Chapter 9

SEISMIC ZONATION AND NATURAL HAZARD ASSESSMENT OF A PROPOSED DEVELOPMENT SITE ALONG THE SOUTH RICHMOND SHORELINE

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Introduction

Earthquakes and other natural catastrophes are impossible to prevent or predict; however, the consequences of their destructiveness can be greatly reduced through proper planning. Knowledge of the natural hazards at a site and of the engineering properties of the substrate can be used to supplement existing building design and construction codes. Buildings designed and erected with these data in mind should have fewer foundation problems, withstand greater seismic shaking, and sustain less damage from earthquakes and other natural hazards (Brown and Kockelman, 1983).

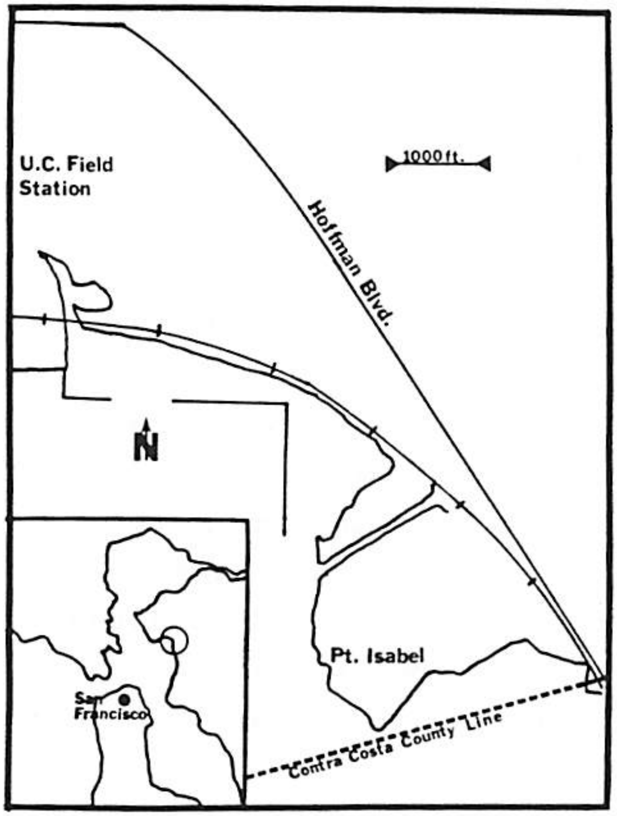

Figure 1. South Richmond Shoreline Study Area
Base Map: Richmond 7 1/2 min. Quadrangle

The location of this study is along the South Richmond shoreline between the Contra Costa County line and the U.C. Field Station, and is bounded by Hoffman Boulevard to the east (Figure 1). Geologically, the site is composed of four materials: a hard bedrock, ancient streambed or alluvial deposits, a mud composed of sediments deposited in the Bay, and artificial landfill. There are problems associated with building on each of these surficial components, as well as with building near the Bay shoreline. The purpose of this study is to identify the natural hazards particular to this site and to examine their potential effects on several types of development.

As the Bay Area continues its rapid population growth, the search for places to expand development will continue as well. An important aspect of this study includes a quantitative land capability analysis in which the potential risks and costs of building on the site are investigated. This analysis will be beneficial in deciding whether expanding onto the Bay margins at this site is advisable and is a practice which we want to continue.

Past Studies

Past studies incorporated into this project include engineering aspects of landfill (Goldman, 1969), problems with placing landfill on Bay Mud (Lee and Praszker, 1969), and land use decisions in conjunction with earth science data (Blair and Spangle, 1979; Brown and Kockelman, 1983; Laird *et al*., 1979). Site specific studies include investigations of borehole data (Arden, 1961), development strategies for South Richmond (Hall *et al*., 1986), seismic safety investigations for the Richmond area (Bishop *et al*., 1973), and the potential effects from earthquakes (Steinbrugge *et al*., 1986).

Methodology

The methods employed in this study are outlined in Laird and others (1979), and were modified for the South Richmond study site. First, basic earth science data were accumulated in the form of geologic maps, a landfill map, borehole data, a liquefaction map, and tsunami and flood maps. A ground response map was derived from the geologic map. The collective data were then analyzed to identify the natural hazards present at the site. On the basis of equations given in Laird and others (1979), these hazards were assigned dollar values which represent the relative costs associated with several types of development at specific sites. Finally, the costs associated with each hazard were summed. These sums were then divided into levels of increasing costs and were plotted onto base maps. The maps can then be compared to one another to show the relative costs of the several land uses at specific sites.

Natural Hazards

The highest potential for property damage along the South Richmond shoreline is due to the damaging effects associated with earthquakes. These effects include problems due to ground shaking, liquefaction, shrink/swell soils, and inundation by water.

The South Richmond site is located near three active faults: the Hayward and Wildcat Canyon faults, which lie approximately one and a half miles east of the site, and the San Andreas fault, which lies about twelve miles to the west. A mile and a half west of the study area lies the San Pablo fault, but it appears to be inactive (Knox, 1973). The Hayward, Wildcat, and San Andreas faults, however, are active, and their activity has been documented. Estimates vary, but it is speculated that the recurrence interval (the time elapsed between large earthquakes) along the Hayward fault for an earthquake with Richter magnitude 7.5 and along the San Andreas for a magnitude 8.0 earthquake is about 50-100 years (Goldman, 1969). However, earthquakes of lesser magnitude will occur even more frequently along the three active faults.

The damages associated with maximum likely earthquakes on the San Andreas or Hayward faults (Richter magnitudes of 8.3 and 7.5, respectively) would be extensive in the study area (Steinbrugge et al., 1986). Some roads could be offset, telephone communication lines would be overloaded, r ing in a Bay Area communication shutdown for an indefinite period of time, electrical power woul lost for several days, natural gas lines would be severed, as well as sewer lines which might re in pumping untreated wastewater into the Bay for up to a month.

Ground Shaking

In terms of human and economic losses, ground shaking is probably the most significant haza an earthquake. Ground shaking is the result of the complex wave motion which travels through th rocky materials of the earth's outer crust during an earthquake. As these waves travel, they pa through different materials which may cause them to be amplified, weakened, reflected, or change period and velocity. Three factors, amplitude, frequency and duration of the waves, contribut to the potential for damage from ground motion (Goldman, 1969). As these waves travel from dens solid rock to less dense alluvial and water-saturated material, the waves experience a reduction velocity, an increase in amplitude, and greater accelerations. As a rule, ground motion lasts lo and is more greatly amplified on loose, water-saturated, poor materials than on dense rock. As a result, far greater damage is incurred in structures erected on these poor materials than on dens rock.

Areas at the study site which exhibit poor or incompetent ground are those underlain by Bay old artificial landfill, or stream sediment within a mile or two of the original landward boundar of the Bay marshlands. Due to the possibility of dike failures during strong shaking, reclaimed marshlands underlain by these materials are especially vulnerable (Brown and Kockelman, 1983). S brugge and others (1986), in assuming a magnitude 7.5 earthquake along the Hayward fault, predict intensities greater than IX on the Modified Mercalli Scale along areas having a high potential for ground failure, notably around the Bay margins. An intensity of IX is defined as strong enough t cause considerable damage in specially designed structures, great damage in substantial buildings with partial collapse, and buildings shifted off foundations (Steinbrugge et al., 1986).

Ground Failure

One of the most common types of ground failure is liquefaction. Liquefaction occurs when sei shaking increases pore water pressure and transforms water-saturated silt and sand into a liquefie state below the ground surface (Goldman, 1969). For liquefaction to occur, all of the following c ditions must be present: a liquefiable bed or lens of porous well-sorted sand, saturation by wate of the pore spaces in the bed (highly likely in the rainy season), confinement of pore water by im permeable layers above and below the bed, and the bed must lie within 50 feet of the surface (Brow and Kockelman, 1983). These criteria are met locally where sand layers are interbedded with Bay M or floodplain silt and clay, and also at some sites on the reclaimed marshlands fringing the Bay. pecially susceptible are marshlands at or below mean sea level which are preserved by dikes; at th eral spreading or settlement from liquefaction may lead to dike failure and extensive flooding. lement is another ground failure that occurs in earthquakes; it is indicated by downward move- he ground surface area which surrounds fixed objects such as well casings and pilings (Goldman, his downward movement may be up to several feet if large amounts of subsurface sediment and flows laterally. The ground failures associated with liquefaction and ground settlement serious damage to structures as well as roads, port facilities, railroads, and utility (Steinbrugge et al., 1986).

n by Water

dation of the land by water is another natural hazard to consider. The damage to risk areas cur through several means: tsunamis, flooding, dike failure, tectonic change in land level, ge in sea level. Tsunamis are earthquake-induced waves, and although it is highly unlikely could develop from a local event (Bishop et al., 1973), the possibility exists for one to rom a distant epicenter. Flooding may also occur due to a dike failure or a temporary rise ater levels as a result of unusually high rainfall.

ong-range, but important, consideration for planning development, is the possibility of mean l rising between two to eight feet over the next one hundred years (Hall et al., 1986). The ental Protection Agency has suggested using a four foot rise for planning purposes. There evidence that this rise is already occurring, and it is thought to be due to gradual warming ocean, possibly as a result of the "greenhouse effect," in which a build-up of carbon dioxide er gasses in the upper atmosphere leads to warming of the polar ice caps (Hall et al., 1986). lication of this for the South Richmond shoreline site is that inevitably the Bay waters will upon the Bay margins, and the lowlands not protected by levees or dikes will be inundated. water levels will result in an increase in sediment loading along the Bay margins (Hall et al.,

Swell Soils

rink/swell soils are soils which swell when wet and shrink when dried. The expansion and con- n of these soils can cause heaving, cracking, and break-up of pavements and concrete-slab tions, as well as sever sewer pipes. The potential is high in many areas of the study site for l to react in this manner. These areas include those underlain with Bay Mud, and many of the al areas.

y of the South Richmond Shore

he substrate at the study site is composed of three types of materials beneath artificial fill e 2). The oldest, the bedrock, is the Franciscan Complex which underlies the entire study area, tcrops at Point Isabel. The Franciscan Complex contains a variety of rocks including sandstone, shale, and metamorphic rocks. In an unsheared state the rocks are hard and dense, and relatively stable during earthquake shaking (Hall et al., 1986).

Deep alluvium overlies bedrock along the lowlands of the shoreline. Alluvium is unconsolidated material deposited during relatively recent geologic time by a stream or other moving body of water (Bishop et al., 1973). The alluvial soils in the stbdy area are a mixture of interbedded sands, gravels, silts, and stiff clays.

The youngest and uppermost layer of natural material is a marine-deposited soft, grey, silty clay referred to as Bay Mud. This mud is interlayered with sand and silt at places along the shoreline.

Artificial landfill, which comprises much of the surficial land area, has shifted the original shoreline into the estuary, resulting in the burial of many marshlands and tidal areas within the last fifty years (Figure 3).

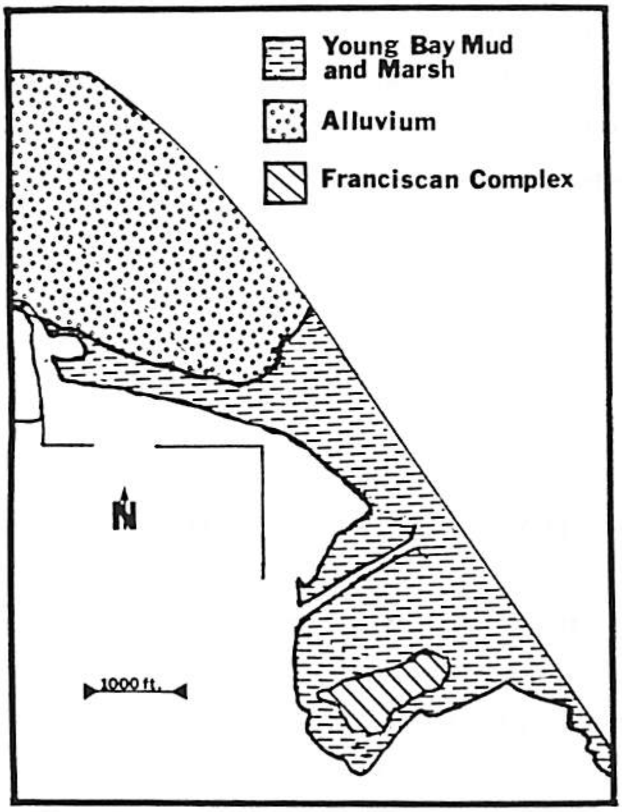

Figure 2. Local Geology Beneath Fill
Source: Bishop et al., 1973

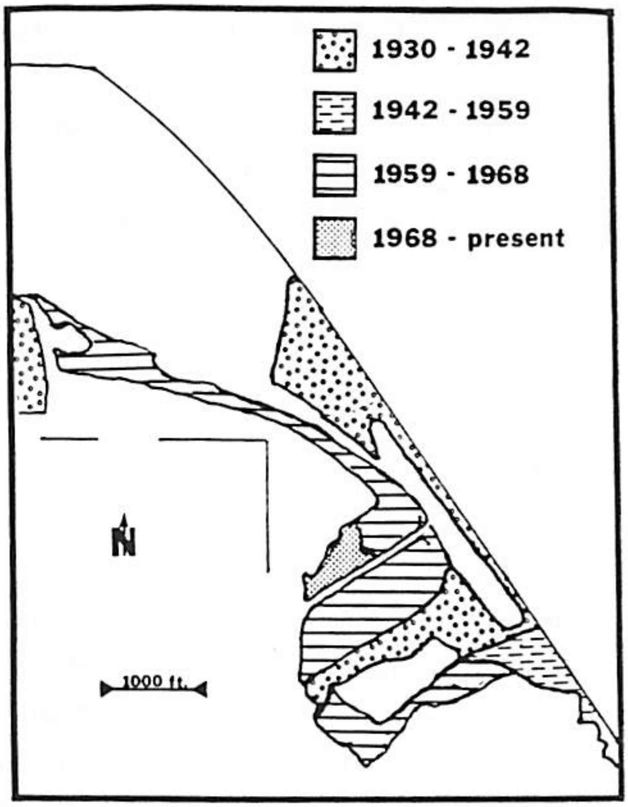

Figure 3. History of Landfill
Source: Hall et al., 1986

Building on Bay Mud and Fill

Areas of Bay Mud and landfill over Bay Mud present several constraints to development on the site. Bay Mud is soft and plastic when wet, has a high natural water content, and is highly compressible (Goldman, 1969). The problems associated with building on Bay Mud are directly related to its thickness, depth, and settlement due to the mud's low strength and high compressibility. When younger Bay d is overloaded by fill, the stability decreases as the height of the fill increases, and if the slopes the fill boundary are too steep, then ground failure results (Goldman, 1969). If poorly compacted ll is used over Bay Mud, then these settlement problems will be accentuated. To lessen the effects these problems the state-of-the-art structural engineering technology should be used in the design buildings to incorporate the advancements made in seismic safety over the past several years.

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Bore holes - Table 1 and 2 summarize geological data from borings at various locations in and near e study area (Figure 4). These tables provide information on the structure and composition of the subrface strata at the site. The expected ground shaking intensity and liquefaction potential at the te can be determined on the basis of the depth and thickness of the formations.

Ground response - The intensity of ground shaking expected at the site, assuming a maximum earthquake 7.5 along the Hayward fault, ranges from A to C (Figure 5) on the San Francisco Intensity Scale aird et al., 1979, p. 27). The intensities are based on the distance from active faults and the subrate present at the South Richmond site (Laird et al., 1979, pp. 27-29).

Liquefaction potential - The liquefaction potential along the South Richmond shore ranges from low bedrock areas to high in alluvial areas which contain liquefiable material (Figure 6).

Tsunami and flood hazard - Twenty tsunamis have passed through the Golden Gate within the last 130 ars, ranging from 3" to the 7 1/2' wave from the 1964 Alaska earthquake (Bishop et al., 1973). The timated maximum height is between 7 and 20 feet, with a recurrence interval for a 10' wave of about years. A tsunami at the South Richmond site is likely to be about one half the wave height at the lden Gate (Bishop et al., 1973); presumably, shoreline areas could be inundated by a large wave if not otected by dikes or levees.

The maximum flood with a recurrence interval of 100 years could inundate the area approximately to e 10' contour (Limerinos et al., 1973), which is roughly parallel to the original pre-landfill shorene of 1895 (Figure 7).

Summary of costs - An integral part of this study is the assignment of dollar values, or a cost, sociated with two factors: the natural hazard present and the type of development proposed. These sts include site-specific studies, design of safe structures, mitigation costs, or costs of potential mage. For each type of land use and related hazard, a cost can be determined by considering the tential losses due to damages caused by the hazard or costs incurred through mitigation of the hazard able 3). These losses might include destruction or damage to personal property, structures, utilities, d loss of improvements made on the land. The types of development considered in this study are recational, industrial, and commercial. Recreational development is defined as leaving the land basically it is with minor improvements; industrial and commercial-type developments are defined as light instrial and office and retail structures such as those found in downtown Berkeley.

TABLE 1. BOREHOLE DATA

Site #	Elevation (mean sea level)	Total depth	Depth of artificial fill	Depth of sand strata	Depth of young Bay Mud	Depth of alluvium	Depth to bedrock
1	13'	78'	13'	no data	28'	70'	57'
2	13'	22'	10'	no data	27'	44'	30'
3	10'	105'	0'	no data	no data	105'+	95'
4	31	71'	0'	no data	no data	71'+	no data
5	20'	20'	0'	no data	no data	no data	no data
6	26'	20'	0'	no data	no data	no data	no data
7	15'	20'	0'	14.5'-16'	no data	no data	no data
8	20'	20'	0'	no data	no data	no data	no data
9	20'	20'	0'	12'-17'	no data	no data	no data
10	13'	20'	0'	no data	no data	no data	no data

Source: Bishop *et al*., 1973

TABLE 2. BOREHOLE DATA

Site #	Depth of sub-sealevel landfill*	Depth of Qmb(u)	Depth of Qmb(l)	Depth of Qm	Depth of N-m	Depth of Qp	Depth of Qsa	Depth of Qa	Depth to Bedrock	Depth of Sand/Gravel
11	0'	0'-12'	12'-23'	23'-25'	23'-30' & 33'-36'	30'-33'	36'-42'	42'-44'	67'	none found
12	0'	0'-10'	10'-17'	17'-25'	25'-29' & 33'-35'	30'-33'	35'-41'	41'-44'	55'	none found
13	0-1'	1'-5'	5'-25'	25'-27'	33'-34'	27'-33'	34'-39'	39'-44'	46'	none found
14	0-2'	2'-5'	5'-25'	25'-27'	none found	27'-36'	36'-40'	40'-41'	41'	none found
15	0-3'	3'-6'	6'-17'	17'-26'	none found	26'-36'	36'-39'	39'-48'	55'	none found
16	0-4'	4'-7'	7'-10'	10'-25'	none found	25'-36'	36'-38'	38'-47'	59'	none found
17	0-2'	2'-5'	5'-9'	9'-23'	none found	23'-36'	36'-38'	38'-46'	63'	none found
18	0-1'	1'-4'	4'-15'	15'-20'	none found	20'-37'	37'-38'	38'-46'	63'	none found
19	0-1'	1'-3'	3'-22'	none found	none found	32'-33'	32'-33'	38'-46'	62'	none found
20	0'	0'-2'	2'-24'	24'-37'	none found	24'-37'	none found	37'-47'	61'	none found
21	0'	0'-3'	3'-15'	17'-22'	none found	22'-37'	none found	37'-47'	61'	15'-17'
22	0'	-1'-0'	0'-8'	11'-15'	8'-11'	22'-37'	none found	37'-47'	60'	15'-17'
23	0'	-1'-0'	0'-6'	11'-15'	6'-11'	23'-38'	none found	38'-47'	58'	15'-17'
24	0'	0'-5'	absent	11'-27'	5'-11'	27'-40'	none found	40'-50'	57'	none found
25	0'	0'-5'	absent	5'-29'	none found	29'-40'	none found	40'-52'	62'	none found

Source: Arden, 1961

Legend:

Qbm(u): upper Bay Mud
Qbm(l): lower Bay Mud
Qm: Merritt Sand
N-m: non-marine materials
Qp: Posey Formation
Qsa: San Antonio Formation
Qa: Alameda Formation

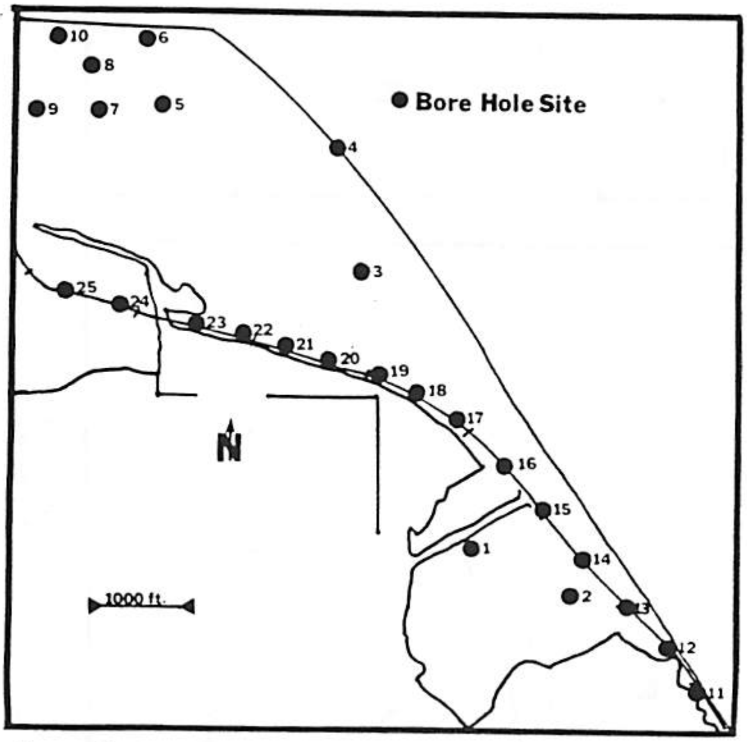

Figure 4. Location of Boreholes
Source: Bishop et al., 1973; Arden, 1961

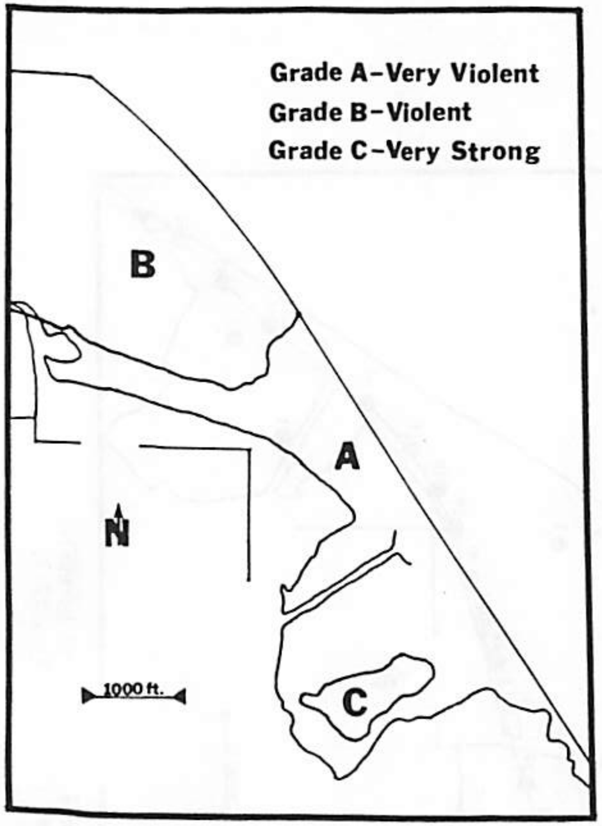

Figure 5. Intensity of Ground Shaking
Base Map: Richmond 7½ min. quadrangle

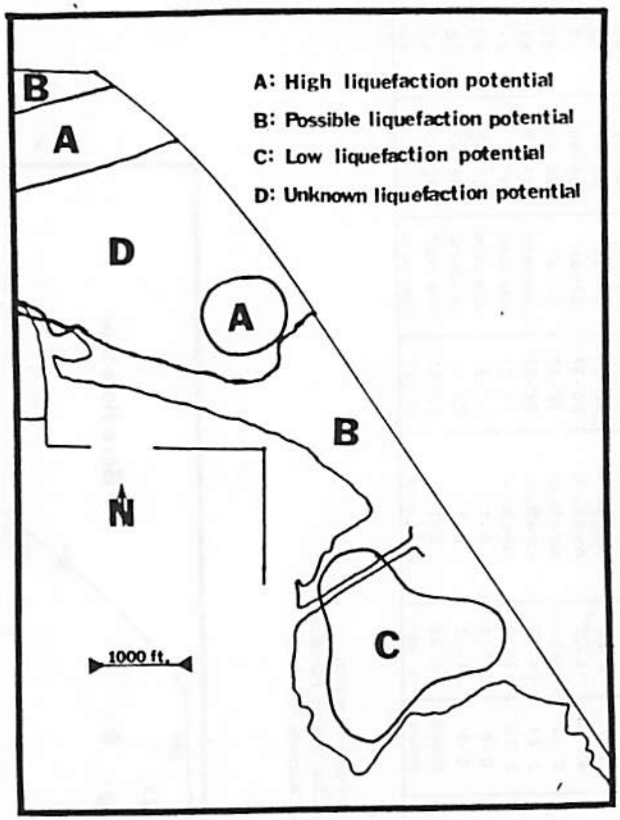

Figure 6. Liquefaction Potential
Source: Bishop et al., 1973

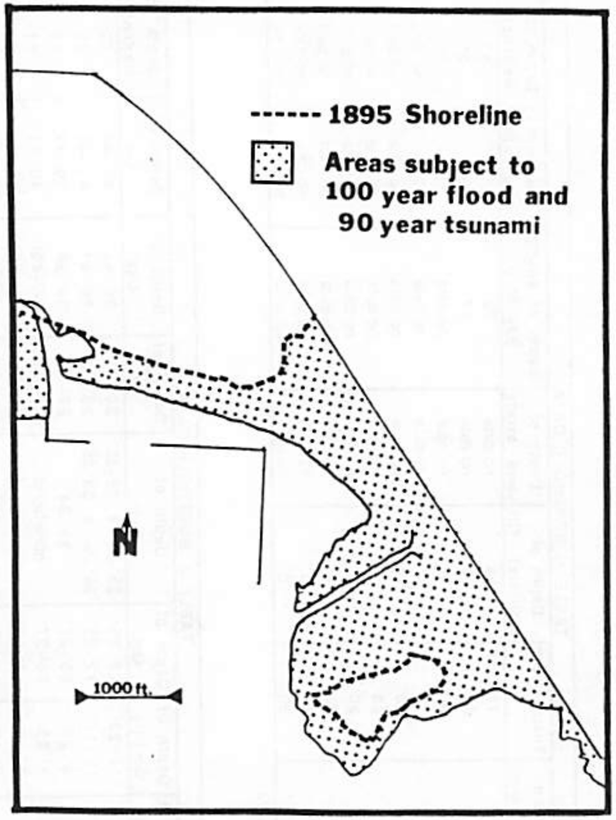

Figure 7. Tsunami and Flooding Potential
Source: Limerinos et al., 1973
Ritter and Dupre, 1972

TABLE 3. LAND USE COST

HAZARD	LAND USE	SEVERE ←			→	SLIGHT
GROUND SHAKING	Recreational	150	100	40	15	0
	Industrial	35000	25000	10000	4000	400
	Commercial	50000	40000	16000	7000	700
FLOODING	Recreational	100	0	0	0	0
	Industrial	40000	0	0	0	0
	Commercial	45000	0	0	0	0
DIKE FAILURE	Recreational	200	0	0	0	0
	Industrial	75000	0	0	0	0
	Commercial	80000	0	0	0	0
SHRINK/SWELL SOILS	Recreational	500	15	0	0	0
	Industrial	10000	4000	0	0	0
	Commercial	25000	8000	0	0	0
SETTLEMENT	Recreational	20	20	5	5	0
	Industrial	10000	10000	700	700	0
	Commercial	100000	100000	2000	2000	0
LIQUEFACTION	Recreational	15	0	0	0	0
	Industrial	4000	20	0	0	0
	Commercial	6000	30	0	0	0

Discussion

The land capability maps (Figure 8) show the total cost of developing the land for recreational, industrial, or commercial uses in 1975 dollars. The total costs per acre for each area are calculated by adding the costs which result from all the natural hazards in the area and their possible effects on the specific types of development (Table 3). In general, recreational land use is the least costly alternative. Industrial use will incur a much greater cost, and commercial use will nearly double the already high cost of industrial development in most areas. These maps also show the relative sensitivities of land parcels to development. It is evident that the marshland and shoreline areas are the most sensitive areas in that a very high cost is associated with their development; notably, \$150,000-\$175,000 per acre for industrial use and $\$300,000^{+}$ per acre for commercial use. Less sensitive are the alluvial areas in the northern sector, but even these areas could incur high costs if industrial or commercial development is undertaken: \$35,000-\$50,000 per acre for industrial use, and \$50,000-\$60,000 per acre for commercial use. The most stable area occurs where the Franciscan Complex outcrops at Point Isabel. There is a relatively low cost, \$0-\$15,000 per acre, associated with all three types of development; however, this prime area has already been developed for the U.S. Postal Service.

Conclusion

It is hoped that the land capability maps can be a useful tool to those in decision-making positions, such as planners and developers. Though natural hazards and geologic constraints are not the sole criteria for development planning, the use of earth science information should be an integral part of the decision-making process. The information presented in this study suggests that development of the marsh and shoreline areas are not the best use of the land's resources, unless the area

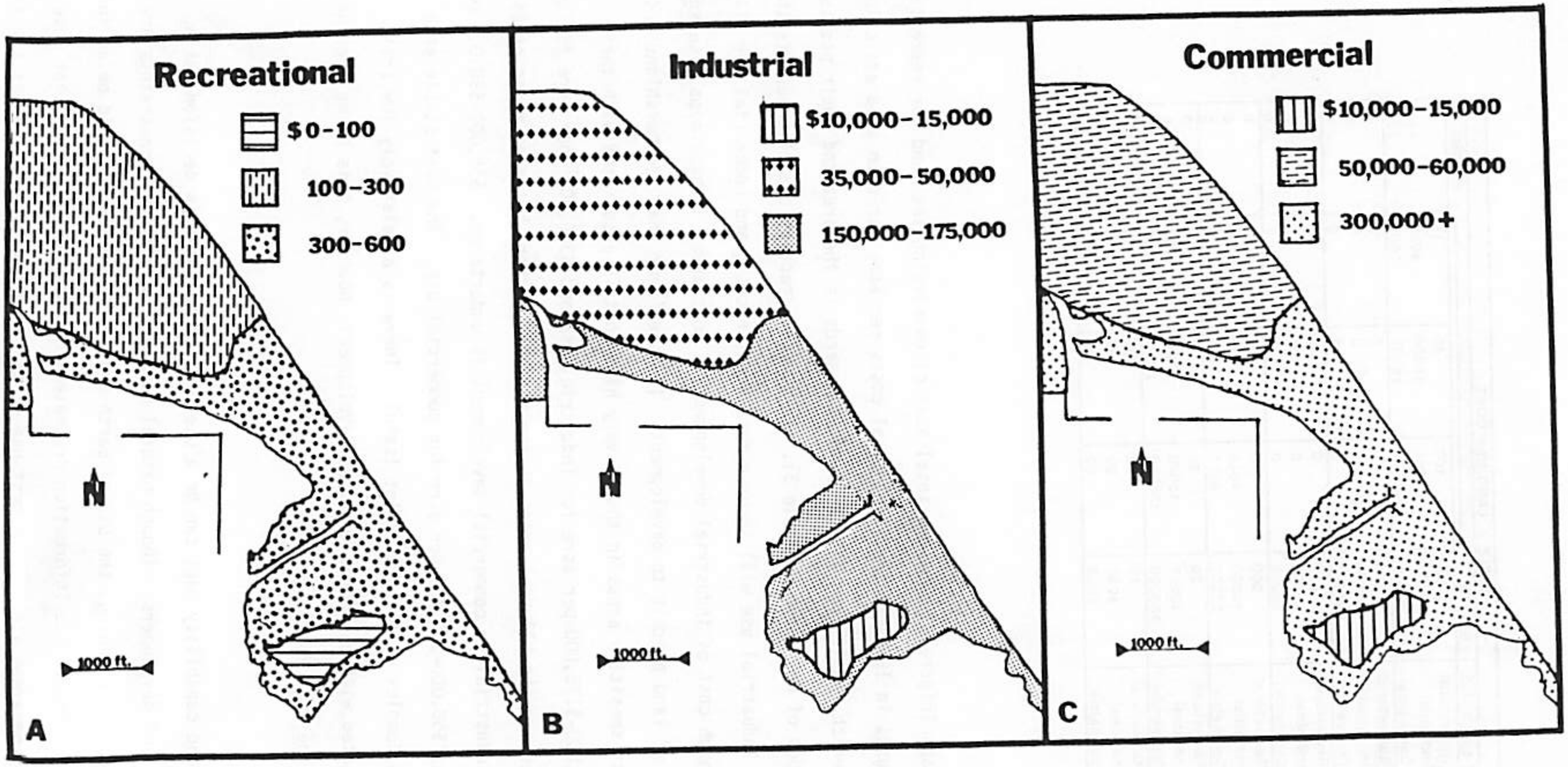

Figure 8. Land Capability Maps, Costs per Acre (1975 dollars)
A. Recreational B. Industrial C. Commercial
Base Map: Richmond 7½ min. quadrangle

is developed for recreational use, in which case very little, if any, change in the land would take place. Even if the high costs associated with industrial or commercial usage are paid, there is no guarantee that all future costs will be avoided. In addition, one cost not tabulated was the opportunity cost, or the cost associated with the loss of valuable, and increasingly scarce, public shoreline and marsh areas to high cost development.

Further development of the alluvial areas in the northern sector of the study area is more feasible, yet it is still costly, and site-specific studies must be done if any development is planned.

As the pressures due to increasing population in the Bay Area force us to seek development on marginal lands, these pressures must be kept in check through examination of the consequences of development to the land, and ultimately to the structures themselves. Site-specific studies of geological conditions should be made along the South Richmond shore wherever development is proposed, and this information must be incorporated into the decision-making process.

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