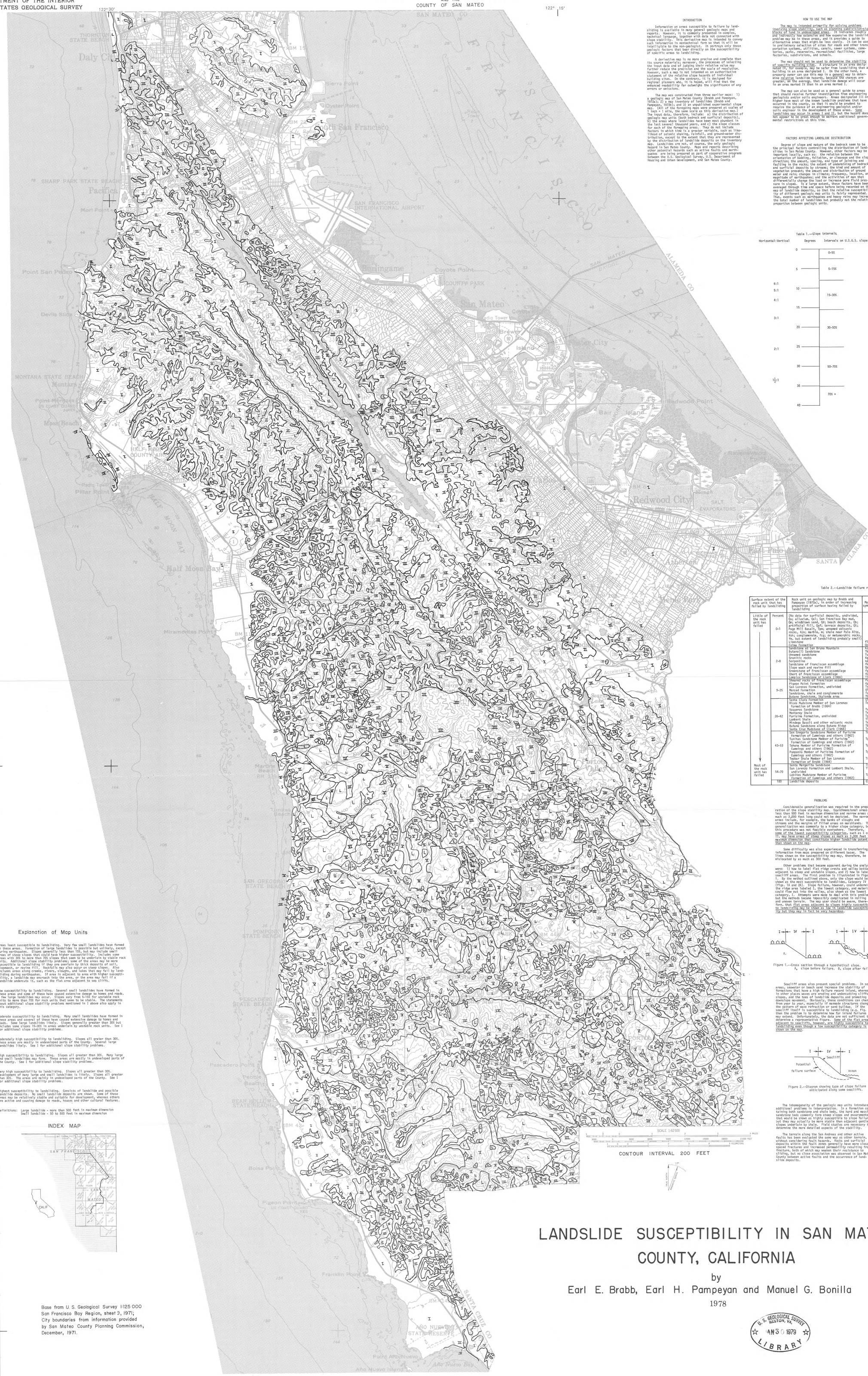
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT
AND THE
COUNTY OF SAN MATEO

MISCELLANEOUS FIELD STUDIES
MAP MF-360



LANDSLIDE SUSCEPTIBILITY IN SAN MATEO COUNTY, CALIFORNIA

by
Earl E. Brabb, Earl H. Pampeyan and Manuel G. Bonilla

1978

U. S. GEOLOGICAL SURVEY
RESTON, VA.
JAN 30 1979
LIBRARY

INTRODUCTION

Information on areas susceptible to failure by landsliding is available in many general geologic maps and reports. However, it is commonly presented in complex, technical language, together with data not connected with slope stability. This derivative map is intended to convey such information in nontechnical form so that it will be intelligible to the non-geologist. It portrays only those geologic factors that bear directly on the susceptibility of specific areas to landsliding.

A derivative map is no more precise and complete than its source materials; moreover, the processes of selecting the input data and of judging their relative value may further reduce the precision and the scale of resolution. However, such a map is not intended as an authoritative statement of the relative slope hazards of individual building sites. On the contrary, it is designed for regional planners who, it is hoped, will find that the enhanced readability far outweighs the significance of any errors or omissions.

The map was constructed from three earlier maps: 1) a geologic map of San Mateo County (Brabb and Pampeyan, 1972a); 2) a map inventory of landslides (Brabb and Pampeyan, 1972b); and 3) an unpublished experimental slope map. (All of the foregoing maps were prepared at scales of 1 inch = 1 mile, the same scale as this derivative map.) The input data, therefore, include: a) the distribution of geologic map units (both bedrock and surficial deposits), b) the areas where landslides have been most abundant in the last several thousand years, and c) the slope classes for each of the foregoing areas. They do not include factors in which time is a greater variable, such as likelihood of seismic shaking, rainfall, and ground-water distribution, except to the extent that they are represented by the distribution of landslide deposits on the inventory map. Landslides are not, of course, the only geologic hazard in San Mateo County. Maps and reports describing other potential hazards such as active faults and earthquakes are being prepared as part of cooperative programs between the U.S. Geological Survey, U.S. Department of Housing and Urban Development, and San Mateo County.

HOW TO USE THE MAP

The map is intended primarily for solving problems involving slope stability, such as planning subdivision-size blocks of land in undeveloped areas. It indicates roughly and indirectly how extensive and how expensive the landslide problem may be in these areas, and it provides a guide to alternative areas that might be less costly. It can be used in preliminary selection of sites for roads and other transportation systems, utilities, canals, sewer systems, cemeteries, parks, reservoirs, recreational facilities, large factories, subdivisions, and schools.

The map should not be used to determine the stability of specific building sites. A structure in an area designated IV, for example, may be safer from landsliding than a building in an area designated I. On the other hand, a property owner can use this map in a general way to determine relative landslide hazards, because the chances are greater, on the average, that landslide damage will occur in an area marked IV than in an area marked I.

The map can also be used as a general guide to areas that should receive further investigation from engineering geologists and/or soils engineers. Areas designated III or higher have most of the known landslide problems that have occurred in the county, so that it would be prudent to require the guidance of an engineering geologist and/or soils engineer in the development of these areas. Some landslides may occur in areas I and II, but the hazard does not appear to be great enough to warrant additional governmental restrictions at this time.

FACTORS AFFECTING LANDSLIDE DISTRIBUTION

Degree of slope and nature of the bedrock seem to be the principal factors controlling the distribution of landslides in San Mateo County. However, other factors may be important locally, such as: the relation between the orientation of bedding, foliation, or cleavage and the slope direction; the amount, spacing, and type of jointing and faulting in the rocks; the extent of undermining of bedrock and surficial deposits by streams; the kind and amount of vegetation present; the amount and distribution of ground water and rain; changes in climate; frequency, location, and magnitude of earthquakes; and the activities of man that differentially change the load or increase pore fluid pressure in slopes. To a large extent, these factors have been averaged through time and space before being recorded on the map of landslide deposits, so that the relative susceptibility of different geologic map units is fairly represented. Thus, events such as earthquakes and heavy rains may increase the total number of landslides but probably not the relative proportion between geologic units.

Table 1.--Slope intervals

Horizontal:Vertical	Degrees	Intervals on U.S.G.S. slope map
	0	
		0-5%
	5	
		5-15%
6:1		
5:1	10	
4:1		15-30%
	15	
3:1		
	20	30-50%
2:1		
	25	
	30	50-70%
1½:1		
	35	
		70% +
	40	

SOURCE MATERIALS

GEOLOGIC MAP COMPILED BY BRABB AND PAMPEYAN (1972A)

The geologic map shows the distribution of rocks and surficial deposits of different type or age. It was compiled largely from older maps that emphasized data of use in exploration for petroleum and mineral deposits, rather than data pertaining to landslide susceptibility. Even so, it does group rocks and surficial deposits that have similar physical properties, at least some of which relate to the formation of landslides.

One limitation to using the geologic map for landslide studies is that it provides relatively little information on surficial deposits. Bonilla (1960) has determined, for example, that about 35 percent of all the landslides in the northern part of San Mateo County occur in slope debris and ravine fill. These surficial deposits are shown on the geologic map in the area mapped by Bonilla (1971), but in most of the county they have generally been overlooked. This omission does not seriously affect the use of the slope stability map for planning any type of development that would affect an area larger than 500 feet across inasmuch as all the known landslides in these surficial deposits are smaller.

LANDSLIDE MAP BY BRABB AND PAMPEYAN (1972B)

The landslide map shows nearly 2,000 landslide deposits ranging in size from 50 feet to a mile or more in greatest dimension. It was prepared largely from the interpretation of aerial photographs, partly by compilation of information in county and public records, and partly by fieldwork.

Most of the landslide deposits shown on the landslide map have not been verified by field checking or investigated by trenching and drilling. However, limited field observations have indicated that more landslide deposits are probably present than shown, and that errors in the map should therefore be on the conservative side. As such, all areas shown as landslides on the map are assumed to be present for purposes of the slope-stability analysis.

SLOPE MAP

A slope map of San Mateo County at a scale of 1:62,500 was made experimentally for the slope-stability analysis. The map was prepared by a combination of manual and photomechanical methods from reduced copies of the contour plates of the Geological Survey's 1:24,000 topographic map series. Slope intervals, shown on table 1, were selected after interviews with city, county, and regional planners in order to determine which slope categories would be most useful.

Minor errors on the slope map are introduced by the photomechanical process. These errors are most prevalent along narrow ridge crests, and valley floors, and they tend to put the areas in a higher slope stability category than the slope warrants.

MAPPING PROCEDURES

A. The area of outcrop within San Mateo County was estimated for each of the units and some subunits on the geologic map using a grid overlay with a resolution of 0.01 mi^2 at the map scale.

B. The landslide inventory map was superimposed on the geologic map in order to identify the units in which failures had occurred, and the areas that had failed in each unit were estimated using the grid.

C. The geologic map units were then listed (as in table 2) in order of percentage of their outcrop areas that have failed by landsliding.

D. The highest class of susceptibility (L) was assigned to the landslide deposits, which contain many more failure surfaces than the rock unit from which they are derived.

E. Other class limits were selected at convenient intervals on the list, and a roman numeral class number was assigned to the map units. That numeral represents the relative susceptibility of any particular map unit.

F. The slope map was then superimposed on the combined geologic map and landslide inventory and systematically examined to determined the slope intervals that displayed maximum landslide frequency for each map unit. Those slope intervals having the maxima were then labeled with the highest roman numeral class. Slope intervals showing significantly fewer slides were reduced in rank and labeled with numerals of lower class. Thus, a unit having a maximum susceptibility of III may be labeled with that numeral only where slopes exceed 30 percent, and because lower slopes may be expected to have significantly fewer slides, the final map labels for the same geologic units on lower slopes may be II or even I, depending on the rate of change of relative susceptibility with slope.

Thus, the map may include within a single boundary line (within the same susceptibility class) resistant bedrock units in steep terrain and weak bedrock units in terrain of moderate to low relief. At the same time, it separates areas underlain by bedrock of similar strength that, nevertheless, have different overall susceptibilities in different slope intervals.

Table 2.--Landslide failure record for rock units in San Mateo County

Surface extent of the rock unit that has failed by landsliding		Rock unit on geologic map by Brabb and Pampeyan (1972a), in order of increasing proportion of surface having failed by landsliding	Map symbol	Approx. area in County (sq mi)	Approx. area that has failed (sq mi)	Relative susceptibility numbers	Susceptibility numbers in each slope interval: 0-5	5-15	15-30	30-50	50-70	> 70
Little of the rock unit has failed	Percent	(No data for surficial deposits, undivided, Qu; alluvium, Qal; San Francisco Bay mud, Qm; windblown sand, Qd; beach deposits, Qb; artificial fill, Qaf; terrace deposits, Qt; Page Mill Basalt, Tpm; unnamed volcanic rocks, KJv; marble, m; shale near Palo Alto, Ksh; conglomerate, fcg; or metamorphic rocks, fm, but extent of landsliding probably small)										
	0-1	Limestone	fl	.20	.00	I	I	I	I	I	I	I
		Colma Formation	Qc	11.11	.01		I	I	I	I	I	I
	2-8	Sandstone at San Bruno Mountain	KJs	4.77	.10	II	I	I	II	II	II	II
		Butano(?) Sandstone	Th?	10.56	.19		I	I	I	I	I	II
		Unnamed sandstone	Tus	1.81	.04		I	I	I	I	I	II
		Granitic rocks	Kgr	24.61	.90		I	I	I	II	II	II
		Serpentine	sp	4.76	.09		I	I	I	II	II	II
		Sandstone of Franciscan assemblage	fs	22.19	.74		I	I	I	II	II	II
		Slope wash and ravine fill	Qsr	4.51	.18		I	I	I	II	II	II
		Greenstone of Franciscan assemblage	fg	15.70	.61		I	I	I	II	II	II
		Chert of Franciscan assemblage	fc	1.43	.10		I	I	I	II	II	II
		Lompico Sandstone of Clark (1966)	Tlo	.40	.03		I	I	I	I	I	I
	9-25	Sheared rocks of Franciscan assemblage	fsr	9.99	.83	III	I	I	II	III	III	III
		Pigeon Point Formation	Tpp	7.77	.84		I	I	II	II	III	III
		San Lorenzo Formation, undivided	Tsl	1.00	.11		I	I	I	II	III	III
		Merced Formation	QTm	7.01	1.01		I	I	II	II	III	III
		Sandstone, shale and conglomerate	Tss	5.34	.51		I	I	I	I	II	III
		Butano Sandstone, Skylonda area	Tb	22.55	4.33		I	I	II	III	III	III
	26-42	Santa Clara Formation	QTs	6.97	1.85	IV	I	I	III	IV	IV	IV
		Rices Mudstone Member of San Lorenzo Formation of Brabb (1966)	Tsr	1.37	.43		I	I	II	III	IV	IV
		Vaqueros Sandstone	Tvq	7.60	2.41		I	I	II	III	III	IV
		Monterey Shale	Tm	5.11	1.76		I	I	III	IV	IV	IV
		Purisima Formation, undivided	Tp	23.06	7.81		I	II	III	IV	IV	IV
		Lambert Shale	Tla	19.95	7.25		I	I	II	III	III	IV
		Mindego Basalt and other volcanic rocks	Tmb	10.80	4.01		I	I	II	III	III	IV
		Butano Sandstone along Butano Ridge	Tb	20.18	7.66		I	I	I	III	IV	IV
		Santa Cruz Mudstone of Clark (1966)	Tsc	19.25	7.98		I	I	I	III	IV	IV
	43-53	San Gregorio Sandstone Member of Purisima Formation of Cummings and others (1962)	Tpsg	2.41	1.06	V	I	I	I	IV	V	V
		Tunitas Sandstone Member of Purisima Formation of Cummings and others (1962)	Tptu	2.76	1.24		I	I	III	V	V	V
		Tahana Member of Purisima Formation of Cummings and others (1962)	Tpt	33.46	16.08		I	II	III	V	V	V
		Pomponio Member of Purisima Formation of Cummings and others (1962)	Tpp	11.97	5.76		I	I	II	V	V	V
		Twobar Shale Member of San Lorenzo Formation of Brabb (1964)	Tst	.80	.42		I	I	III	IV	V	V
	54-70	Santa Margarita Sandstone	Tsm	.65	.41	VI	I	I	I	III	III	VI
		San Lorenzo Formation and Lambert Shale, undivided	Tls	6.83	4.56		I	I	III	V	VI	VI
		Lobitos Mudstone Member of Purisima Formation of Cummings and others (1962)	Tpl	3.71	2.57		I	II	II	VI	VI	VI
Most of the rock unit has failed	100	Landslide deposits	Qls	83.88	83.88	L	L	L	L	L	L	L

PROBLEMS

Considerable generalization was required in the preparation of the slope stability map. Equidimensional areas less than 500 feet in maximum dimension and narrow areas as much as 3,000 feet long could not be depicted. The narrow areas include, for example, the banks of sloughs and streams and the margins of filled areas on marshlands. The generalization was commonly to a higher slope category, but this procedure was not feasible everywhere. Therefore, some of the lowest susceptibility categories, such as I or II, may have areas of steep slopes as much as 3,000 feet in maximum dimension that constitute higher landslide potential than shown on the map.

Some difficulty was also experienced in transferring information from maps prepared on different bases. The lines shown on the susceptibility map may, therefore, be mislocated by as much as 300 feet.

Other problems that became apparent during the analysis were: 1) how to label flat ridge crests and valley bottoms adjacent to steep and unstable slopes, and 2) how to label seacliff areas. The first problem is illustrated in figure 1. By the method outlined above, only the slope would be shown as the most susceptible to landslides, Category IV (figs. 1A and 2A). Slope failure, however, could undermine the ridge area labeled I, the lowest category, and material could flow out into the valley, also shown as the lowest category, I. Attempts were made to deal with this problem, but the methods became impossibly complicated in rolling and uneven terrain. The map user should be aware, therefore, that flat areas adjacent to slopes highly susceptible to landsliding may be shown as low in landslide susceptibility but they may in fact be very hazardous.

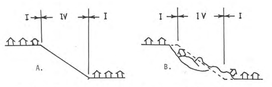


Figure 1.--Cross section through a hypothetical slope. A_1 slope before failure. B, slope after failure.

Seacliff areas also present special problems. In some areas, seawater or beach sand increase the stability of formations that have a high failure record inland, whereas in other places waves are undercutting and undercutting cliffs, slopes, and the toes of landslide deposits and promoting downslope movement. Now (1977) there conditions can change from year to year, especially if manmade structures change the pattern of wave refraction or sand buildup. If the seacliff itself is susceptible to landsliding (e.g. fig. 2) then the problem is to determine how far inland failures may extend. Unfortunately, the data are not sufficient to determine a representative figure. Some of the flat areas adjacent to seacliffs, however, are highly susceptible to landsliding even though a low susceptibility category is shown on the map.

Figure 2.--Diagram showing type of slope failure anticipated along some seacliffs.

The inhomogeneity of the geologic map units introduces additional problems in interpretation. In a formation containing both sandstone and shale beds, the hard and massive sandstone beds commonly form steep slopes and escarpments that would be shown as highly susceptible to slope failure, but they may actually be more stable than adjacent gentle slopes underlain by shale. Field studies are necessary to determine the more detailed aspects of the stability.

The terrain along the San Andreas and other active faults has been evaluated the same way as other terrain, without considering fault hazards. Rocks and surficial deposits within the fault zones generally have more closely spaced fractures and increased permeability resulting from fracture, both of which may weaken their resistance to sliding, but no close association was observed in San Mateo County between active faults and the occurrence of landslide deposits.

Areas underlain by young San Francisco Bay sediments are generally stable under natural static conditions but may be subject to differential settlement and slumping when fill is added. During earthquakes, these areas may develop ground cracks and, if they contain water-saturated sand layers at shallow depth, may fail by landsliding, subsidence or liquefaction even where the ground surface is nearly flat. Similarly, small landslides commonly develop along the banks of streams, rivers, sloughs, and lakes during earthquakes. No attempt has been made to deal with these problems on our map, but they constitute a potential hazard.

Some differences were noted between the failure record of large and small landslides in certain formations, but the information for small landslides is so incomplete for the county as a whole that no attempt was made to deal with this problem. Nevertheless, the user should be aware that the susceptibility map seems most reliable for landslides 500 feet in maximum dimension and larger, and that some rock units may develop more small landslides than might otherwise be inferred from the susceptibility category. For this and other reasons, we feel that the susceptibility map is most suitable for planning any development that affects an area larger than 500 feet across (250,000 square feet).

CONCLUSIONS

The slope stability map provides an easily read analysis of selected geologic factors that bear directly on the problem of landsliding within San Mateo County. It incorporates degree of slope in the analysis, and it provides lower susceptibility for areas of steep slopes, such as Montara Mountain, where few landslides have been recorded. These areas, correspondingly, should be more satisfactory for development than areas of more gentle slope with greater numbers of landslides, provided that there are no other considerations, such as aesthetics, fire hazard, or accessibility.

The map indicates in a general way that areas of San Mateo County that have already been developed are moderately stable and that most of the county now forested or in pasture has many landslides. Inasmuch as the cost of landslide damage in the county is already high, $3,599,018 during the winter of 1968-69, according to Taylor and Brabb (1972), the additional cost of building on landslides or unstable slopes in the areas now undeveloped could be staggering. Even with detailed site investigation and careful engineering studies, landslides are to some degree unpredictable, and the results can be financial disaster and severe mental trauma, as many residents in the hilly parts of communities from San Bruno to Redwood City can testify. A cautious approach to the development on hillside areas is fully justified by the record of county landslide failures.

Explanation of Map Units

Least

I — Areas least susceptible to landsliding. Very few small landslides have formed in these areas. Formation of large landslides is possible but unlikely, except during earthquakes. Slopes generally less than 15%, but may include small areas of steep slopes that could have higher susceptibility. Includes some areas with 30% to more than 70% slopes that seem to be underlain by stable rock units. Additional slope stability problems; some of the areas may be more susceptible to landsliding if they are overlain by thick deposits of soil, slopewash, or ravine fill. Rockfalls may also occur on steep slopes. Also includes areas along creeks, rivers, sloughs, and lakes that may fail by landsliding during earthquakes. If area is adjacent to area with higher susceptibility, a landslide may encroach into the area, or the area may fail if a landslide undercuts it, such as the flat area adjacent to sea cliffs.

II — Low susceptibility to landsliding. Several small landslides have formed in these areas and some of these have caused extensive damage to homes and roads. A few large landslides may occur. Slopes vary from 5-15% for unstable rock units to more than 70% for rock units that seem to be stable. The statements about additional slope stability problems mentioned in I above also apply in this category.

III — Moderate susceptibility to landsliding. Many small landslides have formed in these areas and several of these have caused extensive damage to homes and roads. Some large landslides likely. Slopes generally greater than 30% but includes some slopes 15-30% in areas underlain by unstable rock units. See I for additional slope stability problems.

IV — Moderately high susceptibility to landsliding. Slopes all grater than 30%. These areas are mostly in undeveloped parts of the County. Several large landslides likely. See I for additional slope stability problems.

V — High susceptibility to landsliding. Slopes all greater than 30%. Many large and small landslides may form. These areas are mostly in undeveloped parts of the County. See I for additional slope stability problems.

VI — Very high susceptibility to landsliding. Slopes all greater than 30%. Development of many large and small landslides is likely. Slopes all greater than 30%. The areas are mainly in undeveloped parts of the County. See I for additional slope stability problems.

L — Highest susceptibility to landsliding. Consists of landslide and possible landslide deposits. No small landslide deposits are shown. Some of these areas may be relatively stable and suitable for development, whereas others are active and causing damage to roads, houses and other cultural features.

Most

Definitions: Large landslide - more than 500 feet in maximum dimension
Small landslide - 50 to 500 feet in maximum dimension

INDEX MAP

Base from U. S. Geological Survey 1:125 000 San Francisco Bay Region, sheet 3, 1971; City boundaries from information provided by San Mateo County Planning Commission, December, 1971.

REFERENCES CITED

Bonilla, M. G., 1960, Landslides in the San Francisco South quadrangle, California: U.S. Geol. Survey open-file rept., 44 p.

_____1971, Preliminary geologic map of the San Francisco South and part of the Hunters Point quadrangles: U.S. Geol. Survey Misc. Field Studies Map MF-311, scale 1:24,000.

Brabb, E. E., 1964, Subdivision of San Lorenzo Formation (Eocene-Oligocene), west-central California: Am. Assoc. Petroleum Geologists, v. 48, no. 5.

Brabb, E. E., and Pampeyan, E. H., compilers, 1972a, Preliminary geologic map of San Mateo County, California: U.S. Geol. Survey Misc. Field Studies Map MF-328, scale 1:62,500.

_____1972b, Preliminary map of landslides in San Mateo County, California: U.S. Geol. Survey Misc. Field Studies Map MF-344, scale 1:62,500.

Clark, J. C., 1966, Tertiary stratigraphy of the Felton-Santa Cruz area, Santa Cruz Mountains, California: Dissert. Abs., v. 27, no. 4.

Cummings, J. C., Touring, R. M., and Brabb, E. E., Geology of the northern Santa Cruz Mountains, California, in Geologic guide to the gas and oil fields of northern California: California Div. Mines and Geology Bull. 181.

Pampeyan, E. H., 1970, Geologic map of the Palo Alto 7 1/2 minute quadrangle, San Mateo and Santa Clara Counties, California: U.S. Geol. Survey open-file rept., scale 1:24,000.

Taylor, F. A., and Brabb, E. E., 1972, Maps showing distribution and cost by counties of structurally damaging landslides in the San Francisco Bay region, California, winter of 1968-69: U.S. Geol. Survey Misc. Field Studies Map MF-327, scale 1:500,000 and 1:1,000,000.

Reprinted 1978

Interior--Geological Survey, Reston, Va.--1977
For sale by Branch of Distribution, U. S. Geological Survey
Box 25286, Federal Center, Denver, CO 80225

USGS LIBRARY - RESTON
3 1818 00179142 3
M(200)
MF 360
c1
1978