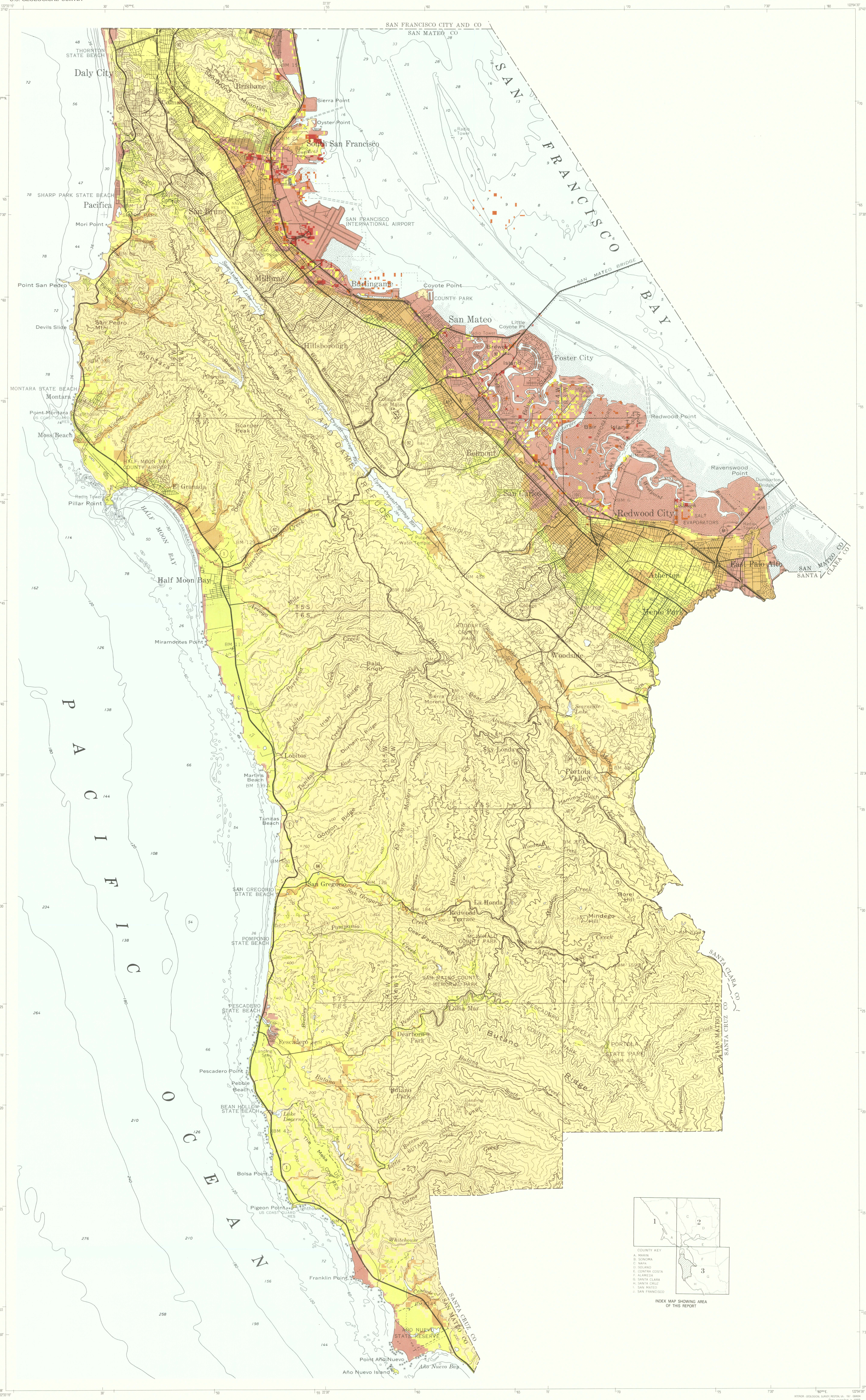




EXPLANATION

Relative liquefaction susceptibility and probability of susceptible sediment in subsurface materials

LOW TO HIGH—Generally low to moderate, locally high near active and abandoned stream channels. Many of the latter channels may be buried and undetectable without subsurface investigation. Overall, there is a 1 to 10 percent probability of liquefiable sediment in these areas based on the average for the map unit.

LOCALLY HIGH—Possibly liquefiable sediment within or above bay mud confirmed by data from borocole drilled within 1 hectare grid cell.

MODERATE TO LOW—0.1 to 1 percent probability of liquefiable sediment based on average for map unit. Most of its average probabilities for these map units, however, are less than 10 percent (table 1). The low end of the range.

LOCALLY MODERATE—Possibly liquefiable sediment immediately below bay mud but not within or above; confirmed by data from borocole drilled within 1 hectare grid cell.

LOW—0.01 to 0.1 percent probability of liquefiable sediment based on average for map unit.

LOCALLY LOW—Liquefiable sediment not found in borocole drilled within 1 hectare grid cell.

VERY LOW—Less than 0.01 percent probability of liquefiable sediment based on average for map unit.

BEDROCK

INTRODUCTION

Ground failures triggered by liquefaction are a major cause of earthquake damage. For example, during the 1906 San Francisco earthquake, ground failures damaged buildings, bridges, obstructed transportation routes, and covered pipelines. Liquefaction is defined as the transformation of a granular soil from a solid state to a liquid state. In the process, the soil undergoes transient loss of strength, which commonly causes ground displacement or ground failure to occur.

Three basic types of ground failure are associated with liquefaction: debris flow (rapid downslope displacement of soil materials in the form of a liquefied flow), lateral spread (limited extensional displacement of surficial soil layers down mild slopes), and loss of bearing strength (loss of foundation support to structures because of weakening of underlying or adjacent soil materials). In flat areas, liquefaction also enhances contraction leading to normal ground settlement, and it may cause transient horizontal oscillations as the ground surface layers are decoupled from underlying firm material by the liquefied layer. When desludging occurs, surficial soil layers vibrate in a different mode than underlying or adjacent firm ground, resulting in lateral displacement. These actions may cause severe damage to buildings, pipelines, and other structures sited in the area. Typical ground failures of these types and consequent damage are shown in figures 1, 2, and 3.

During the 1906 earthquake, buildings, railroads, highways, and pipelines in San Mateo County were damaged by lateral spreading, debris flow, and ground settling. This type of damage occurred primarily in Colma valley (near Colma) and in the Salsola along San Francisco Bay between Redwood and Redwood City. In addition, cracks and settling occurred in some landslides and near several creeks. Several debris flows developed on hillsides near the Pacific Ocean and near Bruno Mountain (Youd and Hosse, 1978). Other ground failures may have occurred in San Mateo County but were not reported because they caused little damage or were in areas not specifically investigated. Because of the substantial amount of commercial and residential development in San Mateo County since 1906, particularly in areas with soil risks, potential for earthquake damage due to liquefaction and ground failure is now considerably greater. Ground failures triggered by liquefaction during future large earthquakes in San Mateo County are likely to be similar to those generated by the 1906 San Francisco earthquake. The most common failure were ground cracks, lateral spreads (on slopes less than 3°), and debris flows (on slopes greater than 3°). In the latter instance, the heaviest intensities with the steepest of the slope and the moisture content of the soil. Expected damage on slopes less than 3° includes minor cracking and minor subsidence; on slopes greater than 3° includes major cracking and minor subsidence; on slopes greater than 3° includes major cracking and minor subsidence; on slopes greater than 3° includes major cracking and minor subsidence.

The purpose of this map is to delineate areas where liquefiable sediment is likely to be beneath the surface. This information is useful to planners, engineers, building officials, and others responsible for mitigating seismic risk by identifying areas where a potential hazard may exist. Further study, zoning, or emergency preparation may be required in the more susceptible areas to ensure public safety and to minimize damage to present facilities and future development. Helley and others (1979). Conversely, the map also delineates areas where there is little potential for liquefaction and where local precautionary measures may not be necessary.

COMPLATION

Liquefaction does not occur at random, but is restricted to certain geologic and hydrologic environments. We used techniques developed by Youd and Perkins (1978) as a basis for delineating these environments and for compiling the liquefaction susceptibility map. In addition, we estimated the probability of liquefiable materials occurring beneath any point in the map unit and we marked the specific locations where borocole data compiled by Nichols and Wright (1977) indicate the presence or absence of liquefaction. The map was compiled using the following factors that control liquefaction susceptibility are: (1) lithology (the presence of sand or silt layers, the presence of loosely packed materials), and (3) depth to free ground water (liquefaction occurs only in saturated or nearly saturated materials). For each map unit, we estimated the probability that each of these three factors is favorable for the development of liquefaction. We then calculated the probability of liquefaction induced by bay mud deposits, we estimated the probability of sand or silt layers from that percentage of borocole data that penetrated these materials (Nichols and Wright, 1977). Nine percent of the borocole revealed sand or silt within the bay mud, mostly concentrated along active or abandoned channels, and 35 percent showed that sand and silt layers lie immediately beneath the mud. We estimated the probability of finding clay-free immediately beneath the mud. We estimated the probability of finding clay-free immediately beneath the mud. We estimated the probability of finding clay-free immediately beneath the mud. We estimated the probability of finding clay-free immediately beneath the mud.

We used results from standard penetration tests to estimate the probability, listed in Table 1, that clay-free sands or silts in a given geologic unit are loose enough to liquefy during a strong earthquake. The criteria used to make this assessment, and an analysis for sand and silt layers in the Santa Cruz Mountains and beneath terrace, river valleys, and beneath west of the mountains as follows: Holocene beach and dune deposits, 100 percent probability of occurrence; clay-free sand or silt, Holocene river channel and flood-plain deposits, 50 percent probability; and Pleistocene beach and dune deposits, 10 to 50 percent probability. The geologic maps by Brabb and Pampunyan (1983) and Lajoie and others (1978) give locations of these geologic units. We used results from standard penetration tests to estimate the probability, listed in Table 1, that clay-free sands or silts in a given geologic unit are loose enough to liquefy during a strong earthquake. The criteria used to make this assessment, and an analysis for sand and silt layers in the Santa Cruz Mountains and beneath terrace, river valleys, and beneath west of the mountains as follows: Holocene beach and dune deposits, 100 percent probability of occurrence; clay-free sand or silt, Holocene river channel and flood-plain deposits, 50 percent probability; and Pleistocene beach and dune deposits, 10 to 50 percent probability. The geologic maps by Brabb and Pampunyan (1983) and Lajoie and others (1978) give locations of these geologic units.

Between San Francisco Bay and the Santa Cruz Mountains, a 100 ft water-table map of Webster (1973) to estimate probabilities that subsurface sand and silt layers are saturated or nearly saturated (Table 1). We digitized the 100 ft and 6 in (20 ft) ground-water level contours from Webster's map and assumed that all sediment between the bay and the 100 ft (10 ft) level is permanently (100 percent) saturated. In the zone between 3 in and 6 in (10 ft) and 20 ft depth contours we assumed that all sediment below the ground-water surface is permanently saturated and that the sediment above is saturated during wet seasons, about 20 percent of the time. The Holocene sediment in this area (landward of the 3 in (10 ft) ground-water contour) is generally less than 3 in (10 ft) thick (Youd and others, 1978) and thus is above the ground-water level except during and immediately following wet seasons, about 20 percent of the time. Where the ground water is greater than 6 in (20 ft) deep, we assume that liquefiable sediment beneath that to gently sloping ground is seasonally saturated about 10 percent of the time, and beneath steeper slopes, about 5 percent of the time.

In the Santa Cruz Mountains and areas to the west where the depth to shallow ground water has not been mapped, we assumed: (1) that the depth to ground water generally is less than 3 in (10 ft) in the Holocene channel and flood-plain deposits, which form narrow bands along streams, and that these deposits are saturated 100 percent of the time; (2) that about 50 percent of the Holocene beach and dune deposits are permanently saturated; (3) that the Holocene colluvial deposits which generally lie on relatively steep slopes, are saturated about 5 percent of the time; and (4) that the Pleistocene fan and terrace deposits and the Colma Formation are saturated about 5 percent of the time.

Areas most likely to be saturated by materials susceptible to liquefaction are landslides along San Francisco Bay, which are underlain by bay mud or coarser (lower) Holocene alluvial fan deposits, channel and flood-plain deposits along streams, and beach and dune deposits along the Pacific Ocean. For the landslides along San Francisco Bay, susceptible sand and silt layers are not randomly scattered, but generally lie in buried stream channels, most of which are not detectable from surface topographic maps. Subsurface investigations therefore are required to verify the presence or absence of these materials. In recent years, many landslides have been drilled near the bay during engineering investigations. The locations of most borocole drilled before 1977 in areas underlain by bay mud, were reported by Nichols and Wright (1977). These study indicated these holes which encountered sand or silt layers above, within, or below the bay mud. This information is incorporated onto this susceptibility map by marking these 1-hectare grid cells in which one or more bore holes were drilled with one of these symbols. These symbols indicate: (1) that one or more sand or silt layers greater than 0.5 in (1.4 ft) thick lie above or within the bay mud and high susceptibility; (2) sand or silt layers were not found within but immediately below the bay mud (moderate susceptibility); and (3) no sand or silt layers were encountered (low susceptibility).

Areas within or near cells showing a high susceptibility have a high probability of containing liquefiable sediment. Conversely, areas near or surrounded by cells in which borocole data indicate low susceptibility have a low probability of containing liquefiable sediment. Even in these apparent low-susceptibility areas, however, some caution should be exercised because the generally wide spacing of borocoles has low subsurface resolution in areas of sand and silt or clay channel.

QUALIFICATIONS AND LIMITATIONS

The evaluation and compilation procedures used in this susceptibility map impose several qualifications and limitations on its use.

1. Because the map is regional in scope and borocole data shown are generalized to area averages, the map cannot be used to determine the actual presence or absence of liquefiable soils beneath any specific locality. Site-specific geotechnical investigations are required to make that assessment.
2. Map boundaries between areas are accurate only to plus or minus 50 m, and mapped areas that do not cover the base of the map have been eliminated. Therefore, the boundaries cannot be taken as absolute demarcations, and local investigation is required in the corner of the map.
3. The susceptibility categories assigned to each map unit are an average rating for the entire unit. Local variations from these averages are to be expected, particularly in units with high susceptibility. Subsurface investigations are required to determine actual liquefaction susceptibility at an individual site.
4. Ground-water levels in much of the county rise and fall with the seasonal rainfall. Susceptibility, which is a function of soil saturation or ground-water level, also varies seasonally, and may also vary with long-term climatic changes. For example, the 1906 San Francisco earthquake occurred near the end of a very wet season when groundwater levels and susceptibility were relatively high. More soils probably liquefied during that event than would have under drier conditions that normally occur during summer and fall seasons in the bay area. In particular, several debris flows that occurred in the hills near Half Moon Bay (Youd and Hosse, 1978, p. 99-102) might not have occurred in a dry season.
5. Our map shows susceptibility to liquefaction rather than susceptibility to ground failure, which is the actual damage-producing consequence of liquefaction. Under some conditions, liquefaction can occur without generating ground failure. Consequently, the probability of ground failure during an earthquake is somewhat less than the probability of liquefaction. Factors that control ground failure, in addition to the control of liquefaction, include soil type, extent, and depth of the liquefied layer, rate of drainage, ground slope, and nature of the soil. San Francisco Bay, which is a key factor controlling the occurrence of ground failure, a liquefaction susceptibility map serves as a general guide to ground failure susceptibility.
6. For many map units, the probability of encountering soils susceptible to liquefaction falls within the lower part of the range for the assigned susceptibility category. For example, the high-susceptibility range is calculated for the San Francisco Bay region, California—their geology and engineering properties, and their importance to comprehensive planning (U.S. Geological Survey Professional Paper 943, 88 p.).

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