track between Oakland and Sacramento sank several feet; a railway bridge over the San Joaquin settled several inches.

5. Failure Type: ✦

Accuracy: C

Effect of Shock Between Suisun City and Benecia. A Telegram from Sacramento to Western Union Telegraph Company's office in this city reports that 3 miles of railroad sank out of sight as a result of the earthquake between Suisun City and Benicia, in Solano County, and all wires were taken with it ... reported sinking of a 3-mile section of the railroad company's tracks between Suisun and Benecia, which are on the direct line between Sacramento and San Francisco. The road crosses some low land at the point where its tracks are reported sunk. The location of this sinking of the earth is about 30 miles from San Francisco.

6a. Failure Type: ✦

Accuracy: C

Trains Brought Back. Trains which had been dispatched for San Francisco early this morning had to be brought back, and they were sent to the Bay City by the Lathrop route.

It was at the spot where the track disappeared that the railroad company had so much trouble last winter, when a loaded passenger train came near going out of sight. A great army of men was then set at work to fill up the sink. The task was a most difficult one, as enormous timbers which were thrown into the hole quickly sank from view, and the train loads of earth dumped in disappeared like snow in a fierce sunshine. But the engineers finally mastered the situation, and after a week's time trains were sent over the route again. It is now feared that it will take several weeks' time to repair the present collapse, and in the meantime all trains will be sent by the Stockton (sic) route.

LOCATION: 254 (Continued)

6b. Failure Type:

Accuracy: C

Earth Cracked Open. There are great crevasses on each side of the track through the Suisun marshes and it is reported that a great ocean of water has flowed over the lowlands between Suisun and Benecia.

Engine Sinks in Earth. A short distance below Suisun, a Southern Pacific switch engine sank into the ground for a distance of 3 feet, not far from where the track disappeared.

6c. Failure Type:

Accuracy: C

The Southern Pacific Company repaired its tracks beyond Suisun yesterday afternoon and trains are now running direct to San Francisco. The local officials state that the rumor to the effect that the tracks had gone out of sight was not so, and it took but two or three carloads of dirt to level the tracks. This was done by 2:30 yesterday afternoon and last night trains were running through to Oakland on schedule time.

7. Failure Type:

Accuracy: C

Sacramento, April 18. A short time after the big shock came a message from Suisun, Solano County, saying that a long section of track had disappeared from view. It was learned later that, in one place between Sprig and Teal Stations, in the Suisun Marshes, for a distance of one mile and a half, the track had sunk down 3 to 6 feet, and at another point nearly 1,000 feet of track went out ... the track sunk by the earthquakes is near the place where a loaded passenger train came near going out of sight ... there are great crevices on each side of the track through the Suisun marshes, and it is reported that a great ocean of water has flowed over the lowlands between Suisun and Benecia.

A short distance below Suisun a Southern Pacific switch engine sank into the ground for a distance of 3 feet, not far from where the tracks disappeared.

LOCATION: 254 (Continued)

8. Failure Type:

Accuracy: B

Sacramento, April 18. A short time after the shock of the earthquake a message came from Suisun, Solano County, saying that a long section of track had disappeared from view. One place between Sprig and Teal Stations in the Suisun marshes for a distance of one mile and a half the track had sunk 3 to 6 feet, and at another point near 1,000 feet of track went out.

9. Failure Type:

Accuracy: B

Sacramento, California, April 18. It was learned that between Sprig and Teal Stations for a distance of one mile and a half the track had sunk 3 to 6 feet. At another point nearly a thousand feet of track sank from sight.

LOCATION: 255

YEAR: 1892

FAILURE TYPE:

ACCURACY: C

REFERENCE: Holden, E. S., 1898.
A Catalogue of Earthquakes on the Pacific Coast 1769-1897, Smithsonian Institute, Miscellaneous Collection. V. 37, 253 p., p. 174 and 176.

QUOTATION: 1892, April 19. Vacaville ... The ground was fissured in many places.

LOCATION: 256

YEAR: 1892

REFERENCE: 1. Holden, E. S., 1898.
A Catalogue of Earthquakes on the Pacific Coast 1769-1897. Smithsonian Institute, Miscellaneous Collection. V. 37, No. 5, 253 p.

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LOCATION: 256 (Continued)

2. Coffman, J. L. and Von Hake, C. A., 1973
Earthquake History of the U. S. (rev. ed.)
U. S. Environmental Data Service
Pub. 41-1, 208 p.

QUOTATIONS:

1a. Failure Type:

Accuracy: C

1892. April 20; Winters. At Winters there have been developed a number of fissures in the earth, water has been ejected, gas has escaped, and the bed of the creek has been filled up for a distance of over 70 yards. Many of the wells have been filled up by the collapse of the walls.

1b. Failure Type:

Accuracy: C

1892, April 19; Winters; 2:50 a.m. On Putah Creek, half a mile west of Winters, a phenomenon was witnessed by a young man named Fred Willis, who was riding past at the time of the big shake. There seemed to be an explosion, and the water was thrown from the creek to a distance of 20 feet on either bank. Then followed a hissing sound as of gas escaping. At daylight several fissures were found in the bed of the creek and in the roadway and fields adjoining. On each side of the creek where the explosion took place the banks caved in, the landslides being 75 feet in length and 12 feet deep.

1c. Failure Type:

Accuracy: C

1892, April 19; Winters ... Near the town the bank of Putah Creek, 10 feet wide, caved in, and along the bottom of the creek for a great distance rents were made by the shocks. West of here about 3 miles an acre of ground slid into the creek.

1d. Failure Type:

Accuracy: C

LOCATION: 256 (Continued)

1892, April 21; Winters ... The railroad track is all right, and telegraphic communication has been uninterrupted, but there are many nasty cracks and fissures in the roadways, and driving is dangerous.

1e. Failure Type:

Accuracy: C

1892, April 21; Winters ... The sand bars in Putah Creek near Winters opened and from the fissures the water spurted high up on the banks. In some places the creek became dry, in others it changed to a torrent. The banks caved in some places and almost dammed the stream.

2. Failure Type:

Accuracy: C

1892, April 19 ... Fissures were found in the bed of Putah Creek, one-half mile west of Winters, and in the adjoining roadway and fields, banks of the creek were caved in.

LOCATION: 257

YEAR: 1892

FAILURE TYPE:

ACCURACY: C

REFERENCE: Holden, E. S., 1898. A Catalogue of Earthquakes on the Pacific Coast. 1769-1897. Smithsonian Institute, Miscellaneous Collection. V. 37, No. 5, 254 p.

QUOTATION: 1892, April 19 ... Up the Berryessa road the passage is blocked by immense bowlders (sic), some weighing several tons, which were thrown down the hillsides into the road. It is near this point where the rents in the road were noticed.

LOCATION: 258

YEAR: 1892

LOCATION: 258 (Continued)

FAILURE TYPE: ☒

ACCURACY: C

REFERENCE: Holden, E. S., 1898. A Catalogue of Earthquakes on the Pacific Coast, 1769-1897. Smithsonian Institute, Miscellaneous Collection. V. 37, No. 5, 253 p.

QUOTATION: 1892, April 21 ... It was reported that several boiling springs had burst from the foothills on the north and west and were flowing steadily.

LOCATION: 259

YEAR: 1892

FAILURE TYPE: ⊟

ACCURACY: C

REFERENCE: Holden, E. S., 1898. A Catalogue of Earthquakes on the Pacific Coast. 1769-1897. Smithsonian Institute, Miscellaneous Collection. V. 37, No. 5, 253 p.

QUOTATION: 1892, April 19; Esparto ... The earth opened in several places between here and Capay.

C-105171

General Comments on the Recent Earthquake that Might Affect The Sacramento-San Joaquin Delta

Bruce Bolt, Chief Seismologist at the University of California, Berkeley, feared that the soft, water-saturated and flood damaged dikes around below-sea-level farm islands in the Delta had probably suffered "liquefaction", and collapsed with widespread flooding. Yet, the dikes also escaped unscratched even though they were closer to the epicenter than was Livermore.

Oakland Tribune
January 26, 1980

The January 23, 1980, 5.5 magnitude earthquake shook the already battered Delta levees. This created large waves, and threatened to destroy hard-won progress made during a week-long battle. A series of aftershocks followed adding to anxieties, but visual inspections did not show any significant earthquake-related damage. A 250-foot slip was detected on Bacon Island midway on the east levee, but it has not been determined if the crack had been caused or only aggravated by the disturbance. Department engineers feared that the earthquake might be the last straw that would lead to structural damage to the substandard levee foundations and to extensive levee failure.

Summary of January 1980 Flood
Events and Conditions in Calfiornia
by Ronald B. Robie, Director
Department of Water Resources

C-105172

APPENDIX B

EARTHQUAKES AND SEISMOGRAPHS

APPENDIX B

EARTHQUAKES AND SEISMOGRAPHS

Earthquakes have occurred throughout the globe. Of known United States earthquakes the most severe were in New Madrid, Missouri - 1811; Charleston, South Carolina - 1886; San Francisco, California - 1906; and Anchorage, Alaska - 1964. The California-Nevada region has had about 5,000 earthquakes a year since the first human record of a California quake in 1769. This amounts to about 2-1/2 percent of all quakes felt in the entire world, and almost 90 percent of all shocks felt in the Continental United States.

The explanation for the intense California earthquake activity is that the State is located on the boundary between the tectonic plate underlying the Pacific Ocean and the one forming the North American Continent. The North American Continental Plate is drifting southwesterly relative to the Pacific Plate and is being forced to override the latter. The collision zone between the plates is the San Andreas Fault system. Resultant earthquakes are vibrations, or oscillations of the ground surface by the transient disturbance of the elastic or gravitational equilibrium of the rocks at or beneath the surface.

Earth Waves and Seismographs

The movement at a given point of the ground surface as caused by an earthquake (or other means) may be resolved into three translations parallel to three mutually perpendicular axes. Translations are measured by seismographs. From the engineering point of view, the strong motion earthquakes are the most important, since such earthquakes bring damage and destruction to engineering structures. Records of shocks produced by such earthquakes are obtained by use of ruggedly constructed seismographs (accelerometers). Three mutually perpendicular components of motion are usually recorded.

The wide use of strong-motion accelerographs is relatively recent. Only in 1932 did the USGS initiate a strong-motion earthquake program in order to obtain instrumental records of ground motion in destructive areas. If the spectra of a large number of strong motion earthquakes could be constructed from accelerograms, an average spectrum indicating the relationship between the period and values in strong-motion earthquakes could be ascertained. Insufficient statistical data for the Delta area does not permit such a compilation. Ground rupture along a fault is dramatic, and generally the physical effects of faulting are highly localized. On the other hand, the effects of ground shaking are widespread and cause most earthquake damage. In a large earthquake, major damage from ground shaking can occur great distances from the source.

For large earthquakes, the zone of energy released may extend hundreds of kilometres from the epicenter. A correlation between earthquake magnitude and distance from the seismic source zone to the most distant liquefaction-induced ground failure considered capable of causing significant damage is presented in Figure 5, page 22.

Major agencies with instrumentation programs include the Earthquake Engineering Branch of DWR, USGS, and the Corps of Engineers which monitors all dams under their jurisdiction.

The Office of Strong Motion Studies of the Division of Mines and Geology has an extensive Strong Motion Instrumentation Program as described in an excerpt from DMG Special Publication 55.

> "Recent earthquakes, in particular the February 9, 1971, San Fernando earthquake, have demonstrated a need by the structural engineering community for additional data on response of structures and foundation materials to earthquake shaking in order to advance the technology of earthquake resistant design. Additionally, increasingly intensive investigations into earthquake mechanics by the seismological community have resulted in a need for data on ground response to earthquake shaking and on earthquake energy propagation effects."

> "It is the mission and objective of the Strong Motion Instrumentation Program to instrument representative structures and geologic settings throughout the State to maximize the probability of the collection of significant engineering and seismological data, and to process the data to usable form for dissemination to the user community for application to improved earthquake resistant structure design and enhancement of the public safety."

Publication No. 77-374 of the USGS identifies all reported instrumentation in the Western Hemisphere. This publication is current through March 1977 and is soon to be updated. DMG has vastly expanded their program since 1976 and therefore many existing sites are not listed in Publication No. 77-374. However, DMG location placement may be easily obtained by directly contacting the Office of Strong Motion Studies. Figure B-1 shows general locations of accelerograph placement (DMG) for mid-California. Although DMG's instrumentation program is the most extensive in our area of concern, they have no stations in the Delta.

USGS Western Hemisphere Strong-Motion Accelerograph
Station List - 1976 (Open File Report No. 77-374)

The U. S. Geological Survey (USGS) maintains a network of strong-motion instrumentation for the National Science Foundation in cooperation with other Federal, State and local agencies within the United States. In addition, the USGS cooperates with similar groups both within the United States and in other countries throughout the world. The present list is an attempt to bring into one document basic information on all of the stations in the Western Hemisphere known to the USGS. Listed stations have been installed and are maintained by many different organizations, although generally one organization is responsible for most of the instruments in any one country. This is not the case in the United States where several organizations operate strong-motion instrument networks.

Descriptions of strong-motion accelerograph records and the circumstances in which the records were recorded are made available through the Strong-Motion Information Retrieval System. The system is maintained by the USGS and the information is continually updated as new information is gathered. With an ordinary phone line and a teleprinter keyboard terminal, users of the system may review the information from their own offices.

Information given for each station is intended to aid in ascertaining the nature of the effect of the site and of the presence of the structure on the motions recorded at each site. In addition to the station coordinates, a brief description of the site conditions and structure at each site is given when known. The brief site descriptions represent an interpretation of conditions at each station based on data in the station files.

The list is necessarily incomplete even for stations in the United States. Only partial information is available on the more recently installed stations and, due to rapid expansion of several of the networks, no information is available on some stations. The list is intended to provide those interested in the strong-motion programs with a reasonably complete indication of the current status of the networks. This list is as compelte as practicable as of March 1977, and is being updated.

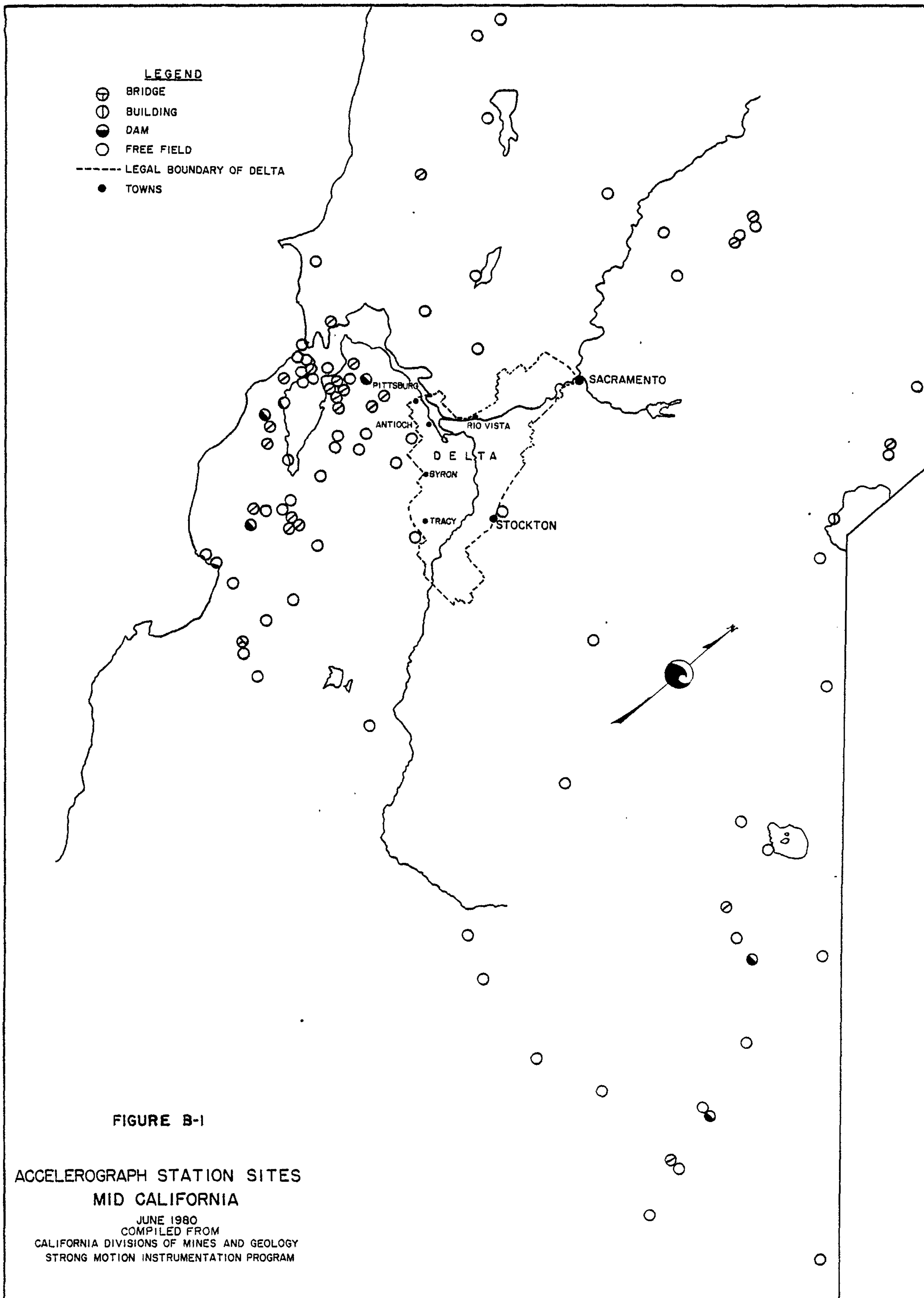

FIGURE B-1

ACCELEROGRAPH STATION SITES
MID CALIFORNIA

JUNE 1980
COMPILED FROM
CALIFORNIA DIVISIONS OF MINES AND GEOLOGY
STRONG MOTION INSTRUMENTATION PROGRAM

APPENDIX C

DETAILS OF EARTHQUAKE HAZARD INVESTIGATIONS

APPENDIX C

DETAILS OF EARTHQUAKE HAZARD INVESTIGATIONS

ABAG's Earthquake Hazard Mapping Program

The Hazard Mapping Program uses the Bay Area Spatial Information System (BASIS) which is a regional geographic data base. Unfortunately the Delta is largely outside ABAG's jurisdiction. BASIS is structured around an array of grid cells representing land areas. For the 9 county Bay Area region there are more than 2 million cells. Cell data input is accomplished by reading tapes or by digitizing a map. Basic data files may be manipulated whereby a composite of many data sets can be produced through an overlay or modeling process.

As of March 1980 ABAG had created earthquake hazard maps based on the following basic data map files: geology, faults, topography, landslides, tsunami inundation areas, dam failure inundation areas, and land use. Other basic files not applicable to earthquakes are the physical environment and social environment files. The seven basic data maps were combined to create six hazard map files and three basic maps were converted to three additional hazard files as follows:

1. Maximum ground shaking intensity.

2. Risk of ground shaking damage.

3. Liquefaction susceptibility.

4. Liquefaction potential.

5. Rainfall-induced landslide susceptibility.

6. Earthquake-induced landslide susceptibility.

7. Fault surface rupture.

8. Tsunami hazard areas.

9. Dam failure hazard areas.

Map files may be manipulated for computer assisted environmental assessment, production of composite hazard maps and assessment of property and population at risk. A series of review papers documenting the data used and the assumptions made in the ABAG/USGS earthquake mapping project are available as follows:

#1 - Faults and Ground Shaking Intensity -- a description of those faults from which significant ground shaking could originate, including source of mapping, length, character of motion, maximum magnitude, maximum intensity, relative slip rate and recurrence intervals for various earthquakes.

#2 - Attenuation, Geologic Materials and Ground Shaking -- a description of an attenuation relationship between intensity and distance from faults for a standard geologic material, a method of combining geologic materials into groups with similar responses to earthquake ground shaking, and intensity increments to be added to the standard intensity for each of the seismically distinct groups of geologic materials.

#3 - Damage and Ground Shaking Intensity -- a description of how experience from past earthquakes can be used to estimate the damage different types of buildings would experience when subjected to various intensities of ground shaking; also a description of how damage data, the intensity maps, and recurrence interval information can be used to produce maps of risk of ground shaking damage for various building types.

#4 - Liquefaction Potential Mapping -- a description of the likelihood of finding cohesionless sediments within a geologic map unit, the likelihood that those sediments (when saturated) would be susceptible to liquefaction, the likelihood of finding those sediments saturated, and liquefaction opportunity (based on recurrence intervals of earthquakes and the distance from various faults at which liquefaction can occur).

#5 - Slope Stability Mapping -- a description of how slope, geology and existing landslides can be used to estimate landslide susceptibility in an earthquake and under more normal circumstances.

#6 - Tsunami Inundation Areas -- a description of the data used to develop a tsunami hazard map and of the relative risk associated with tsunamis.

#7 - Dam Inundation Areas -- a description of dam inundation mapping and of the relative risk associated with dam failure.

#8 - Earthquake Map Applications for Automated Environmental Impact Assessment -- a description of how hazard map files can be used to produce a background document for development proposals that can be incorporated into an environmental impact report.

#9 - Earthquake Map Applications for Composite Earthquake Hazard Mapping -- a description of how the various hazard maps can be combined to yield two types of hazard maps of total earthquake associated damage.

#10 - Earthquake Map Applications for Automated Assessment of Property and Population at Risk -- a description of how tables of area in cities, counties, census tracts and land use can be created for each hazard map category, as well as some sample tables with a discussion of the conclusions that can be formed. In addition, the feasibility of disaggregating census tract data on population using land use to create data on population at risk in various hazard categories is discussed.

The derivation of liquefaction potential (Figure C-1) is constructed primarily from four factors. Three factors may be grouped under the title liquefaction susceptibility (LS). Susceptibility is the term used for the likelihood that a particular geologic/soil material would liquefy. Liquefaction opportunity (LO) is the relative frequency of occurrence of ground shaking sufficient to produce liquefaction. The combination of the two preliminary maps (LS + LO = LP) results in a single liquefaction potential map.

Proposed UCD Earthquake Mapping Program[1]

A basic study to identify factors in the Delta pertinent to earthquake induced liquefaction is necessary. The basic study could provide evidence for determining whether a more detailed and finite study is warranted or necessary. An introductory explanation of a basic study was presented in Chapter V. Details of the proposed study are presented here.

First, identification of area of concern and most pertinent factors in liquefaction is necessary. The area of concern would be the entire Delta levee system as defined in DWR Bulletin 192, "Plan for Improvement of the Delta Levees". Significant factors related to any soil deposit subjected to seismic motion and thus having liquefaction potential depend on the characteristics of the soil, the initial stress action on the soil, and the characteristics of the earthquake involved. Simply stated: the principal seismic-liquefaction constituents are soil type, ground water conditions, void ratio, initial confining pressure, intensity of ground shaking, and duration of ground shaking.[2]

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[1] Department funds are not presently available for this program.
[2] ASCE, JSMFD, Sept. 71 p. 1250.

An initial study can be conducted from information available within the Department. Macro soil characteristics are available from drill logs for the DWR Sailinity Control Barrier Investigation conducted in the late 1950s. Over 1,000 borings were made throughout the Delta. Although these drill logs are not precise and up to date, they provide a good initial approximation. Ground water levels for the Delta may be assumed at minimum channel elevations -- again for a good initial assumption. Earthquake magnitude and distances can be obtained from the recent (1977) Fault and Epicenter Location Map, California Delta Area (compiled in 1977 for the Delta Subsidence Study). Soil characteristics may be better defined by more thorough and up to date test borings and to best fit critical soil parameters, extensive lab work would be required.

Ground water conditions in the Delta are continuously subjected to diversified farming operations and ground water levels are generally at the mercy of the individual farm practices. Farming may influence the ground water by as much as ± 3 metres (10 feet) from week to week. Therefore, a detailed look at ground water maximum fluctuation will be required.

Due to the large variance of opinion on local seismic data it will be necessary to evaluate individual faults and estimates of earthquake recurrence. Various agencies and the private sector have specific information on individual faults. Geological information on the regional structure, regional tectonics, earthquake occurrence data and intensity parameters, characteristics of expected strong ground shaking at the sites, and estimates of ground acceleration from existing accelogram sources will require evaluation. Much information may be obtained from the ongoing accelerogram program discussed in Chapter V.

Since large amounts of raw data are involved and manipulating the data becomes a difficult task, the benefits of computer use are evident. The Department's CDC 3300 and the Teale Center IBM 370-178 systems are adequate for reduction and compilation of data. However, a better system and method to analyze and present study findings on the Delta levee liquefaction potential exists at the University of California, Davis, Division of Agricultural Sciences, in their Computer Map Overlay Program. Mapping appears to be an excellent approach in analyzing and presenting the initial study and more so any future in-depth studies. Neither the Department's computer nor Teale's computer system can economically or practically develop an appropriate mapping program, whereas the UCD system already exists.

The Davis system, known as LUMP (Land Use Mapping Program) provides a fast, relatively inexpensive, highly flexible system for handling and analyzing geographic data. Conceptually the program is a stack of maps on which the user can see all the variable states for a given x-y grid area. Analysis is distinct from data entry and mapping. Computer programs analyze the map, area by area, and compute functions on the variables or look for particular combinations of variable states. The LUMP system can then produce in mapped form any combination or function of variables generated during the analysis phase. This mapping and analysis procedure would be invaluable when we consider the large variation of earthquake hazard parameters. LUMP programs are highly versatile with many possible applications, with program applications and capabilities similar to those of BASIS described in Appendix C.

Proposed Delta Seismology Investigation

A rough outline of a proposed Delta seismology investigation is as follows:

I. Research past work available data on:

   A. Seismology

   B. Subsidence

   C. Geology

II. Inspect visual evidence of faulting and earthquake action

   A. Try to narrow down area of concern or possibilities by leveling (rupture evidence, etc.).

   B. Drilling and subsurface measurements to determine material parameters.

      1. On levees

      2. On islands

   C. Lab work to determine:

      1. Differential settlement (caused by distant EQ's).

      2. Liquefaction

         a. Ground shaking

         b. Ground rupture (caused by in-area EQ faults)

         c. Lateral spreading of levees

Problem: Delta is alluvium ~30,000 feet thick which effectively covers any visual fault features (visual features depending on size, may be concealed by a few inches of alluvium).

III. Determine causes

   A. Tectonic (from active fault)

   B. Settlement (possible conclusion)

IV. Does or does not soil transmit up evidence of underlying faults?

V. Determine properties of earthquakes and faults:

A. Surface rupture

1. Active

2. Inactive

B. Intensity and size

C. Magnitude

D. Extent

VI. A. Determine subjectivity of levees to the range of levels of acceleration and duration (t) for:

1. Differential settlement

2. Rupture

a. Surface

b. Subsurface

3. Lateral movement

B. Check allowable settlement, rupture, lateral movement, etc. for levees to sustain displacement without damage (is 3", 3', 6' ....OK?)

Under perfect field conditions, this Work Plan would run approximately 6 weeks and $60,000. The jelly-type nature of Delta soils poses poor working conditions, whereas bedrock is ideal to work with. Instrumentation disturbances on Delta soils would be higher than ideal, thus time and cost estimates would be considerably increased.

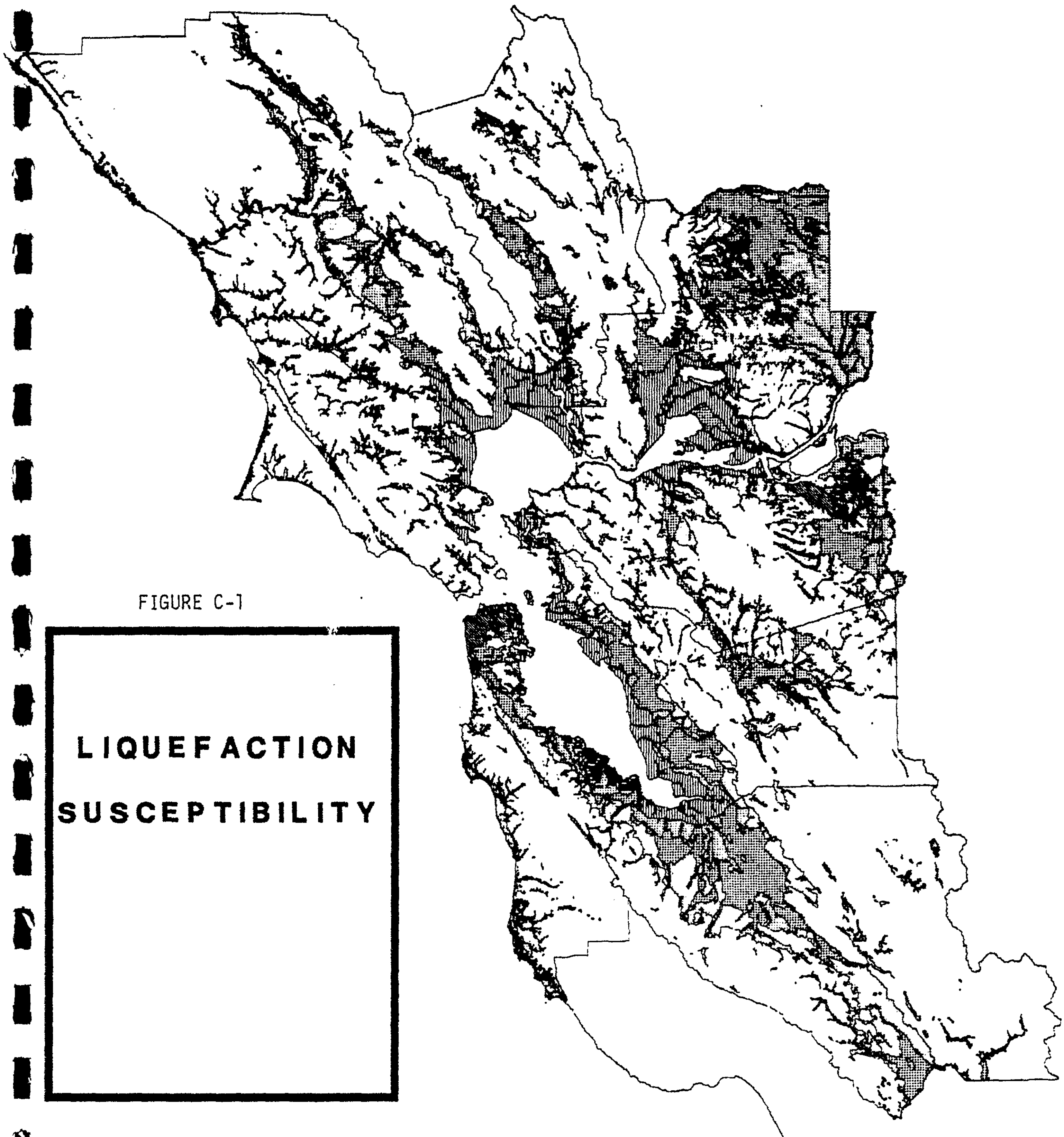

FIGURE C-1

LIQUEFACTION SUSCEPTIBILITY

BASIS BAY AREA SPATIAL INFORMATION SYSTEM

C-105185

EXPLANATION FOR FIGURE C-1

LIQUEFACTION SUSCEPTIBILITY

SHADE PATTERN

LIKELIHOOD OF LIQUEFACTION*

0 %	Very Low
<.1%	Low
.1%	Moderate
.2%	Moderate
1.4%	High
1.8%	High
2.1%	High
2.4%	High
10.0%	Very High

*Numbers indicate work accurate relationships to each other than to absolute values

APPENDIX D

DEFINITIONS

APPENDIX D

DEFINITIONS[1]

Acceleration, maximum - see maximum acceleration.

Accelerogram - the record from an accelerograph showing acceleration as a function of time.

Accelerometer - an instrument for measuring acceleration.

Active earth pressure - the minimum value of lateral earth pressure exerted by soil on a structure, occurring when the soil is allowed to yield sufficiently to cause its internal shearing resistance along a potential failure surface to be completely mobilized.

Active faults - those which have shown historical activity; includes such faults as the San Andreas, San Jacinto, and Newport-Inglewood; see also potentially active faults.

Aftershock - an earthquake, usually a member of an aftershock series, following the occurrence of a large earthquake (mainshock); the magnitude of an aftershock is commonly smaller than the mainshock.

Airborne magnetometer - an instrument carried by an aircraft which is used to measure variations in the earth's magnetic field.

Alignment array - an initially straight row of monuments set at right angles across an active fault trace; progressive fault slip is observed by repeated observation of horizontal displacement of these monuments from their initial positions relative to each other.

Alluvium - a general term for the sediments laid down in river beds, flood plains, lakes, fans at the foot of mountain slopes, and estuaries, during relatively recent geologic times; generally unconsolidated.

Amplification - the increase in earthquake ground motion that may occur to the principal components of seismic waves as they enter and pass through different earth materials.

Amplitude - maximum deviation from mean or center line of a wave; "height" of a seismic wave.

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[1]Definitions are from the American Geological Institute, 1972, and others. Included here are geologic, seismologic, and many soils engineering terms.

C-105188

Amplitude spectrum - amplitude-versus-frequency relationship such as is computed in a Fourier analysis.

Angle of internal friction - angle between the abscissa and the tangent of the curve representing the relationship of shearing resistance to normal stress acting within a soil.

Anomaly - deviation or inconsistency of a specific land feature from uniformity with the larger area.

Aquifer - a formation, group of formation, or part of a formation that is water-bearing and of economic importance.

Aquifer, confined - see confined aquifer.

Aquiclude - a formation which, although porous and capable of absorbing water slowly, will not transmit it fast enough to furnish an appreciable supply for a well or spring.

Arc - a long, narrow triangulation or trilateration network; generally a chain of quadrilateral survey figures.

Artesian water - ground water that is under sufficient pressure to rise above the level at which it is encountered by a well, but which does not necessarily rise to or above the surface of the ground.

Artificial fill - earth and other types of materials either nonengineered or engineered (properly placed and compacted) placed by man.

Attenuation - dying out (decay); reduction of amplitude or change in wave due to energy dissipation or distance with time.

Atterburg limits - see liquid limit and plastic limit.

Attitude (of rock structures) - a term including the terms dip and strike; the attitude of the flat surface of a sedimentary bed, whether inclined or not, is referred to the horizontal plane; dip is its slope inclination (in degrees) from this plane and is measured with a clinometer; strike is the bearing on the line of intersection of its surface with the horizontal plane; the terms may also apply to faults, veins, and dikes, or any natural plane surface.

Avalanche - a large mass of snow or ice and accompanying materials moving rapidly down a steep slope; soil or rock movements, as in debris avalanche.

Basement complex - a name commonly applied to metamorphic or igneous rocks underlying the sedimentary sequence.

Bed - the smallest division of a stratified series; marked by a more or less well-defined plane from its neighbors above and below.

Bedding - a term which signifies the existence of beds (strata) or laminae in rocks which are generally of sedimentary origin.

Bedding plane - in sedimentary or any stratified rock, the division planes which separate the individual layers, beds, or strata.

Bedrock, geologic - a general term for rock that underlies soil or other unconsolidated superficial materials.

Bedrock, seismic - see seismic bedrock.

Benchmark - a permanent marker which designates a point of known elevation.

Body waves - waves propagated in the interior of a body, i.e., compression and shear waves; the P and S waves of seismology.

Bore hole - a hole drilled into the earth for exploratory purposes.

Clastic - in petrology, a textural term applied to rocks composed of fragmental material derived from preexisting rocks or from the dispersed consolidation products of magmas or lavas.

Clay - the term carries three implications: (1) particles or very fine size, less than 1/256 mm; (2) a natural material with plastic properties; (3) a composition of minerals that are essentially hydrous aluminum silicates.

Cohesionless soil - a soil that when unconfined and air-dried has little or no strength.

Cohesive soil - a soil that when unconfined and air-dried has considerable strength and that has significant cohesion when submerged.

Colluvium - loose cohesionless soil material, or loose rock deposited by creep, landslides, and surface wash.

Compaction - decrease in volume (void space) of sediments as a result of compression.

Complex landslides - movement by a combination of two or more of the three principal types of movement (fall, slide, or flow).

Compression wave - see P wave.

Consolidated material - soft or hard rock which requires some medium of loosening at the excavation site before it can be handled; the more loosening required (i.e., blasting as opposed to bulldozing) the more consolidated the material.

Consolidation - reduction in volume and increase in density, often by removal of intergranular water.

Contact (geologic) - a plane or irregular surface between two different types or ages of rocks.

Core sample - a relatively undisturbed cylindral sample of rock or sediment resulting from drilling.

Creep - the imperceptibly slow and more or less continuous down-slope movement of regolith.

Creepmeter - a displacement meter for measuring creep; it actually measures the change in distance between two monuments (generally about 10 m apart) on opposite sides of a fault trace; typically, the instrument provides a continuous chart recording of displacements.

Critical damping - the minimum viscous damping that will allow a displaced system to return to its initial position without oscillation.

Cyclic loading test - laboratory test in which the stress to which a specimen is subjected is reversed from extension to compression and vice versa over a number of stress applications.

Damping - (1) the dissipation of energy with time or distance; (2) resistance which slows down oscillation, expressed as a percentage of critical damping.

Deformation of rocks - a change in the original form or volume of rock produced by faulting, folding, or other tectonic forces.

Depth-of-focus class - a set of earthquakes occurring within a specified depth interval; three common classes are common shallow (0 to 70 km), intermediate (70 to 300 km), and deep (300 to 700 km).

Deviator stress - the difference between the major and the minor principal stresses in a triaxial test.

Differential settlement - nonuniform or uneven lowering of the ground surface.

Diffraction - (1) scattered energy which emanates from an abrupt irregularity of rock type, where faults cut reflecting interfaces; (2) interference produced by scattering at edges; (3) the phenomenon in which energy is transmitted laterally along a wave crest; when a portion of a wave train is interrupted by a barrier, diffraction allows waves to propagate into the region of the barrier's geometric shadow.

Digital filters - filtering data numerically in the time domain by summing weighted samples at a series of successive time increments.

Dilatancy - the expansion of cohesionless soils when subjected to shearing deformation; the swelling of a land surface as a precursor to an earthquake.

Dilatation - a parameter of strain which is equal to the change in area per unit area; it may be thought of as an omnidirectional extension or contraction; see also dilatancy.

Dip - see attitude.

Sip slip - fault displacement parallel to the dip of the fault surface.

Direct shear test - a shear test in which soil or rock under an applied normal load is stressed to failure by moving one section of the soil container relative to the other section.

Dispersion - the dependence of the propagation velocity on wave length or frequency which causes the shape of a disturbance to change continually as time goes on; in an unlimited medium there will be a continual spreading out of the disturbance into trains of waves.

Double amplitude - total excursion or overall height of wave (peak to peak, crest to trough), or, for a sinusoidal wave, twice the amplitude.

Dredge sample - a highly disturbed sample of ocean, lake or river-bottom sediments.

Dynamic soil properties - those soil properties which affect the response of soils subjected to cyclic loading conditions.

Earth pressure at rest - the value of earth pressure when the soil mass is in its natural state without having been permitted to yield or without having been compressed.

Earthquake - group of elastic waves propagating in the earth, set up by transient disturbance of the elastic equilibrium of a portion of the earth; earth shaking.

Effective stress (intergranular pressure) - the average normal force per unit area transmitted from grain to grain of a soil mass; this stress is effective in mobilizing internal friction.

Elastic limit - the maximum stress that a material can withstand without undergoing permanent deformation either by solid flow or by rupture.

Elasticity - the property or quality of being elastic; that is, an elastic body returns to its original form or condition after a displacing force is removed.

Elastic strain - deformation per unit of length produced by load on a material, which vanishes with removal of the load.

Eipcenter - the point on the earth's surface vertically above the focus of an earthquake.

Extensometer - (1) instrument used for measuring small deformations, deflections, or displacements; (2) instrument used for measuring changes caused by stress in a linear dimension of a body.

Factor of safety - available strength divided by applied load.

Falls - mass in motion travels most of the distance through the air; includes freefall, movement by leaps and bounds, and rolling of rock and debris fragments without much interaction of one fragment with another.

Fault - an earth fracture or zone of fracture along which the rocks on one side have been displaced in relation to those of the other side.

Fault, active - a fault along which historic movement has taken place, or one that a competent geologist considers active.

Fault block - a body of rock bounded by one or more faults.

Fault creep - very slow periodic or episodic movement along a fault trace, not always accompanied by earthquakes; fault slip or slippage.

Fault scarp - the cliff formed by a fault; fault scarps which have been modified by erosion since faulting are called fault-line scarps.

Fault set - two or more parallel faults within an area.

Fault slip - the true relative displacement of formerly adjacent points in the fault plane.

Fault system - two or more fault sets formed at the same time.

Fault surface - the surface along which dislocation has taken place.

Fault trace - the intersection of a fault and the earth's surface as revealed by dislocation of fences, roads, or by ridges and furrows in the ground.

Fault zone - instead of being a single clean fracture, a fault may be a zone hundreds or thousands of feet wide; the fault zone consists of numerous interlacing small faults or a confused zone of gouge, breccia, or other material.

Fault, inactive - see inactive faults.

Fault, normal - see normal fault.

Fault, reverse - see reverse fault and thrust fault.

Fault, right-lateral - see right-lateral fault.

Fault, thrust - see thrust fault.

Faulting - the movement which produces relative displacement of adjacent rock masses along a fracture.

Fines - portions of soil finer than no. 200 (74 microns) U.S. standard sieve.

Finite element analysis - an analysis which uses an assembly of elements which are connected at a discrete number of nodal points to represent a structure and/or a soil continuum.

Fissure - crack, break, or fracture in the rocks.

Flows - movement within displaced mass such that the form taken by moving material or the apparent distribution of velocities and displacements resembles those of viscous fluids; slip surfaces within moving material are usually not visible or are short-lived.

Focal depth - depth of an earthquake focus (hypocenter) below the ground surface.

Focus - the point within the earth which marks the origin of the elastic waves of an earthquake; synonymous with hypocenter.

Fold - a bend in rock strata.

Force - resultant of distribution of stress over a prescribed area; an action that develops in a member as a result of loadings given in kips or tons.

Formation - a rock body or an assemblage of rocks which have some character in common; applied to a particular sequence of rocks formed during one epoch; a rock unit used in mapping.

Fourier transforms - the formulae which convert a time function (seismic record) into the frequency domain.

Fracture - break in rocks due to faulting, folding, or other geologic processes.

Free field - the number of seismic wave peaks which pass through a point in the ground in a unit of time; usually measured in cycles per second.

Frequency, natural - see natural frequency.

Gaging station - section in a stream channel equipped with a gage and facilities for measuring the flow of water.

Geodetic - refers to investigation of any scientific questions relating to the shape and dimensions of the earth.

Geodetic measurements - controls on location (vertical and horizontal) of positions on the earth's surface of a high order of accuracy, usually extended over large areas for surveying and mapping operations.

Geodimeter - the tradename for one of the most common electro-optical distance-measuring instruments; often used generically to denote all such instruments; it is capable of measuring distance with an error less than 1 ppm (this amounts to 1 mm in 1 km).

Geologic hazards - geologic features or processes that are dangerous or objectionable to man and his works; they may be natural phenomena or man-induced phenomena.

Geologic map - map showing distribution of formations, folds, faults, and mineral deposits by appropriate symbols.

Geologic section - a graphic representation of geologic conditions along a given line or plane of the earth's crust.

Geology - the science which treats of the earth, the rocks of which it is composed, and the changes which it has undergone or is undergoing.

Geometrical damping - that component of damping which occurs due to the radial spreading of energy waves with distance from a given source.

Geomorphology - the branch of geology which deals with the form of the earth, the general configuration of its surface, and the changes that take place in the evolution of land forms.

Geophone - sensing device used to measure electronically the rate of travel of sound or shear waves transmitted through the earth from a known source.

Geophysical exploration - a variety of indirect methods for determining structure and composition of underground geological formations.

Geophysical surveys - the use of one or more physical techniques to explore earth properties and processes.

Geostatic - capable of sustaining the pressure of the weight of overlying earth materials.

Geothermal - of or pertaining to the heat of the interior of the earth.

Gouge - finely ground rock material occurring between the walls of a fault, the result of grinding movements.

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Grab sample - a random unoriented sample which gives indication of the composition only.

Graben - down-thrown block of earth material, or a trench produced by faulting or landsliding.

Grain size - a term relating to the size of mineral or soil particles that make up a rock or a soil.

Gravel - natural accumulation of small rounded stones and pebbles over 2 mm in diameter, or a mixture of sand and small stones.

Ground cracking - cracks usually occurring in stiff surface materials resulting from differential ground movement or desiccation.

Ground failure - a situation in which the ground does not hold together, such as a landsliding, mud flows, and liquefaction.

Ground response or motion - a general term which includes all aspects of motion (acceleration, particle velocity, displacement, stress, and strain) usually resulting from a nuclear blast or an earthquake.

Ground strength - the limiting stress that ground can withstand without failing by rupture or continuous flow.

Ground water - water beneath the surface of the ground in a saturated zone.

Grout - a pumpable slurry of cement or a mixture of cement and fine sand commonly forced into a borehole to seal crevices in a rock.

Hard rock - rock which requires drilling and blasting for its economical removal.

Harmonic - a frequency which is a simple multiple of a fundamental frequency; the third harmonic, for example, has a frequency three times that of the fundamental.

Holocene - the time period from the close of the Pleistocene or glacial epoch through the present; synonymous with Recent; about the last 11,000 years.

Hummocky - lumpy land, in small uneven knolls; this condition may be a sign of previous extensive landsliding.

Hydrograph - a graph showing the level, flow, or velocity of water in a river at all seasons of the year.

Hypocenter - see focus.

Hydroseism - seismically induced water-level fluctuations, other than tsunamis or seiches.

Hydrostatic pressure - the pressure in a liquid under static conditions; the product of the unit weight of liquid and the difference in elevation between the given point and the ground-water elevation.

Inactive faults - identifiable faults which do not meet any of the criteria listed under active faults.

Inelastic deformation - permanent deformation of materials either by flow, creep, or rupture.

Intensity - a nonlinear measure of earthquake size at a particular place as determined by its effect on persons, structures, and earth materials; the principal scale used in the United States today is the Modified Mercalli, 1956 version; intensity is a measure of effects, as contrasted with magnitude which is a measure of energy.

Interface - the common surface separating two different media in contact.

Intermediate principal stress - the principal stress whose values are neither the largest nor the smallest of the three principal stresses.

Interstitial water - water contained within the minute pores or spaces between the small grains or other units of rock.

Isoseismal line - an imaginery line connecting all those points on the surface of the earth where an earthquake shock is of the same intensity.

Joint - a surface or fracture that divides a rock and along which there has been no visible movement parallel to the surface.

Landfill - a place where solid waste or earth is dumped, usually in the disposal of garbage or to create new land for development; see sanitary landfill.

Landslide - general term that denotes downward and outward movement of slope-forming materials composed of natural rock, soils, artificial fills, or combinations thereof.

Lateral spreading - nearly horizontal land failure; a horizontal landslide.

Left-lateral fault movement - generally horizontal movement in which the block across the fault from an observer has moved to the left.

Linear viscoelastic medium - a medium for which the relationship between stress and strain can be expressed as a linear one between stress, strain, and other nth-order temporal derivatives.

Liquefaction - transformation of a granular material from a solid state into a liquefied state as a consequence of increased pore-water pressure.

Liquid limit - moisture content at which the soil passes from a plastic to a liquid state.

Lithology - the description of rock composition and texture from observation of hand specimens or outcrops.

Local "site" geology - the soil, rocks, and structures that comprise the vertical geologic section at a particular site; local geology.

local wave - water wave produced by areal or submarine slope failures that occur during earthquakes.

Loess - a wind-blown silt or silty clay having little or no stratification.

Love wave - a surface seismic wave associated with layering in which the vibration is transverse to the direction of propagation, with no vertical motion.

Magnitude - the rating of a given earthquake is defined as the logarithm of the maximum amplitude on a seismogram written by an instrument of specified standard type at a distance of 100 km from the epicenter; it is a measure of the energy released in an earthquake; the zero of the scale is fixed arbitrarily to fit small earthquakes; the scale is open-ended but the largest known earthquake magnitudes are near 8.75; every upward step of one magnitude unit means a 32-fold increase in energy release; thus a magnitude 7 earthquake releases 32 times as much energy as does a magnitude 6 earthquake; magnitude differs from intensity.

Mainshock - the largest magnitude earthquake in a series.

Major principal stress (see principal stress) - the largest (with regard to sign) principal stress.

Mantle - the layer of the earth between the crust and the core.

Mass-wasting - a variety of processes by which masses of earth materials are moved by gravity either slowly or quickly from one place to another.

Maximum acceleration - maximum excursion measured on an accelerogram.

Maximum credible earthquake - the most potentially damaging (strongest) earthquake that could ever occur on a given fault; the magnitude of such an event is usually obtained by using a deterministic approach, employing the principle that the length of the fault rupture is proportional to the magnitude of the earthquake caused by the rupture.

Maximum probable earthquake - the largest earthquake that, on a statistical basis, will occur during a given period of time (commonly 100 years).

Meizoseismal - said of or pertaining to the maximum destructive force of an earthquake, i.e., meizoseismal area is the area of strong shaking.

Meteoric water - water in or derived from the atmosphere.

Micro-earthquake - a very small earthquake having a magnitude of 2.0 or less on the Richter scale.

Microseismic event - an earthquake or man-induced vibrations observable only with instruments.

Microtremor - a feeble earth tremor resulting from natural or man-made forces.

Minor principal stress (see principal stress) - the smallest (with regard to sign) principal stress.

Model - a concept from which one can deduce effects that can then be compared to observation, which assists in developing an understanding of the significance of the observations.

Modified Mercalli - see intensity.

Multiple - seismic energy which has been reflected more than once.

Mutiplet - several earthquakes occurring close together in space-time, with comparable magnitudes.

Natural frequency - a constant frequency of a vibrating system in the state of natural oscillation.

Natural oscillation - an oscillation of a vibrating system which may occur in the absence of an external force.

Normal consolidation - soil element that is at equilibrium under the maximum stress it has ever experienced.

Normal fault - vertical movement along a sloping fault surface in which the block above the fault has moved downward relative to the block below; a tensional fault.

Normal stress - that stress component normal to a given plane.

Noise - (1) any undesired signal; a disturbance which does not represent any part of a message from a specified source; (2) energy which is random; (3) disturbances in observed data due to inhomogeneities in surface and near-surface material.

Oceanography - embraces all studies relating to the sea.

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Operating basis earthquake (OBE) - for a reactor site, that earthquake which produces the vibrating ground motion for which those structures and systems of the nuclear powerplant necessary for continued operation without undue risk to the health and safety of the public are designed to remain operable; the maximum vibration ground acceleration of the OBE is equal to at least one-half that of the safe shutdown earthquake.

Outcrop - that part of a geologic formation (rock) or structure that appears at the surface of the earth.

Overburden - deposits that overlie bedrock, or rock materials that overlie useful rock or ore.

Overconsolidated - soil at equilibrium under a stress less than that to which it was once consolidated.

Overconsolidation ratio (OCR) - the ratio of the maximum past pressure or stress to which a soil has been subjected to the computed value of vertical effective pressure or stress existing in the field at present.

Particle acceleration - the time rate of change of particle velocity.

Passive earth pressure - the maximum value of lateral earth pressure.

Penetrometer - a soil-sampling device which is pushed or driven with a hammer into the undisturbed soil at the bottom of a boring.

Perched ground water- unconfined ground water separated from an underlying main body of ground water by an unsaturated zone.

Perched water table - the water table of a body of perched ground water.

Period - the time (t) for one cycle; the time for a wave crest to traverse a distance equal to one wave length, or the time for two successive wave crests to pass a fixed point.

Permafrost - permanently frozen ground.

Permeability - the capacity in a rock or unconsolidated material for transmitting a fluid.

Photogrammetry - the art and science of obtaining reliable measurements from photographs.

Physiography - a description of existing nature as displayed in the surface arrangement of the globe, its features, atmospheric and oceanic currents, climate, and other physical features.

Piezometric - refers to the surface to which the water from a given aquifer will rise under its full head.

Plastic deformation - under some conditions solids may bend instead of shearing or breaking as a result of seismic and geologic forces.

Plastic flow - a continuous and permanent change of shape in any direction without breakage.

Plastic limit - moisture content at which the soil passes from a solid to a plastic state.

Plasticity index - the numerical difference between the liquid limit and the plastic limit; these limits are determined in the laboratory by standard tests and serve as a basis for estimating the relative plasticity of a given soil sample.

Poisson's ratio - the ratio of the lateral linear strain to the longitudinal linear strain with the elastic behavoir of a material subjected to axial load.

Pore water pressure - pressure or stress transmitted through the pore water (water filling the voids of the soil).

Porosity - the proportion, usually stated as a percentage, of the total volume of a rock material or regolith that consists of pore space or voids.

Porous - containing pores, voids, or other openings which may or may not be interconnected.

Potentially active faults - those (based on available data) along which no known historical ground-surface ruptures or earthquakes have occurred; these faults, however, show strong indications of geologically recent activity; potentially active faults can be placed in two subgroups that are based on the boldness or sharpness of their topographic features and the estimates related to recency of activity:

1. Subgroup One - High Potential

    a. Offsets affecting the Holocene deposits (age less than 10,000-11,000 years).

    b. A ground-water barrier or anomaly occurring along the fault within the Holocene deposits.

    c. Earthquake epicenters (generally from small earthquakes occurring close to the fault).

    d. Strong geomorphic expression of fault origin features (e.g., faceted spurs, offset ridges, or stream valleys or similar features, especially where Holocene topography appears to have been modified).

2. Subgroup Two - Low Potential

This subgroup is the same as 1 a, b, or d above, with the exception that the indications of fault movement can only be determined in Pleistocene deposits (less than 2 million to 3 million years old).

Precision depth recorder (PDR) - an echo (depth) sounder having an accuracy better than 1 in 3000.

Predominant period - a number representing the time between seismic wave peaks to which a building on the ground is most vulnernable, usually measured in seconds.

Pressure ridge - raised structure at top of slope failure, or the ridge formed in a compressional or thrust fault.

Principal stress - stresses acting normal to three mutually perpendicular planes intersecting at a point in a body, on each of which the shearing stresses are zero.

Pulse - a waveform whose duration is short compared to the time scale of interest and whose initial and final values are the same (usually zero); a seismic disturbance which travels like a wave but does not have the cyclic characteristics of a wave train.

P wave - compressional wave = longitudinal wave; body wave in which the direction of the particle motion is the same as the direction of wave propagation; wave velocity is commonly measured in geophysical refraction surveys to define the contact between and dynamic properties of competent layers (high velocity materials) and softer or less competent layers (low-velocity materials), such as bedrock and soil overburden; see body waves.

Random noise - energy which exhibits only a small degree of phase coherence or continuity between successive receiving channels; by adding together in elements, random noise can be attenuated by a factor (square root n).

Rayleigh wave - a type of seismic wave propagating along the surface, one type of ground roll; particle motion is elliptical and retrograde in the vertical plane containing the direction of propagation and its amplitude decreases exponentially with depth.

Reflection - the return of a wave incident upon a surface to its original medium.

Refraction - the deflection of a wave due to its passage from one medium to another of different density.

Regional geology - the geology of a relatively large area.

Regolith - the layer of mantle of loose, incoherent rock material, of whatever origin, that nearly everywhere forms the surface of the land and rests on the bedrock.

Relative density - the ratio of (1) the difference between the void ratio of a cohesionless soil and the loosest state and any given void ratio to (2) the difference between its void ratios in the loosest and the densest states.

Remote sensing - the acquisition of information or measurement of some property of an object by a recording device that is not in physical or intimate contact with the object under study; the technique employs such devices as the camera, lasers, infrared and ultraviolet detectors, microwave and ratio frequency receivers, radar systems, and others.

Residual soil - a soil deposit formed by the decay of rock in place.

Resonance - induced oscillations of maximum amplitude produced in a physical system when an applied oscillatory stress and the natural oscillatory frequency of the system are the same.

Response spectrum - a plot of the maximum response of a family of idealized, linear, single-degree-of-freedom, damped, spring mass systems, subjected to a prescribed forcing function, plotted as a function of the undamped natural frequency of the spring mass system.

Reverse or thrust fault - vertical to nearly horizontal movement along a sloping fault surface in which the block above has moved upward or over the block below the fault.

Right-lateral fault movement - generally horizontal movement in which the block across the fault from an observer has moved to the right.

Safe shutdown earthquake - for a reactor site, that earthquake which produces the vibratory ground motion for which structures and systems of the nuclear powerplant necessary to shut down the reactor and maintain the plant in a safe condition without undue risk to the health and safety of the public are designed to remain functional.

Sag ponds - ponds occupying depressions in the land surface along faults; the depressions are due to uneven settling of the ground or other causes.

Sand - particles of sediment having a size range of 1/16 mm to 2.0 mm.

Sand boils - turbid upward flow of water and some sand to the ground surface resulting from increased ground water pressures when saturated cohesionless materials are compacted by earthquake ground vibrations; characteristic of liquefaction.

C-105203

Sanitary landfill - a disposal area for solid wastes where the wastes are compacted and covered daily by a layer of impermeable material such as clay.

Saturated soil - soil with zero air voids; a soil which has its interstices or void spaces filled with water to the point where runoff occurs.

Scarp - a cliff, escarpment, or steep slope of some extent formed by a fault or a cliff or steep slope along the margin of a plateau, mesa, or terrace.

Scattering - the irregular and diffuse dispersion of seismic energy caused by inhomogeneities in the medium through which the energy is traveling.

Sediment - solid material, both mineral and organic, that, in suspension, is being transported, or has been moved from its place of origin.

Sedimentary rocks - rocks formed by the accumulation of sediment in water (aqueous deposits) or from air (eolian deposits); a characteristic feature of sedimentary deposits is a layered structure known as stratification or bedding.

Seiche - a free or standing wave oscillation of the surface of water in an enclosed or semi-enclosed basin (lake, bay or harbor).

Seismic - pertaining to shock waves within the earth produced by earthquakes, or in some cases artificially produced shock waves.

Seismic bedrock - naturally occurring earth materials, found either at or below the ground surface, that have a shear wave velocity of 2500 feet per second or over; used in mathematical models for ground-motion studies.

Seismicity - a measure of the probability of an earthquake occurrence in an area.

Seismic reflection profiler (SRP) - instrument similar to echo sounder which uses low-frequency (instead of high frequency) sound in pulses for less attenuation traveling through sediment layers.

Seismic velocity - the rate of propagation of seismic waves in earth materials (usually measured in feet per second).

Seismograph - an instrument for recording earthquake or seismic waves; the record made by a seismograph is called a seismogram.

Seismology - the science of earthquakes and the study of seismic waves.

Seismometer - a device which detects vibrations of the earth, and whose physical constants are known sufficiently for calibration to permit calculation of actual ground motion from the seismographic record.

Separation - apparent rather than relative displacement in a fault.

Settlement - the subsidence of artificial material due to compaction, consolidation, or liquefaction.

C-105204

Shadow zone - little or no direct penetration of seismic waves.

Shattered ridge tops - area of heavy ground cracking at the crest of a topographic high.

Shear - a mode of failure whereby two adjacent parts of a solid slide past one another parallel to the plane of contact; to subject a body to shear, similar to the displacement of the cards in a pack relative to one another.

Shear strength - the stress or load at which a material fails in shear.

Shear wave - a body wave in which the particle motion is perpendicular to the direction of propagation.

Side-scan sonar (SSS) - makes a continuous graphic record of the sea floor (similar to a shaded relief map).

Silt - a fine-grained sediment having a particle size intermediate between that of fine sand and clay, between 1/16 mm and 1/265 mm in diameter.

Slickensides - a polished and smoothly striated surface that results from friction along a fault plane.

Soil dynamics - the study of the engineering properties of soils as they are affected by transient impulsive loading.

Spectrum - the amplitude and phase angle characteristics as a function of frequency for the components of a seismic wavetrain or wavelet, filter response characteristic.

Strain - deformation resulting from applied force; within elastic limits strain is proportional to stress.

Strain-dependent property - that property of soil, the magnitude of which depends on the magnitude of the induced strain.

Strain meter - an instrument for measuring deformation due to stress or force; in geophysical applications, the quartz-rod extensometer is most commonly used; this instrument typically operates over a base 10 to 30 m long and has a sensitivity of 0.001 ppm or better; it actually measures change in distance between two monuments, the quartz rod serving as a constant-length reference.

Strata - sedimentary rock layers.

Standing wave - a wave produced by simultaneous transmission in opposite directions of two similar waves resulting in fixed points of zero amplitudes called nodes.

Strike-slip - fault displacement parallel to the strike of the fault.

C-105205

Stress - force per unit area.

Strong motion - ground motion of sufficient amplitude to be of engineering interest in the evaluation of damage due to earthquakes, or total-time single-component acceleration (+ or -) was above 0.05 g.

Structural - pertaining to, part of, or consequent upon the geologic structure, as a structural valley.

Structural feature - features produced in the rock by movement after deposition, and commonly after consolidation, of the rock.

Submergence - a term which implies that part of the land has become inundated by the sea.

Subsidence - sinking or lowering of a part of the earth's crust.

Subsidiary faulting - generally minor faulting associated with major fault breaks.

Surface waves - energy which travels along or near the surface, ground roll; includes Rayleigh, Love, hydrodynamic, Stoneley, and other waves.

Swarm - an earthquake series in which no one event is sufficiently larger than the others to be classified as the mainshock.

S wave (shear wave, transverse wave) - eddy wave in which the particle motion is at right angles to the direction of wave propagation.

Talus - the heap of coarse rock waste at the foot of a cliff or a sheet of waste covering a slope below a cliff.

Tectonic - pertaining to or designating the rock structure and external forms resulting from the deformation of the earth's crust; pressures causing such deformations often result in earthquakes.

Texture - the physical appearance of a rock, as shown by size, shape, and arrangement of the mineral particles in the rock.

Thrust fault - see reverse fault.

Tiltmeter - an instrument for measuring change in the attitude or slope of the local ground surface.

C-105206

Time-dependent response analysis - structural dynamic analysis where the displacement and force response history of a structure is determined from an earthquake time acceleration history record; the maximum forces and displacements of the structure are determined through superposition of the significant modal responses of the structure or numerical techniques.

Topographic effect - the amplification or deamplification of seismic waves due to the presence of a topographic high (knoll, hill, mountain, etc.).

Topography - the physical features of the land, especially its relief and contour.

Travel path - the course along which seismic waves propagate from the source outward.

Tsunami - a sea wave produced by large areal displacements of the ocean bottom, often the result of earthquakes or volcanic activity; also known as a seismic sea wave.

Turbidity current - a relatively rapid, downslope, underwater density current which may be generated by a seismic disturbance which causes a slumping of sediment on the slope and starts a flow of sediment and water.

Unconsolidated strata - rocks consisting of loosely coherent or uncemented particles, whether occurring at the surface or at depth.

Undrained shear strength - the shear strength of a soil in which the pore water is not allowed to escape from the specimen during testing.

Undisturbed sample - a soil sample that has been obtained by methods in which every precaution has been taken to minimize disturbance to it.

Urban geology - the application of geology to problems in the urban environment.

Vane shear test - an in-place shear test in which a rod with thin radial vanes at the end is forced into the soil and the resistance to rotation of the rod is determined.

Velocity - a vector quantity which indicates time rate of motion; often refers to the propagation rate of a seismic wave without implying any direction; when used in this sense the term is not a vector.

Viscoelastic medium - a stress-strain relationship in which the stress is a function of both strain and strain-rate, though not necessarily proportional to both.

C-105207

Viscosity - the cohesive force existing between particles of a fluid which cause the fluid to offer resistance to a relative sliding motion between particles; internal fluid friction.

Void ratio - the volume of the voids divided by the volume of the solids.

Water table - the upper limit or surface of the zone of saturation of ground water.

Waveform - a plot of seismic displacement as a function of time.

Wave guide - a region, usually a layer, in the solid earth that tends to channel seismic energy.

Wave height - the difference in elevation between adjoining wave crests and troughs.

Wave length - the distance between successive similar points on two wave cycles.

Weathering - response of materials that were once in equilibrium within the earth's crust to new conditions at or near contact with water, air, and living matter; with time the materials change in character and decay to form soil.

Wedge effect - unusual ground motion that occurs at the edge of alluvial valleys.

White noise - random energy containing all frequency components in equal proportions.

Yield stress - a stress at which the stress-to-strain relationship becomes nonproportional.

APPENDIX E

EARTHQUAKE INTENSITY SCALES

E Earthquake Intensity Scales

1. Modified Mercalli Earthquake Intensity Scale of 1931 (Abridged)*

I. Not felt except by a very few under especially favorable circumstances. (I. Rossi-Forel Scale).

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (I to II Rossi-Forel Scale.)

III. Felt quite noticebly indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing truck. Duration estimated. (III Rossi-Forel Scale.)

IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably. (IV to V Rossi-Forel Scale.)

V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel Scale.)

VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight. (VI to VII Rossi-Forel Scale.)

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars. (VIII Rossi-Forel Scale.)

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motor cars disturbed. (VIII+ to IX Rossi-Forel Scale.)

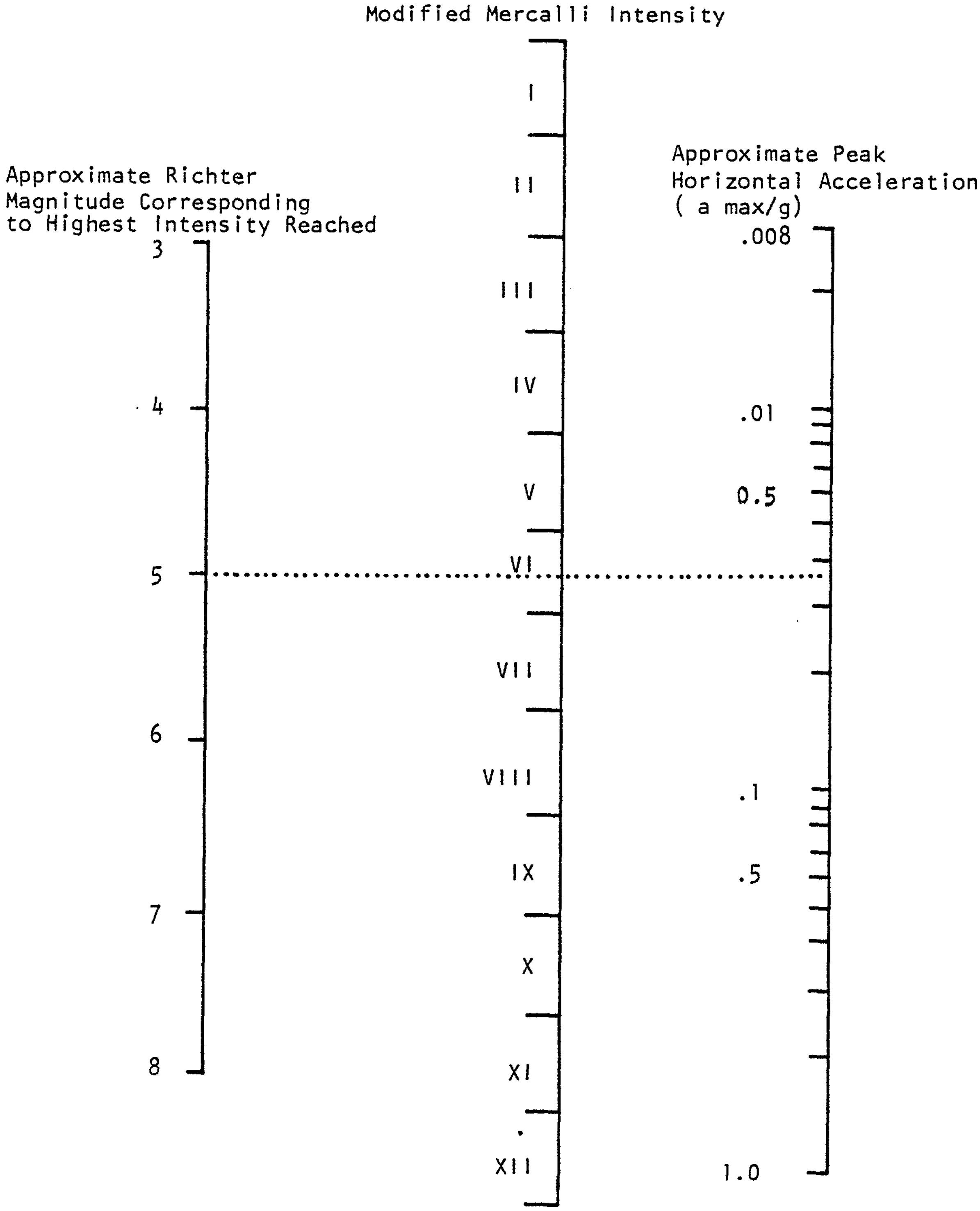
IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX+ Rossi-Forel Scale.)

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks. (X Rossi-Forel Scale.)

XI. Few, if any, (Masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

*Modified Mercalli Intensity Scale of 1931. Harry O. Wood and Frank Neumann, Bulletin of the Seismological Society of America, Vol. 12, No. 4, December 1931.



EARTHQUAKE MEASUREMENT CORRELATION

Approximate relationship of Modified Mercalli Intensity to Richter magnitude and peak horizontal acceleration (modified after Holmes, 1965, p. 901).

For example, an earthquake having a Richter magnitude of 5.0 would be expected to have a maximum intensity of VI on the Modified Mercalli Scale. The approximate peak horizontal acceleration for such an event would be less than .085.

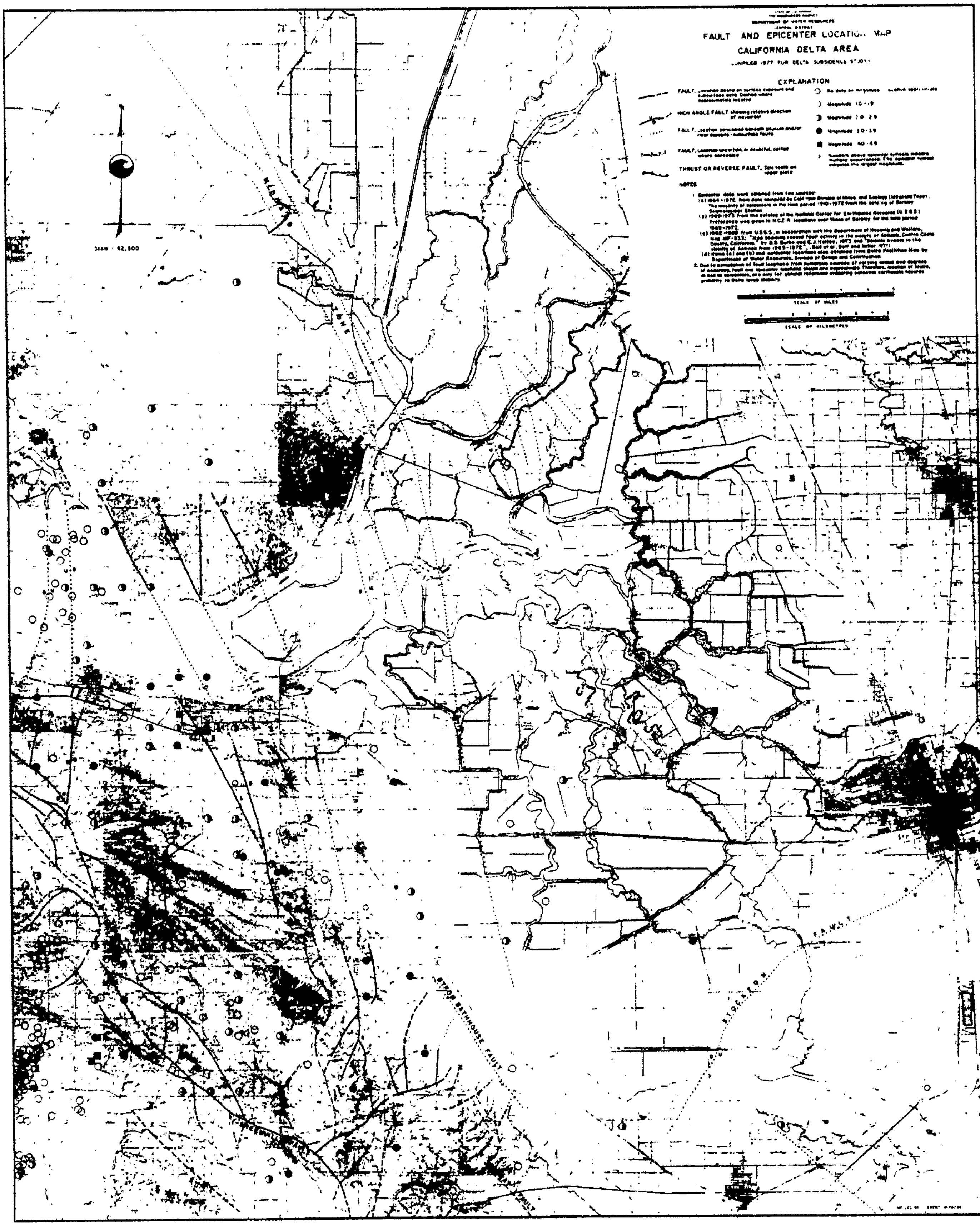
SOURCE: Contra Costa Planning Department, Seismic Safety Element, Technical Background Report, August 1975, p. 25.

C-105212

APPENDIX F

DELTA AREA EARTHQUAKE FAULTS

A 3-foot by 4-foot copy of this map is available (at $1.50) from the Department of Water Resources, P. O. Box 388, Sacramento, CA 95802.



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APPENDIX G

LEGISLATIVE MANDATE FOR DELTA LEVEE STUDIES

C-105215

Senate Bill No. 1390

CHAPTER 1302

An act to amend Section 12987 of, and to add Chapter 3 (commencing with Section 12225) to Part 4.5 of Division 6 of, the Water Code, relating to Sacramento-San Joaquin Delta levees, making an appropriation therefor, and declaring the urgency thereof, to take effect immediately.

[Approved by Governor September 28, 1976. Filed with Secretary of State September 29, 1976.]

The people of the State of California do enact as follows:

SECTION 1. Chapter 3 (commencing with Section 12225) is added to Part 4.5 of Division 6 of the Water Code, to read:

CHAPTER 3. SACRAMENTO-SAN JOAQUIN DELTA LEVEES

Article 1. Plan for Improvement

12225. The plan for improvement of the Sacramento-San Joaquin Delta levees, as set forth in Bulletin No. 192 of the Department of Water Resources, dated May 1975, is approved as a conceptual plan to guide the formulation of projects to preserve the integrity of the delta levee system.

Article 2. Construction

12226. The department may prepare detailed plans and specifications for the improvement of the levees or levee segments specified in Section 12225.

12226.1. The department shall report on its recommendations to the Legislature concerning the improvement of the levees specified in Section 12225, including, but not limited to, recommendations concerning construction, cost sharing, land use, zoning, flood control, recreation, fish and wildlife habitat, and aesthetic values. The department shall submit interim reports to the Legislature concerning the status of the delta levees program on or before January 15 of each year beginning in 1978, with the final report on its recommendations to be made on or before January 15, 1980.

12226.2. The department may proceed immediately with the improvement of a pilot levee project which the department determines, after a public hearing, is in critical need of improvement and which is highly susceptible to failure in the absence of such immediate improvement. Prior to commencing such improvement, the department shall enter into an agreement with a local agency whereby the local agency will bear at least 20 percent of the cost of the improvement.

Article 3. Short Title

12227. This chapter shall be known and may be cited as the "Nejedly-Mobley Delta Levees Act".

SEC. 2. Section 12987 of the Water Code is amended to read:

12987. Local agencies maintaining nonproject levees shall be eligible for reimbursement pursuant to the provisions of this part upon submission to and approval by the board of plans for the maintenance and improvement of such nonproject levees, including plans for the annual routine maintenance of such levees, in accordance with the criteria adopted by the board. Such plans shall also be compatible with the plan for improvement of the delta levees as set forth in Bulletin No. 192 of the department, dated May, 1975, and as approved in Section 12225, and shall include such provision for protection of the wildlife habitat as the board deems proper. Such plans shall also take into account the most recently updated Delta Master Recreation Plan prepared by the Resources Agency. Upon approval of such plans by the board, the local agencies shall enter into an agreement with the board to perform the maintenance and improvement work, including the annual routine maintenance work, specified in such plans. In the event that applications for state funding in any year exceed the state funds available, the board shall apportion the funds among those levees or levee segments that are identified by the department as most critical and beneficial, considering the needs of flood control, water quality, recreation, and wildlife.

SEC. 3. The sum of three hundred fifty thousand dollars ($350,000) is hereby appropriated from the General Fund in accordance with the following schedule:

Schedule:

(a) To the Department of Water Resources for expenditure without regard to fiscal years for the purposes of Chapter 3 (commencing with Section 12225) of Part 4.5 of Division 6 of the Water Code	$150,000
(b) To the Department of Water Resources for expenditure during the 1976–1977 fiscal year for the purposes of Part 9, (commencing with Section 12980) of Division 6 of the Water Code	$200,000

SEC. 4. This act is an urgency statute necessary for the immediate preservation of the public peace, health, or safety within the meaning of Article IV of the Constitution and shall go into immediate effect. The facts constituting such necessity are:

In order to make available for expenditure during the 1976–77 fiscal year the funds appropriated by this act for the maintenance and improvement of levees in the Sacramento-San Joaquin Delta and to provide vitally needed flood protection at the earliest possible time, it is necessary that this act take effect immediately.

C-105217

Senate Concurrent Resolution No. 151

Introduced by Senators Cologne, Rodda, and Short.
(Coauthors: Assemblymen Monagan and Porter)

July 10, 1969

WHEREAS, The Sacramento-San Joaquin Delta, as defined in Section 12220 of the Water Code, has been subjected to long periods of high flow during the first half of the 1969 calendar year; and

WHEREAS, Much of the delta consists of lands below sea level protected by a vast network of levee systems; and

WHEREAS, A number of delta levees failed during the early part of 1969, and others were threatened and seriously weakened by such high flows and high tides; and

WHEREAS, Many of the levees have been constructed by local reclamation districts and a few have been constructed and maintained by state and federal agencies as project levees, and some areas are protected by both locally constructed and project levees, necessitating high standards of maintenance on locally constructed levees to insure the functioning of the project levees; and

WHEREAS, The failure of any of such levees results in severe economic loss to the local area, the state, and the United States; and

WHEREAS, During times of emergency large sums of federal and state moneys are expended to keep the various levee systems from failing and to repair levees which have failed; and

WHEREAS, Many of the levees within the delta area have deteriorated over the years due to a variety of causes, and others must be periodically raised to offset settlement, and these levees may be subject to failure at almost any time; and

WHEREAS, It has become increasingly recognized that preservation of natural beauty, shade, and wildlife habitat on the levees is important from a recreational and esthetic viewpoint; now, therefore, be it

Resolved by the Senate of the State of California, the Assembly thereof concurring, That the Department of Water Resources is requested to undertake a general review of the condition of all levees within the Sacramento-San Joaquin Delta area, with particular emphasis on those levees considered to be substandard, and to include in such review a preliminary evaluation of the factors and costs involved in bringing the levees up to a safe condition and maintaining them in a safe condition and the extent to which such improvements might reduce the requirements of emergency expenditures; and be it further

Resolved, That in undertaking such review recognition be given to those areas where growth on such levees or the berms thereof can be permitted for esthetic purposes without endangering the maintenance of safe levees; and be it further

Resolved, That recommendations be made as to the sharing by local, state, and federal governments of costs necessary to bring such levees up to safe standards and for the continuous operation and maintenance thereof, and as to a means of collection of such costs; and be it further

Resolved, That the Department of Water Resources is requested to confer, in making its review, with local, federal, and other state agencies, including the State Reclamation Board, and flood control, recreational, and navigational interests, and to submit a preliminary report to the Legislature not later than February 1, 1970, containing recommendations on surveys and studies that are necessary to develop a comprehensive plan of action; and be it further

Resolved, That the Secretary of the Senate transmit a copy of this resolution to the Director of Water Resources.

C-105218

Excerpt From DWR Bulletin 192

Earthquake Hazards

As far as is known, earthquakes have not damaged the Delta levees; however, because the levees in the lowlands of the Delta are founded on and constructed of unconsolidated peat and silt soils of low density, low shear strength, and high moisture content, there is a potential for earthquake damage. During a major earthquake, these water-saturated materials may be subjected to liquefaction, a reaction of soil and water which is similar to the movement of quicksand. Earthquake-induced seiches, or oscillations of the water surface, also could develop in the network of sloughs and river channels during a major earthquake, causing overtopping of the levees. These two types of earthquake-related phenomena should receive further evaluation to determine their significance as potential hazards in the Delta.

APPENDIX H

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CONVERSION FACTORS

Metric to Customary System of Measurement

Quantity	Metric Unit	Multiply by	To get customary equivalent
Length	millimetres (mm)	0.03937	inches (in)
	centimetres (cm) for snow depth	0.3937	inches (in)
	metres (m)	3.2808	feet (ft)
	kilometres (km)	0.62139	miles (m)
Area	square millimetres (mm^2)	0.00155	square inches (in^2)
	square metres (m^2)	10.764	square feet (ft^2)
	hectares (ha)	2.4710	acres (ac)
	square kilometres (km^2)	0.3861	square miles (mi^2)
Volume	litres (l)	0.26417	gallons (gal)
	megalitres	0.26417	million gallons (10^6 gal)
	cubic metres (m^3)	35.315	cubic feet (ft^3)
	cubic metres (m^3)	1.308	cubic yards (yd^3)
	cubic metres (m^3)	0.0008107	acre-feet (ac-ft)
	cubic dekametres (dam^3)	0.8107	acre-feet (ac-ft)
	cubic hectometres (hm^3)	0.8107	thousands of acre-feet
	cubic kilometres (km^3)	0.8107	millions of acre-feet
Flow	cubic metres per second (m^3/s)	35.315	cubic feet per second (ft^3/s)
	litres per minute (l/min)	0.26417	gallons per minute (gal/min)
	litres per day (l/day)	0.26417	gallons per day)(gal/day)
	megalitres per day (Ml/day)	0.26417	million gallons per day (mgd)
	cubic metres per day (m^3/day)	0.0008107	acre-feet per day
Mass	kilograms (kg)	2.2046	pounds (lb)
	tonne (t)	1.1023	tons (short, 2,000 lb)
Velocity	metres per second (m/s)	3.2808	feet per second (ft/s)
Power	kilowatts (kW)	1.3405	horsepower (hp)
Pressure	kilopascals (kPa)	0.145054	pounds per square inch (psi)
	kilopascals (kPa)	0.33456	feet head of water
Specific capacity	litres per minute per metre drawdown	0.08052	gallons per minute per foot drawdown
Concentration	milligrams per litre (mg/l)	1.0	parts per million
Electrical conductivity	microsiemens per centimetre (μS/cm)	1.0	micromho per centimetre
Temperature	degrees Celsius (°C)	$(1.8 \times °C) + 32$	degree Fahrenheit (°F)

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