SAN FRANCISCO BAY CONSERVATION AND DEVELOPMENT COMMISSION
Thirty Van Ness Avenue, San Francisco 94102 557 - 3686

November 9, 1989

TO: All Commissioners and Alternates
FROM: Alan R. Pendleton, Executive Director

SUBJECT: STAFF REPORT ON EARTHQUAKE SAFETY
(For Commission consideration on November 16, 1989)

Introduction

The recent devastating earthquake has again pointed out to the Bay Area public the unique problems faced by communities which are located along active earthquake faults. On November 16, 1989, the Commission staff will brief the Commission about its policies and planning efforts regarding earthquakes and their effect on the conservation and development of San Francisco Bay. Mr. L. Thomas Tobin, Executive Director of the California Seismic Safety Commission, will summarize the impacts of the earthquake. In addition, Dr. Robert E. Wallace of the U. S. Geological Survey, who is Chairman of the Commission's Engineering Criteria Review Board (ECRB), will discuss the role the ECRB plays in the Commission's efforts to improve seismic safety.

Background

On September 17, 1965, the California Legislature established the Commission as a temporary agency to prepare a plan to protect San Francisco Bay and develop its shoreline in the long-term interest of the general public. The Commission and its staff began this comprehensive planning effort by studying individual physical characteristics of and the major planning issues confronting the Bay using separate, but related, technical background reports. The Commission then individually considered and adopted the reports' conclusions and recommendations (summaries of all the reports were published in the San Francisco Bay Plan Supplement). These conclusions and recommendations were then merged to form the findings and policies of the San Francisco Bay Plan.

Four of these reports deal directly with the issue of the safety of fills during an earthquake: (1) "Geology of San Francisco Bay" by Harold Goldman, Senior Geologist with the State Division of Mines and Geology (February 1967); (2) "Seismic Problems in the Use of Fills in San Francisco Bay" by H. Bolton Seed, Professor of Engineering at the University of California, Berkeley; (3) "Seismic Risk to Buildings and Structures on Filled Lands in San Francisco

Bay" by Karl V. Steinbrugge, Structural Engineer; and (4) "Bay Mud Developments and Related Structural Foundations" by Lee and Praszker, Consulting Engineers. The last three reports were combined into the background report entitled "Fill: Three Reports on Aspects of Fill in San Francisco Bay" (May 1967).

The Background Reports

1. Geology. The background report on Geology described how San Francisco Bay was formed and noted that bedrock under the Bay was generally very deep and irregular. Layers of Bay mud have been deposited on the bedrock; the older Bay muds are more consolidated by the pressure from above and contain less moisture. The younger Bay mud is more troublesome from an engineering standpoint because it is pliable, weak and highly compressible. When younger Bay mud is overloaded by fill, it becomes increasingly unstable as the thickness of the fill increases and, if the slopes at the edge of the fill are steep, it can ultimately fail.

Damaging earthquakes result from movement on faults, which are long, abrupt breaks in the earth's crust. There are active major faults on both sides of the Bay -- the San Andreas Fault on the west and the Hayward and Calaveras Faults on the east. Earthquakes consist of vibrations that travel through the earth's crust. Resulting ground motions change in magnitude and frequency as they pass through different earth materials; the violence of ground motion in soft mud materials is much greater than in solid rock. Poor ground is a greater potential hazard than is nearness to the fault or the epicenter of a quake. Other aspects of earthquakes include movement, or slippage, along the fault, surface cracks and fissures, changes in elevations, and resulting landslides, rock falls, avalanches, fires, mud and debris flows, and seismic sea waves (seiches and tsunamis). All of these phenomena can occur in the Bay Area.

2. Fill. The background report on Fill identifies the special soils problems inherent in constructing on land created by filling parts of San Francisco Bay. In designing a fill project, both the stability of the Bay bottom upon which the fill rests and the potential problems of sinking and settlement within the fill itself must be considered. In addition, consideration must be given to the behavior of both the fill and the underlying ground over many years of settlement and in the event of shaking from an earthquake.

The report describes the stability of fill under normal settling conditions. For example, under the weight of the fill, mud can squeeze out at the edge (mud waves), too rapid or too much fill at one time can exert too much pressure and the mud becomes semi-fluid, and a sloped Bay bottom can cause the fill to slide down the slope. The report also provides a description of the stability of fill under earthquake conditions. In addition to major shifts in large areas of ground, the shaking often causes soil particles to shift and settle in relation to each other. This shifting and settling is greatest in soils - such as silt, sand and gravel - that are least

cohesive. If the silts and sands that are being shaken are loose and saturated with water, the entire soil may become fluid, which is called "liquefaction." Liquefaction can result in rapid settlement or flows which can collapse structures or geological formations. Such soil failures are the most destructive to buildings and utilities. The other major cause of damage in a quake is the shaking of the buildings. Buildings on solid rock foundations are shaken less severely than buildings on softer materials.

Bay mud under a fill is not as likely to become liquid during an earthquake as some have believed, but if a clay soil underlying a fill slope is near the point of failure before a quake, it is likely to fail. If fill slopes on clay foundations are designed to prevent failure during a quake, the main cause of damage will be ground vibrations. But, the soft muds and clays transmit fewer shock waves per minute than do other natural soils and bedrock, and this action is particularly damaging to tall buildings. Natural sand deposits in the Bay are likely to be loose to medium dense and are potentially vulnerable because of settlement, liquefaction, and sliding.

The report noted that uncompacted dumped fills of all types of soil are poor foundations for any kind of structure. Hydraulic sand fills are often fairly loose unless mechanically compacted and may settle or become liquid during a quake. Well-compacted fills of select materials on good foundations can be sound, though some settling can occur during a quake.

The report concluded that in order to meet earthquake and normal settlement requirements, stable fills require proper analysis and design by competent engineers using the latest technological information available and thorough inspection during construction. Factors affecting the stability of fill are: (1) avoidance of loose, unconsolidated materials; (2) consideration of relative sand and water heights to avoid liquefaction; (3) uniform placement of fill material during construction; (4) avoidance of excessive rates of filling; (5) carefully designed slopes to avoid heaving at the edge of the fill; (6) surcharging filled areas to reduce the amount of settlement of a fill; and (7) designing the fill and subsequent structures to withstand some differential settlement.

The report further pointed out that the safety of construction may be evaluated from two points of view: hazard to life and hazard to property. The underlying philosophy is that buildings only need to be safe to their occupants. Therefore, buildings must be designed to not collapse in an earthquake, although the building itself might be damaged to the point where it is too expensive to repair. To minimize hazard to life and property, the report recommended assigning the following risk categories in order to develop precise criteria for maximum safety. A "minimum risk zone" would "require that, for all structures more than two stories high, a structural engineer must file a report with the local building department that certifies that all structural engineering aspects of the plans and specifications were complied with during construction." A "moderate risk zone" would "limit construction to a maximum of two stories and would require that all residential buildings be of wood frame construction. Buildings with concrete, brick, or concrete

block walls would generally require design and inspection by a structural engineer. No large places of assembly of people would be permitted." A "substantial risk zone" would "permit only one-story buildings used as warehouses, storage areas, or other uses requiring a minimum number of employees." Finally, a "maximum risk zone" would "permit only open recreational uses such as parks and golf courses, but no facilities where large numbers of people could collect in one place."

The report indicated that in 1968 there were no minimum codes regulating construction on fills on Bay mud because of the absence of sufficient data upon which to base a code. Therefore, the report recommended that in the absence of such codes or data, public safety in regard to construction on Bay fill requires a review board competent to: (1) set and then constantly adjust standards as rapidly as new information becomes available; (2) review all fill proposals on the basis of available knowledge; and (3) prescribe an inspection system to ensure the placement of the fill according to the approved design.

As a result of the recommendations of these reports, the Commission appointed a Board of Consultants to Review Safety of Proposed Fills on February 16, 1968. As a first step, the new Board began the study of criteria which would be necessary to establish a satisfactory level of safety in a field where no generally accepted standards existed. The Board believed that these safety criteria should be developed and made enforceable by including them in any plan for the conservation and development of the Bay. The Board adopted a report entitled "Carrying out the Bay Plan: The Safety of Fills." This report recommended a set of qualitative criteria involving geological and seismological considerations, soil and foundation engineering considerations, and engineering safety requirements. The report also recommended that the Commission include in the Bay Plan a consultant board to continue working on seismic safety considerations. The Board would: (1) establish and revise safety criteria for Bay fills and structures thereon with respect to risk zones; (2) review all except minor projects for the adequacy of their specific safety criteria; (3) gather and make available data developed from projects in the Bay; and (4) complement the functions of local building and planning departments.

The Bay Plan

Based on the technical background reports and the recommendations of the Board of Consultants, the Commission included findings and policies on the safety of fills in the San Francisco Bay Plan (see Attachment 1). Fundamental to implementing the "Safety of Fills" policies of the Bay Plan, the Commission also created a permanent Engineering Criteria Review Board consisting of geologists, civil engineers specializing in soils engineering, structural engineers, and architects.

The Engineering Criteria Review Board

The ECRB reviews all major applications for Bay fills to ensure that appropriate safety criteria are used to construct structures using state-of-the-art concepts. A number of subjective and quantitative factors are balanced to establish these safety criteria, such as the professional judgment and technical skill of the designer, the degree of geologic hazard, the importance, use and configuration of the structure, the sophistication of analysis, and the choice of construction materials and techniques.

Overall, this review has resulted in a significant improvement in the seismic engineering of fills and structures built on them. In many cases, the ECRB has advised applicants that additional soils and geologic information were necessary to properly define the hazards inherent in a development, which has led in turn to design changes to reduce the hazard. For example, many important changes were made in the design of the new Dumbarton Bridge as a result of the ECRB's suggestions. Moreover, the mere existence of the ECRB, with its reputation for thorough review, encourages developers, public agencies, and their consultants to consider seismic safety carefully in the design of projects and to use more sophisticated analytical methods than those required by existing code standards.

The October 17th Earthquake

On October 17, 1989, the San Francisco Bay Area experienced its most severe earthquake since the 1906 quake. The quake, measuring 7.1 on the Richter Scale and located along the San Andreas Fault, had an epicenter about six miles northwest of Watsonville, about fifty miles south of San Francisco. The quake's "hypocenter" was between 3.76 and 11.25 miles underground. There was no rupture at the epicenter, but there was ground rupturing along over thirty miles. The 1906 quake ruptured the ground along 250 miles. This quake caused over 2 yards of horizontal movement and over 1 yard of vertical movement at the epicenter.

Liquefaction problems extended from Bolinas in the north, to Orinda in the east, to King City in the southeast, to Gorda on the Big Sur coast in the southwest. While there was considerable liquifaction around Monterey Bay, there was virtually none south of the San Mateo-Hayward Bridge. Landslides extended from Bolinas to Big Sur and many more are expected when the rains begin. This problem is seen to be particularly acute in the Santa Cruz Mountains. This quake is expected to put additional pressure on the Hayward Fault.

Commission Response

The Executive Director has issued, after consultation with the Chairman, several emergency permits for activities ranging from repair of the San Francisco-Oakland Bay Bridge to the creation of ferry terminals along the East and West Bay shorelines. Many more permits are expected to be issued in the next several months for minor repairs and reconstruction of structures damaged in the quake.

In addition, the Commission staff has responded to numerous inquiries regarding the disposal of debris from earthquake-damaged structures. This debris included rubble and construction materials from the collapsed portions of I-880 in Oakland, from damaged portions of the Embarcadero and I-280 freeways in San Francisco, and debris from other structures within the region. Suggestions for debris disposal included deposition in the Pacific Ocean, in the Bay, and along riprapped levees in the region. However, most debris has been taken to approved solid waste disposal sites around the region or is being recycled.

In the 1989-90 fiscal year, the Commission included within its planning program an earthquake-caused debris removal feasibility study. The Commission feared that without a strategy for rubble disposal in the Bay Area, the Bay may become the disposal site for lack of well thought out alternatives. Rubble and debris disposal in aquatic sites at inappropriate locations and under improper conditions could cause water quality, fisheries, and navigational problems.

The study would be coordinated with the Bay Area Earthquake Preparedness Program and be evaluated the feasibility of developing a joint rubble disposal strategy and plan. The project would also be coordinated with the California Seismic Safety Commission and the ECRB. Completion of the study would have cost about $26,000. At this time, it is uncertain whether funds for this study will be included in the Governor's proposed budget for the Commission.

Inventory of ECRB Reviewed Projects

The Commission staff has evaluated the impact of the earthquake on a number of Bay fill projects which had been reviewed by the ECRB according the conditions of their Commission permits. The following inventory provides a sample of types of projects and locations around the Bay and how these structures fared during the strong quake.

1. Permit No. 2-84. South Beach Marina (reviewed August 7, 1984).

The project is in the vicinity of Pier 40. The project included three sections of breakwater, one off-shore section and two sections connected to shore. Public access is provided on the two sections connected to the shore but not allowed on the off-shore section.

The Engineering Criteria Review Board, in their review of the project was concerned about the possibility of liquefaction in the area landward of the old seawall. The soils engineers had taken borings outside of the seawall and reported that they had found no liquefiable materials; therefore liquefaction was discounted.

The structures on the project have been inspected and no structural damage has been observed.

2. Permit No. 22-76. Pier 39 (reviewed April 26, 1983, June 23, 1977, and December 13, 1976).

The project was reviewed several times. The Board was concerned about lateral pressure on the piles and liquefaction potential. The Board requested the permittees to furnish additional information regarding these two items. Subsequently this additional information was received by the Board, reviewed, and found to satisfy their concerns.

Inspections after the quake revealed some spalling of concrete, but only superficial and nothing that would affect the structural integrity of the deck or piles.

3. Permit No. 17-79. Wickland Oil Tanker Facility (reviewed June 2, 1981).

The Board was concerned about this project because there was evidence that the Franklin Fault ran through it. Discussion and documentation did not provide a clear picture if the fault was active or inactive. The Board requested further documentation regarding the location of the Franklin Fault, whether it is active or inactive, and an evaluation of the consequences of fault movement on the structure and piping. The Board subsequently received, reviewed, and found the additional documentation satisfactory.

The Board was further concerned that the pipeline crossed over the fault and could be vulnerable in the event of an earthquake. It suggested that shutoff valves be placed in the pipe on either side of the fault. This change was built into the design of the project.

Inspection after the earthquake revealed no damage to the terminal.

4. Permit No. 18-76. Pier 41 Reconstruction (reviewed January 22, 1980).

This was a project by Harbor Carriers to remove an existing pier, build a new concrete slab, office building, catering kitchen, gift shop and snack bar. The Board was concerned about the possible unrestrained bending of some of the piles and about the possibility of liquefaction and requested a written confirmation of the elevations of lateral support of the piles, and of the safety against liquefaction. The Board subsequently received, reviewed and accepted the written confirmation.

Inspections after the quake revealed six split wooden piles under the deck and movement of approximately four inches transversely along an expansion joint between two sections of the deck.

5. Permit No. 13-78. Port of Oakland Howard Terminal (reviewed November 13, 1979).

The project included building a marginal-type wharf, building a dike and filling behind the dike. The Board stressed the importance of removal of the Bay mud layer underneath the dike and requested that an inspection system be set up to guarantee that. This was agreed to by the Port.

Inspection of the wharf since the earthquake has revealed that the wharf itself sustained no damage. There was some minor pavement cracking on the yard side of the project but this does not affect the wharf.

6. Permit No. 20-73. Dumbarton Bridge (reviewed many times between June 5, 1972 and November 27, 1977).

This project was reviewed by the Board eleven times in all and many suggestions were offered and implemented by CalTrans. CalTrans was asked to provide a plan for installation of strong motion instrumentation on the bridge and subsequently that plan was implemented.

Inspection of the bridge subsequent to the earthquake revealed no structural damage. In fact, this was the only major bridge across the Bay that did not have to be closed at some point after the quake.

7. Permit No 10-73. Golden Gate Bridge Ferry Terminal at San Francisco (reviewed October 15, 1975).

In its review the Board was concerned about the "glass roof option" in the specification for the project because the glass framing would undergo distortion due to lateral forces. The Board requested that testing be done on the glass to see if it would withstand the distortion without breaking. This was agreed on by the permittee.

Inspection subsequent to the earthquake revealed no structural damage and minor cracking in the walls of the Terminal Building.

8. Permit No. 2-84. P. G. & E. Fuel Oil Pipeline (reviewed February 26, 1989).

This project proposed to construct a 42-mile-long welded steel pipeline between the Richmond Long Wharf and the P. G. & E. plant in Antioch. The Board was concerned about mud distortion during an earthquake and the possibility of the nearby railroad fill causing lateral displacement in the mud by settling during an earthquake. The permittee said it would analyze those two potential effects on the pipeline.

That portion of the pipeline between Richmond and Pittsburgh has not been in service since 1984, but there has been no reported damage on it. Before P. G. & E. returns the section to service, it will be carefully examined. The remainder of the pipeline suffered no damage from the earthquake.

9. Permit No. 3-72. Blue Dolphin Restaurant at San Leandro (reviewed June 5, 1972).

This project was for an addition, over the water, to the existing restaurant. As a result of the Board review, the design criteria were upgraded to double the amount of shear walls, making the structure stronger and more resistant to damage in the event of an earthquake.

An inspection subsequent to the earthquake, revealed only some surface damage but no structural damage.

10. Permit No. 16-71. Fruitvale Avenue Bridge in Oakland (reviewed July 27, 1971).

The Board was concerned that: (1) the San Fernando earthquake disclosed that present bridge design standards were inadequate; (2) there are unconsolidated deposits 1,000 feet thick at the Oakland Estuary, in close proximity to the Hayward fault; (3) insufficient information on the structural response had been presented; and (4) the bridge was a very important artery and would be vitally needed in the event of an earthquake. Because of these concerns, the Board requested that detailed information concerning seismic investigations and design for the bridge be submitted for evaluation before it would approve construction. Subsequently the Board received, reviewed and approved as adequate the information requested.

An inspection subsequent to the earthquake revealed that only minor concrete spalling occurred. Two anti-sway beams were sheared off the main structure, but this did not effect the structural integrity of the bridge and they have been replaced.

Safety of Fills

Findings and Policies Concerning Safety of Fills in the Bay

Findings

a. To reduce risk of life and damage to property, special consideration must be given to construction on filled lands in San Francisco Bay. (Similar hazards exist on the poor soils throughout the Bay Area, including soft natural soils, steep slopes, earthquake fault zones, and extensively graded areas.)

b. Virtually all fills in San Francisco Bay are placed on top of Bay mud. Under most of the Bay there is a deep, packed layer of old Bay mud. More recent deposits, called younger Bay mud, lie on top of the older muds. The top layer of young mud presents many engineering problems. The construction of a sound fill depends in part on the stability of the base upon which it is placed.

c. Safety of a fill also depends on the manner in which the filling is done, and the materials used for the fill. Similarly, safety of a structure on fill depends on the manner in which it is built and the materials used in its construction. Construction of a fill or building that will be safe enough for the intended use requires: (1) recognition and investigation of all potential hazards—including (a) settling of a fill or building over a long period of time, and (b) ground failure caused by the manner of constructing the fill or by shaking during a major earthquake—and (2) construction of the filling or building in a manner specifically designed to minimize these hazards. While the construction of buildings on fills overlying Bay deposits involves a greater number of potential hazards than construction on rock or on dense hard soil deposits, adequate design measures can be taken to reduce the hazards to acceptable levels.

d. There are no minimum construction codes regulating construction of fills on Bay mud because of the absence of sufficient data upon which to base such a code. Hazards vary with different geologic and foundation conditions, use of the fill, and the type of structures to be constructed on new fill areas. Therefore, the highest order of skilled judgment, utilizing the available knowledge of all affected disciplines, is required to: (1) recognize and investigate all potential hazards of constructing a fill; and (2) design the fill and any construction thereon to minimize these hazards.

e. In the absence of adequate fill construction standards or codes, the Commission appointed a Board of Consultants consisting of geologists, civil engineers specializing in soils engineering, structural engineers, and other specialists, to review, on the basis of available knowledge, all new fills that might be permitted in the Bay Plan, so that no fills would be included upon which construction might be unsafe. No specific fills are included in the Plan, but the Board of Consultants has completed an initial set of criteria (published separately as "Carrying Out the Bay Plan: The Safety of Fills") as a guide to future consideration of specific fill proposals.

f. Flood damage to fills and shoreline areas can result from a combination of heavy rainfall, high tides, and winds blowing onshore. To prevent such damage, buildings near the shoreline should be above the highest expected flood mark (nine feet above sea level is generally set as the safe mark except in the southern part of the South Bay, where the higher tides require almost a foot more elevation), or should be protected by dikes of an adequate height.

g. Excessive pumping from underground fresh water reservoirs has caused extensive subsidence of the ground surface in the San Jose area and as far north as Dumbarton Bridge (map of Generalized Subsidence and Fault Zones shows subsidence from 1934 to 1967). Indications are that if heavy groundwater pumping is continued indefinitely in the South Bay area, land in the Alviso area (which has already subsided about seven feet since 1912) could subside up to seven feet more; if this occurs, extensive dikes may be needed to prevent inundation of low-lying areas by the high tides.

Policies

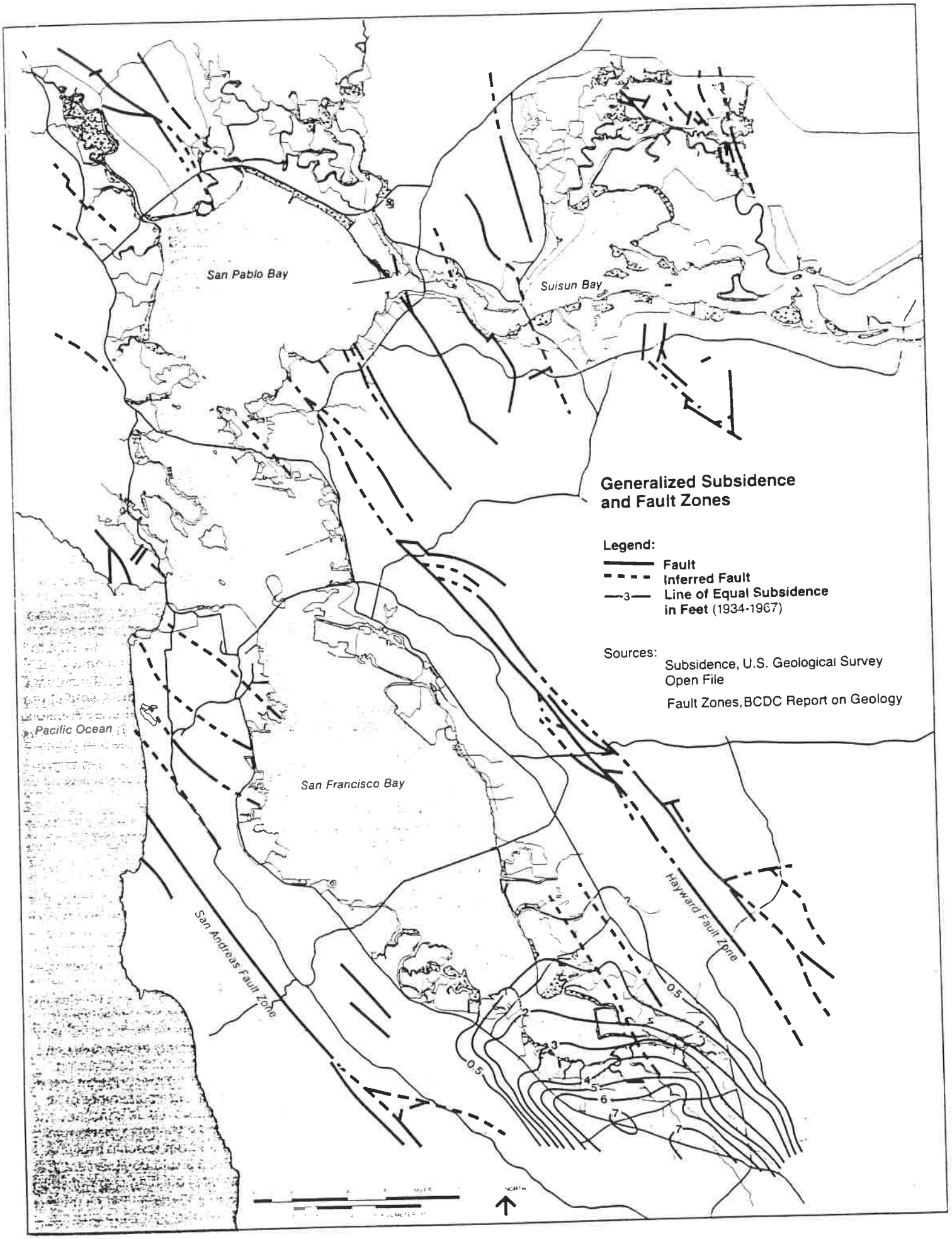
1. The Commission has appointed the Engineering Criteria Review Board consisting of geologists, civil engineers specializing in soils engineering, structural engineers, and architects competent to and adequately empowered to: (a) establish and revise safety criteria for Bay fills and structures thereon; (b) review all except minor projects for the adequacy of their specific safety provisions, and make recommendations concerning these provisions; (c) prescribe an inspection system to assure placement of fill according to approved designs; and (d) gather, and make available, performance data developed from specific projects. These activities would complement the functions of local building departments and local planning departments, none of which are presently staffed to provide soils inspections.

2. Even if the Bay Plan indicates that a fill may be permissible, no fill or building should be constructed if hazards cannot be overcome adequately for the intended use in accordance with the criteria prescribed by the Engineering Criteria Review Board.

3. To provide vitally-needed information on the effects of earthquakes on all kinds of soils, installation of strong-motion seismographs should be required on all future major land fills. In addition, the Commission encourages installation of strong-motion seismographs in other developments on problem soils, and in other areas recommended by the U. S. Coast and Geodetic Survey, for purposes of data comparison and evaluation.

4. To prevent damage from flooding, buildings on fill or near the shoreline should have adequate flood protection as determined by competent engineers. As a general rule, buildings near the shoreline should be at least nine feet above mean sea level (standard U.S.G.S. datum) or should be protected by dikes of an equivalent height and by any necessary pumping facilities. In the southern half of the South Bay, this height should be at least ten feet. Exceptions to the general height rule may be made for developments specifically designed to tolerate periodic flooding.

5. To minimize the potential hazard to Bayside development from subsidence due to groundwater withdrawal, all proposed developments at the lower end of the South Bay should be sufficiently high above mean sea level or sufficiently protected by dikes to allow for the effects of additional subsidence, utilizing the latest information available from the U. S. Geological Survey.


San Pablo Bay
Suisun Bay
Pacific Ocean
San Francisco Bay
San Andreas Fault Zone
Hayward Fault Zone
0.5
3
4
5
6
7
Generalized Subsidence and Fault Zones
Legend:
Fault
Inferred Fault
—3— Line of Equal Subsidence in Feet (1934-1967)
Sources:
Subsidence, U.S. Geological Survey Open File
Fault Zones, BCDC Report on Geology