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MISCELLANEOUS FIELD STUDIES
MF 480 (SHEET 1 OF 2)

# MAPS SHOWING AREAS OF POTENTIAL INUNDATION BY TSUNAMIS IN THE SAN FRANCISCO BAY REGION, CALIFORNIA

by

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## INTRODUCTION

Areas in the San Francisco Bay coastal region that might be inundated by tsunamis with a runup[1/] of 20 feet are shown on the maps on sheets 1 and 2. The maps show places where highway traffic may be disrupted as a result of inundation or damage caused by a tsunami and may be used to suggest possible routes for detours. Determination of local areas where erosion, deposition, or damage may cause serious problems is beyond the scope of this report. The delineations in this report are generalized, but may be used as a guide for further detailed study prior to development of structures, such as a nuclear reactor, where safety is critically important.

Tsunamis, often incorrectly called tidal waves, are long period waves usually caused by underwater seismic disturbances, volcanic eruptions, or submerged landslides. Only 1 or 2 feet high as they speed across the Pacific Ocean at about 450 miles per hour, the tsunami waves may increase in height to tens of feet as they approach a coast. Runups along the shore of more than 50 feet by tsunamis are not uncommon, and destruction by such waves may reach catastrophic proportions. For example, a tsunami that struck Japan in 1896 produced a runup of 100 feet, killed 27,122 people, and destroyed 100,617 houses (Leet, 1948, p. 169). In 1964 a tsunami that was associated with the Alaska earthquake produced a runup of about 20 feet and caused eight deaths and $11,000,000 damage at Crescent City, Calif. (Magoon, 1966). In 1960, a tsunami caused by the Chilean earthquake, produced some fairly high runups in the San Francisco Bay region, especially at Half Moon Bay, although not much damage was done.

## INUNDATION ALONG THE PACIFIC COAST

Coastal areas in the San Francisco Bay region that may be inundated by tsunamis with a coastal runup of 20 feet are shown on sheets 1 and 2. It must be stressed that the 20-foot runup used in the report is an estimate that was selected because it approximates the runup caused by the tsunami that struck at Crescent City in 1964. Under proper conditions tsunamis may produce much higher runups. For the purposes of this report, however, it was assumed that a tsunami could produce a potential 20-foot runup at any coastal area, and that its runup, because of friction, would decrease by 1 percent with distance traveled over the land (modified from Cox, 1961). In other words, the runup of the wave would decrease by 1 foot for every 100 feet of land over which the wave passed. A single tsunami capable of producing a 20-foot runup may not inundate all of the coastal areas shown on the maps. The depth of inundation is not shown on the maps, and the indicated areas of potential inundation should not be considered flooded to a depth of 20 feet.

The method outlined above is an oversimplification of a little understood phenomenon. Factors affecting tsunamis and their runup, such as the area of generation and its distance from California, coastal orientation with respect to direction of tsunami origin, the submarine topography, and reinforcement due to resonance, are not considered.

## INUNDATION IN SAN FRANCISCO BAY

The areas in San Francisco Bay shown on sheet 1 to be subject to tsunami inundation were based on a tsunami runup of 20 feet at the Golden Gate. The tsunami runup was assumed to decrease in elevation inland from the Golden Gate in the same proportion as the wave attenuation that was observed for the 1960 and 1964 tsunamis (fig. 1). Figure 1 indicates that the runup from a tsunami would be decreased by half within a distance of 10 miles from the Golden Gate, and that the runup would be negligible by the time the wave reached Alviso and the Carquinez Strait. The areas affected by the runup shown on the map was reduced accordingly. Areas most likely to be inundated are marshlands, tidal flats, and former bay margin lands that are now artificially filled but are still at or below sea level.

1/Runup is defined as the rush of water up a structure on the breaking of a wave. The amount of runup is the vertical height above still water level that the rush of water reaches (Howell, 1957, p. 252).

## LIKELIHOOD OF OCCURRENCE

Wiegel (1970, p. 296) reported that at least 19 tsunamis were recorded at the Golden Gate tide gage during the period 1868-1968; during that period the maximum recorded wave height of a tsunami was about 7.4 feet. Although no devastating tsunami has been recorded and the likelihood of one is small, the possibility still exists. For example, the Hawaiian Islands, which are much less protected from tsunamis than the San Francisco Bay region, had a period of almost 70 years (1877-1946) when no devastating tsunamis occurred (MacDonald and others, 1947). During the next 15 years (1946-60) four damaging tsunamis struck the Islands.

A tsunami having a wave height or runup of 20 feet may arrive at the Golden Gate once every 200 years (fig. 2). For purposes of this report, the tsunami was assumed to occur at a tidal stage of average higher high water, a tidal stage which is equaled or exceeded about 4 percent of the time at the Golden Gate (Borcherdt and Borgman, 1970). Figure 2 also shows that a tsunami capable of generating a 30-foot runup (which would be greater at lower low water than a 20-foot runup at higher high water) may arrive at the Golden Gate about once every 500 years. On the other hand, present information indicates that, except for beaches and other low-lying coastal areas, a tsunami-generated 10-foot runup would occur more frequently, but probably would produce little inundation damage. Such a tsunami, however, could be disastrous to people participating in shoreline-recreation activities, like surfing, swimming, and surf fishing. Swift currents generated by tsunamis can damage moored boats and marinas. For example, the 1964 tsunami caused little damage in San Francisco Bay as the result of inundation, but the Clipperton Yacht Harbor at Sausalito suffered $100,000 damages from currents generated by the tsunami (Magoon, 1966, p. 48).

## SOME TSUNAMI WARNINGS

1. A tsunami is not a single wave but a series of waves. The first wave usually is not the highest or most damaging wave.
2. At times, "a withdrawal of the water from the coast is likely to be the first substantial manifestation of approaching (tsunami) waves, although a slight crest often precedes" (Shepard, 1963, p. 89). Although not observed with every tsunami, this phenomenon exposes large areas of the shore seldom seen by humans. People, lured out into the newly exposed shore, may be trapped by the next incoming wave.
3. Offshore bottom topography may refract a tsunami in such a way that runup along the shore in one area is much greater than in others.
4. Observers have noted that tsunamis originating around the Gulf of Alaska seem to produce higher runups in the seemingly more protected northern parts of the hooked bays along the California Coast. For example, tsunamis that entered Monterey Bay in 1946 and in 1964 created higher runups at the city of Santa Cruz on the north side of the bay than they did at the city of Monterey on less protected south side (Wiegel, 1970, p. 290; Wilson and Tørum, 1968, p. 128).

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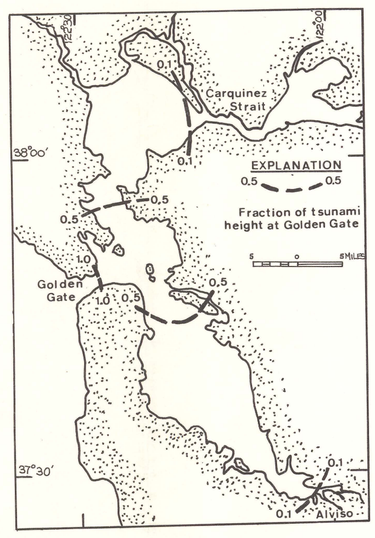


FIGURE 1.--Tsunami attenuation in San Francisco Bay based on the May 1960 and March 1964 tsunamis (modified after Magoon, 1966, p. 64, Presidio gage at Golden Gate taken as 1.0).

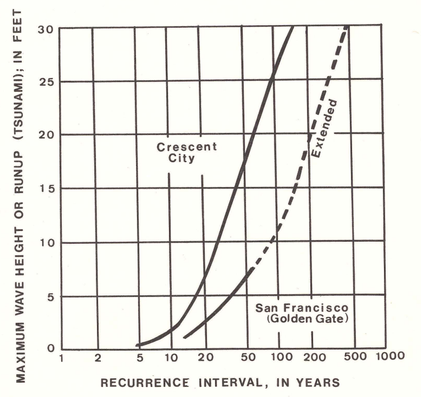


FIGURE 2.--Frequency of occurrence for maximum tsunami waves at the Presidio in San Francisco (Golden Gate) and at Crescent City (modified from Wiegel, 1970, p. 294).

Area that may be inundated by tsunami waves with a runup of 20 feet at Golden Gate.

Index map shown on sheet 2.

SCALE 1:125 000

1 ½ 0 1 2 3 4 5 6 7 8 9 10 MILES
5000 0 5000 10000 15000 20000 25000 30000 35000 40000 45000 FEET
1 ½ 0 1 2 3 4 5 6 7 8 9 10 KILOMETERS

CONTOUR INTERVAL 200 FEET
DOTTED LINES REPRESENT 40-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL
DEPTH CURVES AND SOUNDINGS IN FEET—DATUM IS MEAN LOWER LOW WATER

122°30' 122°15' 122°00'

150 000 FEET
100 000 FEET
500 000 FEET
450 000 FEET
400 000 FEET
350 000 FEET
38°00'
37°45'
37°30'

Base from U.S. Geological Survey
San Francisco Bay Region 1:125,000, 1970, sheets 2 and 3

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