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MAPS SHOWING ELEVATION OF BEDROCK AND IMPLICATIONS FOR DESIGN OF ENGINEERED STRUCTURES TO WITHSTAND EARTHQUAKE SHAKING IN SAN MATEO COUNTY, CALIFORNIA

by

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[1]Menlo Park, California

Table of Contents

List of Illustrations

List of Tables

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Introduction

Depth to bedrock has been established by the Applied Technology Council (1978) and the Uniform Building Code (1985, 1988) as one of the important parameters for determining the design and construction of earthquake-resistant structures. Depth to bedrock and the thickness of alluvial material around San Francisco Bay are also important in determining the occurrence and yield of ground water, the likelihood of compaction, liquefaction and subsidence of the ground, and the feasibility and cost of installing tanks, foundations, and other structures in the ground. The purpose of this report, therefore, is to provide a preliminary estimate of the elevation of bedrock throughout the county, and to determine the implications of this information when the Uniform Building Code (UBC) is used to design earthquake-resistant structures. The information is intended for use by engineers and other professionals concerned about engineered structures, which include dwellings, offices and commercial buildings as well as industrial structures such as storage tanks, refineries, and power plants.

Previous Work

Investigation of the character of materials beneath the ground surface around San Francisco Bay began at least 100 years ago when soundings and boreholes were used to plan a seawall for the San Francisco waterfront (American Society of Civil Engineers, 1932). Maps at 1:31,680 scale showing depth to bedrock in the San Francisco North and South Quadrangles, including the northern part of San Mateo County, were prepared by Schlocker (1961) and Bonilla (1964); their contours are reproduced by Kahle and Goldman (1969, pl. 2). Carlson and McCulloch (1970) show depth to bedrock at 1:24,000 scale in central San Francisco Bay but their map does not extend to San Mateo County. Hazelwood (1976) used seismic refraction surveys and 20 well logs to prepare a depth to bedrock map at 1:62,500 scale that includes the eastern part of San Mateo County. Atwater and others (1977) have two sections across San Francisco Bay that include part of San Mateo County, but nearly all of the data are for surficial deposits, not bedrock. McDonald and others (1978) used 4,000 wells to prepare a map at 1:125,000 scale showing the thickness of young bay mud in the southern San Francisco Bay area, including San Mateo County; their map provides a minimum depth to bedrock that was taken into account in the preparation of our map. Carle and others (1990) prepared a map showing depth to bedrock in the flatland areas of Menlo Park and Atherton; their contours are reproduced on our map.

Geography

San Mateo County is bounded by San Francisco City and County to the north, the counties of Santa Clara and Santa Cruz to the south, San Francisco

Bay to the east and the Pacific Ocean to the west. A ridge of mountains, which are the northern extension of the Santa Cruz Mountains, extends in a northwesterly direction from Portola Valley and Woodside on the south to Daly City on the north. The San Andreas fault is in a depression in these mountains, passing through Crystal Springs Reservoir and San Andreas Lake. The fault extends into the Pacific Ocean at Mussel Rock in Daly City.

San Bruno Mountain in the northeastern portion of the county rises to a maximum elevation of 1,314 feet above sea level. The Santa Cruz Mountains have high points of 1,132 feet above sea level west of Millbrae and 2,572 feet above sea level at Borel Hill at the county line south of Portola Valley.

The principal urbanized portion of San Mateo County extends along the edge of San Francisco Bay, from South San Francisco to Redwood City and East Palo Alto. This portion of San Mateo County is referred to as "the Peninsula" and is predominantly residential. The individual towns have merged into a continuous mix of residential, commercial and industrial complexes, from San Francisco to San Jose, extending from the uplands of the hills to the shore of San Francisco Bay. The west side of the County fronts on the Pacific Ocean and is referred to as "coast-side." The level valleys and terraces of the coast are mostly agricultural, with residential areas extending north from the town of Half Moon Bay.

Geology

The geology of San Mateo County is complex, with more than 50 geologic units extensively folded and faulted (Brabb and Pampeyan, 1983; Brabb and Olson, 1986). The area southwest of the Pilarcitos fault consists mainly of granitic rocks of Mesozoic age overlain by several thousand feet of Cretaceous and Tertiary sedimentary and volcanic rocks. Northeast of the Pilarcitos fault, the rocks are mainly sandstone, shale, and greenstone of the Franciscan assemblage (Jurassic and Cretaceous). Sedimentary and volcanic rocks of Tertiary age overlie the Franciscan. Overlying these Tertiary rocks and the Franciscan assemblage are the Santa Clara Formation (early Pleistocene and late Pliocene), a nonmarine, poorly indurated conglomerate, sandstone and mudstone; the Merced Formation (early Pleistocene and late Pliocene), a marine, poorly indurated sandstone, siltstone and claystone; and the Colma Formation (Pleistocene), a poorly-consolidated nearshore sand with subordinate amounts of silt and clay.

The Santa Clara, Merced, and Colma Formations are generally considered by geologists as bedrock, and in a few places the Santa Clara and Merced Formations, at least, are semi-consolidated, folded and faulted rocks. At most localities, however, these formations are poorly-consolidated clay, silt, sand and gravel that cannot be distinguished in wells from overlying surficial deposits. Moreover, Fumal (1978) indicates that the shear wave velocities of the formations are similar to those of most of the surficial deposits. Accordingly, we define bedrock in this report as geologic units below and older than the Santa Clara, Merced, and Colma Formations.

Some of the sedimentary rocks of Tertiary age are also difficult to recognize in well logs, especially if the formation is weathered. The Franciscan assemblage, in contrast, is generally so well indurated and distinctive lithologically that it is easily separated from the overlying sediments and sedimentary rocks.

Unconsolidated clay, silt, sand, and gravel of Quaternary age underlie most of the flatland areas around San Francisco Bay and the Pacific Ocean (Lajoie and others, 1974; Helley and others, 1979; Atwater and others, 1977). These surficial deposits represent estuarine, marsh, alluvial-fan, channel, flood-basin, levee, dune, and beach environments.

The presence or absence of soft clay is another factor used by the Applied Technology Council (1978) and the Uniform Building Code (1985, 1988) in determining the design of structures (Joyner, 1982). In San Mateo County, soft clay is most prevalent in Bay mud, but it can also occur in other surficial deposits. Because many areas of Bay mud in San Mateo County are covered by artificial fill, the best guide to the distribution of Bay mud is the historic landward boundary of the marshlands, as shown by Nichols and Wright (1971). Their information has been added to this map. The thickness of soft clay as represented by Bay mud, another factor in seismic design, can be obtained from the map by MacDonald and others (1978).

Pampeyan (1981b) has pointed out that part of San Pedro Valley and an area in Pacifica just north of Mori Point were shown as lakes and marshy areas on an 1853 U.S. Coast and Geodetic Survey Map (no. 395). These areas are now largely covered by fill. Soft clay similar to Bay mud could be present in these areas beneath the fill and in other places along the Pacific Coast of San Mateo County where streams have emptied into the ocean, but no information has been found to confirm this idea. For this map, we have considered the material in those areas to be similar to the sand, silt, gravel, and clay of Quaternary age that underlies much of the area from Daly City to Menlo Park.

Procedures

Information for the map was derived largely from confidential water well reports at the California Department of Water Resources archives in Sacramento, from U.S. Geological Survey water records and unpublished data, from data provided by the California Department of Transportation (CALTRANS), and from logs of boreholes to bedrock furnished by engineering consultants and geotechnical engineering firms. These firms are recognized in the acknowledgements.

A few records were obtained from reports by Wood (1975), Hogenson and others (1967), Sokol (1964), Poland (1970), and the California Water Commission (1955). The map by Hazelwood (1976) derived from the interpretation of seismic refraction profiles was used to determine the elevation of the bedrock surface in the area of salt evaporators northeast of Bayshore Freeway and in San Francisco Bay.

A total of 215 boreholes to bedrock and 58 boreholes not extending to bedrock were used to prepare the contours for this map. The wells were plotted on 7.5' U.S. Geological Survey topographic maps, and the elevation of each well was estimated if not provided on a log. The contours were drawn by hand on the topographic maps and were then reduced photographically to publication scale. The map by Bonilla (1964) was used for the San Francisco South 7.5' quadrangle except for small areas near San Francisco Airport where his data were supplemented by unpublished reports from consulting firms.

Consideration of surficial deposits less than 50 feet thick overlying bedrock on hillsides is a substantial problem not solved completely by this map. Slope debris and ravine fill in the sense of Schlocker and others (1958) were not mapped anywhere in the County if the deposit is thinner than 5 ft. Slope debris and ravine fill thicker than 5 feet were mapped by Bonilla in the San Francisco South and Hunters Point quadrangles (1971 and verbal comm., 1989), and by Pampeyan in the Palo Alto, San Mateo, and Montara Mountains quadrangles (1970, 1981a, 1981b, and verbal comm., 1989), but have not been mapped consistently in the rest of the County. Nevertheless, the quadrangles mentioned cover most of the urbanized part of the County located on hillside areas with the exception of communities in the Woodside quadrangle, including parts of San Carlos, Redwood City, and Woodside.

Surficial deposits thicker than 50 feet have been contoured around the margins of San Francisco Bay and the Pacific Ocean, except between Lobitos and Purisima Creeks in the west-central part of the County, where marine terrace deposits are considered by Lajoie (1986 and verbal comm., 1988) to be about 60 ft. thick. Lajoie indicated that the wave-cut platform on bedrock beneath the terrace deposits has been deformed by movement on the San Gregorio fault, but we do not share his confidence in distinguishing the poorly-consolidated bedrock from the overlying terrace deposits. However, the wells used by Lajoie to construct a structure contour map have been added to our map.

Outcrops of the Santa Clara Formation along the San Andreas fault zone between Crystal Springs Reservoir and Portola Valley are another special problem. No wells have been located penetrating this formation in that area. Several outcrops of older rock within the outcrop area of Santa Clara Formation have been mapped by Brabb and Pampeyan (1983), indicating that the Santa Clara is probably quite thin, but no other thickness data are available.

Interpretation

East of the San Andreas fault zone

Bedrock exposed in communities from Woodside north to Millbrae generally slopes downward beneath the sediments around San Francisco Bay to depths of 700 feet and more. Erosional remnants of the Franciscan assemblage poke up through the sediment cover at Coyote Point and several other localities. Other variations in the subsurface contours may reflect erosional processes, tectonism, errors in the data, or errors in interpreting the data (Brabb and others, 1990).

The area between the San Andreas and San Bruno faults has at least 5,000 feet of sand, silt and clay of the Merced Formation. The great thickness of these sedimments and their inferred northeast dip in close juxtaposition to the Franciscan assemblage at San Bruno Mountain led Lawson (1895) to invent the San Bruno fault to explain the relationship. As pointed out by Bonilla (1959), the dip is not consistently northeast as Lawson supposed, and his evidence for the San Bruno fault, at least with the magnitude of movement proposed by Lawson, is not convincing. Nevertheless, we have retained the San Bruno fault and the interpretation of the elevation of bedrock by Bonilla (1964) because no new data are available in that area.

The Serra fault zone, a series of thrusts dipping southwest (Brabb and

Olson, 1986), further complicates interpretation of the bedrock surface between San Bruno Mountain and the San Andreas fault zone. We have followed the interpretation by Bonilla (1964) with minor modifications.

West of the San Andreas fault zone

Bedrock along the coast between the San Andreas fault zone and Sharp Park is interpreted by Bonilla (1964) to dip into the ocean at about the same moderate slope as the hills rising above Pacifica and other communities. This interpretation is supported by two wells on his map that show bedrock at an elevation of about -200 feet near California Highway 1. We have extended his contour lines south to the Pilarcitos fault using the same scheme. South of the Pilarcitos fault, however, with the exception of the steep cliffs at and near Devils Slide, the hills have been flattened by wave erosion, leaving a bedrock surface or several surfaces dipping gently seaward and mantled by thin terrace and alluvial fan deposits. Several creeks, such as San Vincente, Purisima and Lobitos Creeks, have bedrock bottoms extending from the hills and mountains inland across the marine terraces to the beach. Other creeks, such as Pescadero, Pomponio, San Gregorio, and Tunitas Creeks, have bedrock exposed along much of their course. As mentioned previously, the bedrock and the overlying terrace deposits in the Half Moon Bay area, at least, have been folded and faulted by drag along the San Gregorio fault zone (Lajoie, 1986), allowing as much as 60 feet of terrace deposits to be preserved, but at most localities, the terraces and other surficial deposits are less than 25 feet thick. The thinness of these surficial deposits along the coast, in contrast to their great thickness east of the San Andreas fault zone, has adversely impacted the development of a stable water supply.

Implications for Users of the Uniform Building Code

The design of buildings and engineered structures in communities that have adopted the Uniform Building Code (UBC) of 1985 and 1988 must take into account the character of earth materials underlying the site. The design lateral forces to be used depend on the site characteristics and the construction materials used as well as the stiffness or flexability which determines the fundamental period of vibration. Structures built on sites located on soft clay may require much different bracing and foundation systems from those on bedrock. The rules and regulations for the seismic design of structures are set forth in the Uniform Building Code (UBC) (1985, 1988), in Chapter 23, Earthquake Regulations, Section 2312. These rules have been primarily developed and formulated by the Seismology Committee of the Structural Engineers Association of California. The rules are periodically revised and upgraded as new information develops from study of results of past earthquakes on various sites and structures. These regulations are formulated in a document referred to as the "Blue Book", Recommended Lateral Force Requirements and Commentary of the Seismology Committee of the Structural Engineers Association of California. The work of this committee is augmented by research done by the Applied Technology Council (ATC) as a multidiscipline group of highly qualified engineers, seismologists and geologists working with research grants. They have developed the scientific basis for site-structure interaction which is being discussed here.

The objective and design philosophy of seismic design have been stated in the Commentary of the "Blue Book" (p.1-C, 1975) as follows:

"Structures designed in conformance with these recommendations should, in general, be able to:

1. Resist minor level of earthquake ground motion without damage;

2. Resist moderate levels of earthquake ground motion without structural damage but possibly experience some non-structural damage.

3. Resist major levels of earthquake ground motion having an intensity equal to the strongest either experienced or forecast for the building site, without collapse, but possibly with some structural as well as non-structural damage.

"It is expected that structural damage, even in a major earthquake, will be limited to a repairable level for structures that meet these provisions. The level of damage depends upon a number of factors, including the configuration, type of lateral force resisting system, materials selected for the structure and care taken in construction.

"Conformance to these Recommendations does not constitute any kind of quarantee or assurance that significant structural damage will not occur in the event of a maximum level of earthquake ground motion. In order to fulfill the life safety objective of these recommendations, there are requirements that provide for collapse resistance in the event of extreme structural deformations; provisions protect the vertical load carrying system from fracture or buckling at these extreme states. While damage to the primary structural system may be either negligible or significant, repairable or virturally irreparable, it is reasonable to expect that a well-planned and constructed structure will not collapse in a major earthquake. The protection of life is reasonably provided, but not with complete assurance."

Different types of earth materials and the site factors needed to determine the design of structures are shown on Table 1 (Table 23-J in UBC 1988):

Table 1

SITE COEFFICIENTS[1]

Type	Description	S Factor
S_1	A soil profile with either: (a) A rock-like material characterized by a shear-wave velocity greater than 2,500 feet per second or by other suitable means of classification, or (b) Stiff or dense soil condition where the soil depth is less than 200 feet.	1.0
S_2	A soil profile with dense or stiff soil conditions, where the soil depth exceeds 200 feet.	1.2
S_3	A soil profile 40 feet or more in depth and containing more than 20 feet of soft to medium stiff clay but not more than 40 feet of soft clay.	1.5
S_4	A soil profile containing more than 40 feet of soft clay.	2.0

[1]The site factor shall be established from properly substantiated geotechnical data. In locations where the soil properties are not known in sufficient detail to determine the soil profile type, soil profile S_3 shall be used. Soil profile S_4 need not be assumed unless the building official determines that soil profile S_4 may be present at the site, or in the event that soil profile S_4 is established by geotechnical data.

Geologic materials in San Mateo County are not generally homogeneous and are not easily correlated with the site coefficients on Table 1. Variations in the engineering and physical character of the geologic map units are shown on a chart by Wentworth and others (1985) and Lajoie and others (1974); variations in the shear-wave velocity are discussed by Fumal (1978) and Wilson and others (1978). The effects of local geology on ground motion are described by Borcherdt (1970) and Borcherdt and Gibbs (1976). Steinbrugge (1969) has discussed the seismic risk to buildings and structures on filled land in the San Francisco Bay area.

Bedrock units beneath the Santa Clara, Colma, and Merced Formations have shear-wave velocities that range from 470 m (1,540 ft) to 1,680 m (5,510 ft) per second, depending on the degree of weathering, hardness of the rock, and fracture spacing. They generally range from 760 m (2,500 ft) to 1460 m (4,800 ft) per second. The Merced, Colma and Santa Clara Formations have velocities as low as 250 m (820 ft) and as high as 1,100 m (3,608 ft) per second, but at most localities the shear-wave velocities are comparable to many of the surficial deposits of late Pleistocene and Holocene Ages (Fumal, 1978, Table 3), that is, 300 m (984 ft.) to 400 m (1,312 ft.) per second. Unconsolidated surficial deposits, except for Bay mud, have shear-wave velocities as low as 150 m (492 ft) and as high as 500 m (1,640 ft) per second, depending on soil texture and depth below the surface (Fumal, 1978, p. 25 and Table 4). Bay mud velocities are as low as 54 m (177 ft) and as high as 114 m (374 ft) per second.

Soil profile S_4 on Table 1 is interpreted in this report to indicate an area underlain by Bay mud at least 12 m (40 ft) thick. Soil profile S_3 is an area underlain by Bay mud 6 m (20 ft) to 12 m (40 ft) thick, plus surficial deposits of Pleistocene and/or Holocene Age. S_3 comprises a mixture of Bay mud (Qm) and younger alluvial fan deposits (Qyf and Qyfo), basin deposits (Qb), colluvium (Qcl), sand dune and beach deposits (Qs), alluvium (Qal), older alluvial fan and stream terrace deposits (Qof), older basin and alluvial fan deposits (Qob), and marine terrace deposits (Qmt) as used by Brabb and Pampeyan (1983). Soil profile S_2 is an area underlain by at least 60 m (200 ft) of surficial deposits (but not Bay mud) of Pleistocene and/or Holocene Age listed for S_3, and/or the Santa Clara (QTs), Merced (QTm) or Colma (Qc) Formations. Soil profile S_1 is an area underlain by any of the bedrock units beneath the Colma, Santa Clara and Merced Formations, or an area underlain by these formations or any surficial unit other than Bay mud (Qm) where the thickness is less than 60 m (200 ft).

Artificial fill (Qaf) is a special problem that this map does not solve. Some artificial fill, especially Bay mud that was dredged and used to construct levees, might have little strength and could require a site coefficient for soil profile S_4. Other artificial fill could have much stronger physical properties similar to the Merced, Colma and Santa Clara Formations. Fumal (1978, Table 4) indicates that the artificial fill he sampled has a shear wave velocity from 200 m (655 ft) to 360 m (1,180 ft) per second, which is higher than the Bay mud and comparable to most of the surficial units.

The map indicates that in the bayland areas of Daly City through Burlingame, San Mateo, Redwood City, Atherton and Menlo Park, more substantial bracing may be needed for multistory buildings. In areas built on filled ground and underlain by Bay mud from Brisbane and South San Francisco to Redwood City, East Palo Alto and in a small area of Pacifica, considerably more bracing and special foundation considerations may be needed. Fortunately, soil profiles S_3 and S_4 are generally restricted to small areas beyond the historic landward boundary of the marshlands, as shown by Nichols and Wright (1971). <u>However, more specific examinations should be carried out by a qualified person to determine whether any site for a multistory building has geologic materials that will require special foundations and special seismic bracing.</u>

The boundaries of the site coefficient areas are not extended into San Francisco Bay or the Pacific Ocean because the type of structures built there do not come under the UBC regulations.

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REFERENCES CITED

American Society of Civil Engineers (ASCE), San Francisco Section, Subsoil Committee, 1932, Subsidence and the foundation problem in San Francisco.

Applied Technology Council, 1978, Tentative provisions for the development of seismic regulations for buildings: National Bureau of Standards, Special Publication 510, 505 p. (ATC-3).

Atwater, B.F., Hedel, C.W. and Helley, E.J., 1977, Late Quaternary depositional history, Holocene sea-level changes and vertical crustal movement, southern San Francisco Bay, California: U.S. Geological Survey Professional Paper 1014, 15 p.

Bonilla, M.G., 1964, Bedrock-surface map of the San Francisco South Quadrangle, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-334, scale 1:31,680.

-----, 1959, Geologic observations in the epicentral area of the San Francisco earthquake of March 22, 1957: California Division of Mines and Geology Special Report 57, p. 25-38.

-----, 1971, Preliminary geologic map of the San Francisco South Quadrangle and part of the Hunters Point Quadrangle, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-311, scale 1:24,000.

Borcherdt, R.D., 1970, Effects of local geology on ground motion near San Francisco Bay: Seismological Society of America Bulletin, v. 60, no. 1, p. 29-61.

Borcherdt, R.D., and Gibbs, J.F., 1976, Effects of local geological conditions in the San Francisco Bay region on ground motions and the intensities of the 1906 earthquake: Seismological Society of America Bulletin, v. 66, no. 2, p. 467-500.

Brabb, E.E. and Pampeyan, E.H., 1983, Geologic map of San Mateo County, California: U.S. Geological Survey Miscellaneous Investigation Series Map I-1257-A, scale 1:62,500.

Brabb, E.E., and Olson, J.A., 1986, Map showing faults and earthquake epicenters in San Mateo County, California: U.S. Geological Survey Miscellaneous Investigations Map I-1257-F, scale 1:62,500.

Brabb, E.E., Carle, S.F., and Pampeyan, E.H., 1990, Map showing elevation of the bedrock surface beneath the flatlands of Menlo Park, Atherton, and adjoining areas, California, <u>in</u> Oliver, H.O., ed., Preliminary ground water quality data and the extent of the ground water basin from drill hole, seismic and gravity data in the Palo Alto 7.5' quadrangle, California: U.S. Geological Survey Open File Report 90-74, scale 1:24,000.

California Water Commission, 1955, Santa Clara Valley investigation:

California State Water Resources Board Bull. 7, 154 p.
Carle, S.F., Langenheim, V.E., Brabb, E.E., and Pampeyan, E.H., 1990, Geophysical interpretation of bedrock surface beneath the flatland areas of Menlo Park, Atherton, and adjoining areas, California, in Oliver, H.O., editor, Preliminary ground water quality data and the extent of the ground water basin from drill hole, seismic and gravity data in the Palo Alto 7.5' quadrangle, California: U.S. Geological Survey Open File Report 90-74, scale 1:24,000.
Carlson, P.R., and McCulloch, D.S., 1970, Bedrock-surface map of central San Francisco Bay, California: U.S. Geological Survey Open File Report, scale 1:24,000.
Fumal, T.E., 1978, Correlations between seismic wave velocities and physical properties of near-surface geologic materials in the southern San Francisco Bay region, California: U.S. Geological Survey Open File Report 78-1067, 114 p.
Hazelwood, R.M., 1976, Contour map and interpretive cross sections showing depth and configuration of bedrock surface, south San Francisco Bay region, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-796, scale 1:62,500.
Helley, E.J., Lajoie, K.R., Spangle, W.E., and Blair, M.L., 1979, Flatland deposits of the San Francisco Bay Area Region, California - Their geology and engineering properties and their importance to comprehensive planning: U.S. Geological Survey Professional Paper 943.
Hogenson, G.M., Wahl, K.D., and Brennan, Robert, 1967, Effects of proposed salinity-control barriers in San Francisco Bay, California, upon ground-water resources: U.S. Geological Survey Open File Report.
Joyner, W.B., 1982, Map showing the 200-foot thickness contour of surficial deposits and the landward limit of bay mud deposits of San Francisco, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1376, scale 1:24,000.
Kahle, J.E., and Goldman, H.B., 1966, Contours on top of the bedrock underlying San Francisco Bay, in geologic and engineering aspects of San Francisco bay fill, scale approximately 1:80,400, Goldman, H.B., ed.: California Division of Mines and Geology, 1969, Special Report 97.
Lajoie, K.R., Helley, E.J., Nichols, D.R., and Burke, D.B., 1974, Geologic map of unconsolidated and moderately consolidated deposits of San Mateo County, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-575, scale 1:62,500.
Lajoie, K.L., 1986, Coastal tectonics, in Active Tectonics: National Academy Press, p. 95-124.
Lawson, A.C., 1895, Sketch of the geology of the San Francisco peninsula: Extract from the Fifteenth Annual Report of the U.S. Geological Survey, 1893-94, Washington, Government Printing Office, p. 401-476.
MacDonald, S.D., Nichols, D.R., Wright, N.A., and Atwater, B.F., 1978, Thickness of young bay mud, southern San Francisco Bay, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-976, scale 1:125,000.
Nichols, D.R., and Wright, N.A., 1971, Preliminary map of historic margins of marshlands, San Francisco Bay Area, California: U.S. Geological Survey Open File Map, scale 1:125,000.
Pampeyan, E.H., 1970, Geologic map of Palo Alto, 7.5' quadrangle, San Mateo and Santa Clara Counties, California: U.S. Geological Survey Open File Map, sheet 1 of 2, scale 1:24,000.
-----, 1981a, Geologic map, geology and former shoreline features of the San Mateo 7.5 minute quadrangle, San Mateo County, California: U.S.

Geological Survey Open File Report 81-839, sheet 1 of 2, scale 1:24,000.
-----, 1981b, Geologic map of the Montara Mountain Quadrangle, San Mateo County, California: U.S. Geological Survey Open File Report 81-451, sheet 1 of 2, scale 1:24,000.
Poland, J.F., 1970, Ground water conditions in the Redwood City area, California, with particular reference to water supply for the Pacific Portland Cement Company: U.S. Geological Survey Open File Report.
Schlocker, Julius, 1961, Bedrock-surface map of the San Francisco North Quadrangle, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-334, scale 1:31,680.
Schlocker, J., Bonilla, M.G., and Radbruch, D.H., 1958, Geology of the San Francisco North Quadrangle, California: U.S. Geological Survey Miscellaneous Geologic Investigation Map I-272.
Seismology Committee of the Structural Engineers Association of California, 1988, Recommended Lateral Force Requirements and Commentary.
Sokol, Daniel, 1964, The hydrogeology of the San Francisquito Creek basin, San Mateo and Santa Clara Counties, California: Stanford University unpublished PhD thesis, 238 p.
Steinbrugge, Karl V., 1969, Seismic risk to buildings and structures on filled lands in San Francisco Bay, in Geologic and engineering aspects of San Francisco Bay fill: California Div. Mines and Geology Special Report 97, p. 101-115
Uniform Building Code (UBC), 1985 and 1988 editions, The International Conference of Building Officials, Earthquake Regulations, Sec. 2312.
Wentworth, C.M., Ellen, Stephen, Frizzell, V.A., Jr., and Schlocker, Julius, 1985, Map of hillside materials and description of their engineering character, San Mateo County, California: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-1257D, scale 1:62,500.
Wilson, R.C., Warrick, R.E., and Bennett, M.J., 1978, Seismic velocities of San Francisco bayshore sediments: Proc. American Society of Civil Engineers Specialty Conference on Earthquake Engineering and Soil Dynamics, Pasadena, California, June 19-21, 1978, p. 1007-1023.
Wood, Perry, 1975, Sources of emergency water supplies in the San Mateo County, California: U.S. Geological Survey Open File Report 75-43, 25 p., map scale 1:125,000.