STATE OF WASHINGTON

DEPARTMENT OF NATURAL RESOURCES

BERT L. COLE, Commissioner of Public Lands
DON LEE FRASER, Supervisor

DIVISION OF GEOLOGY AND EARTH RESOURCES

VAUGHN E. LIVINGSTON, JR., State Geologist

INFORMATION CIRCULAR 58

ENGINEERING GEOLOGIC STUDIES

1976

For sale by Department of Natural Resources, Olympia, Washington.
Price $1.00

CONTENTS

SOIL—WHAT IS IT?

By

Kurt L. Othberg
Department of Natural Resources
Division of Geology and Earth Resources
Olympia, WA 98504

Department of Natural Resources
Division of Geology and Earth Resources
Information Circular 58, Engineering Geologic Studies

1976

SOIL—WHAT IS IT?

By

Kurt L. Othberg

Information concerning the physical conditions of the land is being sought increasingly for land use planning. The great majority of that land surface is composed of earth material, which we all refer to as soil. However, in current usage, especially in reports and maps prepared for urban planning, the meaning of "soil" is ambiguous. Unfortunately, many lay people, and some technical people, are not aware of the different meanings. The most serious consequence, in my opinion, is misinterpretation of "soil" properties which are important to urban development. This paper presents the varied, technical meanings of "soil," some suggestions for increasing clarity of usage, and a discussion of the importance of distinguishing between different "soils."

The physical nature of the land we live on is studied by geologists, soil scientists (pedologists), and soil engineers (geotechnical engineers). Each of these professions is concerned with a different aspect of the earth's surface. The geologist is concerned, primarily, with the mapping of rocks and surface deposits.[1/] He emphasizes the origin and age relationships of these materials and the processes that form or modify them. Originally, geologists regarded soil as the unconsolidated sediments overlying rock (Leggett, 1967). However, during this century, many geologists have come to restrict their use of the term soil to the thin, weathered[2/] part of rock or surface deposits that forms on the surface of the earth, which is the result of climatic and biologic processes acting upon rock or unconsolidated sediment.

Pedologists and agricultural soil scientists have been primarily concerned with the mapping of the uppermost layers, or profile, of the land surface in which plants anchor their roots and derive the nutrients and water necessary for growth. The profile development varies from place to place, depending on many factors that control the degree of weathering and organic accumulation.

As used by the National Cooperative Soil Survey, soil "is the collection of natural bodies on the earth's surface, in places modified or even made by many of earthy materials, containing living matter, and supporting or capable of supporting plants out-of-doors. Soil includes horizons near the surface differing from the underlying rock material as a result of interactions among climate, living organisms, parent materials, and relief in combination. In the places where the soil has genetic horizons, it is at least as deep as the horizons that have evidence of biological activity in combination with other factors. Where the soil lacks genetic horizons, it grades at its lower margin to hard rock or the earthy materials virtually devoid of roots, animals, or marks of other biologic activity," (Soil Survey Staff, 1973). Below soil in the pedological sense lies parent rock or parent material, which include consolidated igneous, metamorphic, and sedimentary rocks, as well as unconsolidated surface deposits.

Engineers have continued to use the word soil in the original meaning defined as "sediments or other unconsolidated accumulations of solid particles produced by the physical and chemical disintegration of

---

1/ Surface deposits are geologically young sediments, such as alluvium, glacial deposits, landslide debris, etc.

2/ Weathering: The mechanical, chemical, and biological processes whereby mineral matter on exposure to the weather (wind, water, or ice) changes in character and decays and crumbles.

rocks, and which may or may not contain organic matter" (American Society for Testing and Materials, 1967). Engineering soil is the combination of raw, unaltered surface deposits, plus the pedological horizons in which plants root. This is approximately equivalent to regolith, as used by soil scientists and some geologists to mean all loose earth materials above solid rock.

To generalize, there are two different technical definitions and usages for the word "soil": (1) the plant-related genetic profile (hereafter refered to as "agricultural soil"), and (2) regolith (hereafter referred to as "engineering soil"). Soil scientists and surficial geologists use definition (1), soil engineers (geotechnical engineers) and engineering geologists use definition (2). Rarely, however, will the distinction of usage be explained in a report written by technical people.

In order to be clearly understood, our usage of the word soil must be carefully defined, and further, we must point out to others that the ambiguity exists. By specifying the actual usage of the term in existing maps and reports, and by precisely defining terminology in future maps and reports, applied earth science can serve the public in a better way.

Some of the ways that earth materials can be described specifically are as follows:

Earth materials or geologic materials: The most general case, from solid rock to a humic A-horizon.

Rock: Consolidated earth materials, sedimentary, igneous, and metamorphic in origin.

Surface deposits: Unconsolidated[1/] earth materials deposited or accumulated by geologic agencies, and which underlie agricultural soil. Surface deposits arbitrarily begin at the lower limit of agricultural soil.

Agricultural soil: Unconsolidated earth materials comprising that part of the surface of the ground which has been modified through time by climatic and biologic agents. Its lower limit is hard rock or mineral matter devoid of roots or other marks of biologic activity.

Engineering soil or regolith: All unconsolidated earth materials. Includes agricultural soil and surface deposits.

Geotechnical reports written by soils engineers and engineering geologists will deal with the particle size, strength, and a number of other factors important to engineering work. They study soil at all depths, depending on need. The need for a light-duty roadway requires study of only a few feet of engineering soil. For building foundations, the investigation may go tens of feet deep via bore holes and trenches. The properties of the more than 3,000 feet of soil underlying Seattle may be studied by engineers for earthquake response in that city. There can be little doubt that soil studied by engineers is the soil most important to urban planning.

The U.S. Department of Agriculture Soil Conservation Service has published a number of reports with maps of agricultural soils. These maps have frequently been utilized for urban planning purposes. The older reports do not clearly define soil, and, in fact, use the term in both senses: "soil (definition 1) is the product of the forces of the environment acting on the soil (definition 2) materials deposited or accumulated by the geologic agencies" (Glassey and others, 1958). Soil (1) is agricultural soil, soil (2) refers to surface deposits, or the unweathered part of engineering soil. Newest reports, such as the Jefferson County Soil Survey (McCreary, 1975), define soil in the glossary and avoid the ambiguity by using "parent material" instead of "soil materials" when referring to surface deposits.

1/ Unconsolidated in the geologic sense rather than the engineering sense; for example, surface deposits such as glacial till are very compact, but have not been cemented into hard rock.

The modern soil surveys include interpretations of engineering properties for urban uses. Detailed, valuable data is presented for each significant horizon of the agricultural soil. However, one must not assume that the properties can be extrapolated into the engineering soil lying below.

Geologic maps, which are published by the U.S. Geological Survey, the Washington Division of Geology and Earth Resources, and the Washington Division of Water Resources, vary in the types of earth materials mapped and their intended use. Many geologic maps show bedrock but either ignore engineering soils or commonly lump them together as alluvium. Surficial geologic maps show rocks and sediments that directly underlie the earth's surface. They emphasize distinctions between types of sediments and are, in effect, maps of surface deposits or that part of engineering soil that lies below agricultural soil. Geologic maps have little or no value for agricultural purposes. Although surficial geologic maps deal directly with engineering soils, many, such as the geology and ground water reports, have no engineering interpretations. However, land use interpretative geologic maps are available through engineering geology consultants, and have been made, upon request, by the Washington Division of Geology and Earth Resources for counties. Land use interpretive geologic maps present specific engineering soil and rock interpretations.

Urban planning requires analysis of land characteristics so that each land use can have the least number of deleterious effects for the land, buildings, and people. Agricultural soils should be studied so that the ideal land for crops and timber can be identified. Engineering soils and rocks should be studied so that mineral and ground water resources can be conserved and the effects of geologic hazards such as landsliding, shoreline erosion, earthquakes, and subsidence can be minimized.

As a result of repeated invasions of glaciers, the Puget Lowland has thick engineering soils, with thin agricultural soils developed in them. In order to understand the character and distribution of the engineering soils, and in turn make the best land use plans, one needs information about both aspects of engineering soils: agricultural soils and the underlying surface deposits. The best information available on surface deposits is a surficial geologic map.

SELECTED REFERENCES

American Society for Testing and Materials, 1967, Book of A. S. T. M. Standards, Part 2: American Society for Testing and Materials, Philadelphia, p. 298.

Flint, R. F., 1971, Glacial and Quaternary geology: John Wiley and Sons, New York, 892 p.

Haynes, Vance, 1973, Soil redefined: Geotimes, v. 18, no. 11, p. 8.

Hunt, C. B., 1972, Geology of soils; their evolution, classification, and uses: W. H. Freeman and Co., San Francisco, 344 p.

Gary, Margaret; McAfee, Robert, Jr.; Wolf, C. L., 1972, Glossary of geology: American Geological Institute, Washington, D. C., 805 p. plus 52-page appendix.

Gillott, J. E., 1968, Clay in engineering geology: Elsevier Publishing Co., New York, 296 p.

Glassey, T. W.; and others, 1958, Soil survey of Thurston County, Washington: U.S. Department of Agriculture Soil Conservation Service, in cooperation with the Washington Agricultural Experiment Station, 79 p. plus 35 map sheets.

Leggett, R. F., 1967, Soil— Its geology and use: Geological Society of America Bulletin, v. 78, no. 12, p. 1433-1456.

Leggett, Robert, 1973, Soil: Geotimes, v. 18, no. 9, p. 38-39.

McCreary, F. R., 1975, Soil survey of Jefferson County area, Washington: U.S. Soil Conservation Service, in cooperation with the Washington Agricultural Experiment Station, 100 p., plus 70 map sheets.

McLerran, J. H., 1954, State of Washington Engineering Soils Manual; Part 1, The Engineer and Pedology: Washington State Council for Highway Research, 56 p.

Millot, Georges, 1970, Geology of clays: Springer-Verlag, New York, 429 p.

Soil Science Society of America, 1973, Glossary of soil science terms: Soil Science Society of America, Madison, Wisconsin, 33 p.

Soil Survey Staff, 1973, Soil taxomony—A basic system of soil classification for making and interpreting soil surveys [preliminary, abridged text]: U.S. Soil Conservation Service, 330 p.

THE ROLE OF GROUND WATER IN SLOPE STABILITY

By

Walter D. Paterson
Consulting geologist
405 Alaska Trade Building
Seattle, WA 98101

Department of Natural Resources
Division of Geology and Earth Resources
Information Circular 58, Engineering Geologic Studies

1976

CONTENTS

THE ROLE OF GROUND WATER IN SLOPE STABILITY

By

Walter D. Paterson

INTRODUCTION

Slope stability exists as long as the shear strength [1/] of the soil [2/] exceeds the shearing stresses. [3/] Any change of conditions that causes the stress to equal or exceed the strength will result in instability and probable slope failure, in the form of landslides, mudflows, or other mass movements of earth. Increases in stress, with the exception of those caused by earthquakes, blasting or other dynamic forces, are generally related to visible changes, such as erosion, man-made cuts and fills, or building loads, whereas decreases in strength are due to internal changes within the mass of the soil. The most important element affecting the strength of soil is ground water.

GROUND WATER

Precipitation that reaches the ground either returns to the atmosphere by evaporation and transpiration, runs off through surface streams, or percolates downward through the soil. If the quantity of water is sufficient, downward percolation will continue until either an impermeable barrier or a zone of saturated soil is reached.

The upper boundary of the zone of saturated soil marks the water table. The zone of saturation may be supported by an impermeable formation of limited lateral extent, with incomplete saturation occurring below the barrier. The water table in this situation is said to be perched.

EFFECTS OF GROUND WATER ON THE STRENGTH OF SOIL

The processes by which ground water affects the stability of soil are described below.

Subsurface Erosion (Piping)

A highly permeable formation may develop a subsurface water flow of sufficient concentration and velocity to remove the finer grains of soil; this can result in the formation of narrow conduits or pipes through which the soil material is removed. The process accelerates as removal of the fine grains increases the permeability, which in turn increases the flow of water and causes larger grains to be eroded from the formation. The limiting factors are the available supply of ground water and the grain-size distribution within the soil.

Ultimately, the slopes may slump into groundwater discharge area. Piping has been a problem in improperly constructed earth dams and reservoir em-

---

1/ Shear strength is the resistance of a material to deformation or fracture by sliding of one section of the material against another section.

2/ Soil is a natural aggregate of mineral grains that can be separated by gentle mechanical means, such as agitation in water (Terzaghi and Peck, 1948).

3/ Shearing stress is the force, per unit area of material, that tends to cause deformation or fracture by sliding of one section of the material against another.

bankments where, because of the essentially unlimited water supply, the process may accelerate until failure of the structure occurs. Any excavation that cuts a permeable sand and gravel formation could initiate the piping process, and slumping along slopes may result if a sufficient supply of ground water is available.

Solution

Some granular soils are cemented by chemically precipitated minerals, which are soluble in water. Removal of the cement may reduce a relatively strong formation, capable of standing nearly vertical, to a cohesionless granular soil that tends to be unstable in steep slopes. Chemical cements are rare in the glacial deposits of the Puget Sound Lowland, and those soils that do contain soluble cementing materials are not vulnerable to rapid solution unless there is a radical change in either the rate of flow or the acidity of the ground water.

Frost

Freezing and thawing of water in the soil causes a heaving of the surface. The heaving on steep slopes results in sloughing and may, over a period of years, undercut overlying soils, which are not affected by the freezing. Glacial tills[1/] are particularly subject to frost action because they are heterogeneous soils capable of carrying some water, but they are not free draining. The readily observable instability developes slowly so that serious damage can generally be prevented.

Surface Tension

Completely dry, clean sand will stand at an angle of repose determined by the shape and roughness of the individual grains. The angle is generally less than 30 degrees. The addition of sufficient moisture to form a film around each grain creates added strength through surface tension; therefore, damp, fine sand may stand in a vertical bank. As the grain size increases, the effect of surface tension becomes less.

Sand in freshly exposed slopes is generally damp, and as drying takes place, slumping and running of the sand reduces the slope to the angle of repose of dry sand. Surface tension may also be destroyed by increasing the moisture content of a granular soil to the point of saturation. Saturation implies the development of pore pressure which is discussed in detail below.

Pore Pressure

The most common cause of landslides in the Puget Sound area is the reduction of soil strength resulting from an increase in ground-water pressure. The shear strength of soil is partly a function of the internal friction between the grains. The hydrostatic pressure of the water in the pore space of the soil is pore pressure. Increasing the pore pressure reduces the contact pressures between the grains of soil; consequently, the internal friction and the shear strength are reduced. In an extreme case, the entire weight of overburden may be carried by the pore water and the shear strength is reduced to nearly zero. Pore water also increases the stress in soil by increasing the weight.

Pore pressure is increased by a rising water table, which in turn, may be due to any of the following events.

1. An increase in the rate of precipitation.
2. Abnormal accumulations of surface water through diversion or blockage of surface drainage, creation of new reservoirs, or raising water levels in existing reservoirs.

[1/] Glacial till is a soil deposited directly by glacial ice. In the Puget Lowland, till usually refers to the dense soil deposited under a moving glacier and is commonly referred to as "hardpan."

3. Stripping of overburden from more permeable formations causing an increase in the downward percolation of ground water.

4. Introduction of water to the soil through drain fields or other subsurface structures.

5. Blockage of subsurface drains, springs, or seeps.

6. Reduction in the rate of pumping from ground-water reservoirs.

In the Puget Lowland, landslides, caused by increased pore pressures, are frequently the rotational type in which shearing occurs along a concave surface. In areas where soil formations dip toward a steep slope, movement may take place along a bedding plane.

Movement of a slide block tends to relieve the pore pressure through the release of water. If the released water readily escapes from the slide mass, a more stable condition will develop; however, if the water does not escape, all or part of the disturbed soil may become supersaturated and form a mudflow. Mudflows are potentially the most dangerous of all earth slides because they may move great distances at high velocities over relatively low slopes. Mudflows are not always secondary effects resulting from block slides. A mass of loosely packed soil may tend to absorb precipitation at a much greater rate than it will drain. Once the mass becomes saturated, any disturbance may reduce the average porosity and produce a supersaturated mixture that will flow as a liquid. In a like manner, fine soils, known as sensitive silts or clays, have an intergranular structure, which may be altered when disturbed. The alteration of the structure rapidly produces the supersaturated condition required to cause flow.

Lubrication

The lubrication effect of water is often considered to be a major factor in slope stability. Actually, water content in the soil tends to improve cohesion in fine-grained materials through the development of surface tension provided the water does not reach the saturation point. As the water content increases to saturation, the internal pore pressure becomes the dominating influence. Slides, which move along a clay layer interbedded between stronger formations, are in a sense lubricated by the wet clay.

PREVENTION OF GROUND-WATER-INDUCED SLIDES

Subsurface Erosion (Piping)

Piping could be controlled by reducing or eliminating the flow of ground water; however, this is generally less practical than controlling the flow in the area of discharge. A cover or blanket of sand and gravel properly graded on the slope over the area of ground-water discharge, with the coarser material on the outside of the blanket, forms an inverted filter over the discharging water. The blanket reduces the velocity of flow by increasing the length of the discharge path and increasing the area of discharge. Under no circumstances should the discharge of ground water be blocked or retarded.

Solution

A known source of acidic water might be prevented from percolating into the ground; otherwise, there is no practical way to prevent solution of cementing material. Fortunately, the solution process is rare in the Puget Lowland.

Freezing and Thawing

Slopes, which are subject to sloughing under freezing and thawing conditions, may be protected by a layer of free draining sand or gravel. The permeable layer is not affected by freezing and at the same time prevents frost from reaching the underlying soil. However, the maintenance of a permeable blanket on a steep slope may be difficult.

Surface Tension

Loss of surface tension, through drying of fine-grained noncohesive soil, can be prevented or at least retarded in our cool, humid climate by a cover of vegetation. Loss of surface tension through saturation requires control of ground water as described below.

Pore Pressure

Landslides caused by excessive pore pressure can best be prevented by controlling the ground water. Ground-water levels can be lowered by reducing the recharge at the source or by removing water from the aquifer. Lowering of reservoirs and improvements of surface drainage will reduce recharge, but these procedures are not often practical. In most areas, the water table must be lowered by dewatering the aquifer.

The choice of dewatering methods depends on the characteristics of the aquifer and its relationship to the surface topography. The methods described below have been used successfully in the Puget Lowland.

Deep Wells

Deep wells are most effective where the soil to be dewatered is a part of, or is directly connected to, a deeper aquifer with good permeability. A single deep well may be capable of dewatering a large area. The disadvantage of this system is the cost of drilling and developing the well and the long period of time required to lower the water table.

Large Diameter—Shallow Wells

A large diameter perforated pipe may be dropped into a rapidly excavated hole dug by a bucket auger, backhoe, or similar type of equipment. Gravel is packed around the casing. The method is relatively inexpensive; however, the hole usually cannot be dug more than a few feet below the water table.

Water pumped from a well may contain substantial quantities of fine sand and silt. This is particularly true for dewatering wells, which are necessarily pumped at or near the highest possible rate. The removal of fines from the soil can result in a loss of bearing strength and settlement in the area immediately surrounding the well.

Well Points

In soils of low permeability, the effective radius of wells may be only a few feet. Well points are 1- to 4-inch diameter screens that are constructed to be either drilled or driven into the soil. The spacing is usually four to eight feet between centers with several of the points being connected to a manifold at the surface. A suction pump is used to pull the water from the system. The disadvantage of the system is that it cannot be made to work at depths greater than about twenty-five feet below the elevation of the pump.

Drilled Horizontal Drains

Horizontal drains can be drilled into slopes. They should, if possible, be directed along the most permeable layers of soil. Drains have the advantage of not requiring a pump.

Excavated Drains

Excavated drains vary from simple inexpensive ditches to complex underground galleries. The more elaborate systems require detailed knowledge of the soil and ground-water conditions.

All dewatering systems should include observation wells or piezometers to measure changes in ground-water levels. The monitoring of the water levels is necessary to determine the effectiveness of the system at the site and to indicate possible effects on the surrounding area. Lowering of the water table can result in excessive settlement and damage to structures founded on compressible organic soils. The possible damage to existing wells and springs should also be considered.

SELECTED REFERENCES

Eckel, E. B., editor, 1958, Landslides and engineering practice: National Academy of Sciences-National Research Council Publication 544, 232 p.

Gilluly, James; Waters, A. C.; Woodford, A. O., 1968, Principles of geology, 3rd edition: W. H. Freeman Co., San Francisco, 687 p.

Paige, Sidney, chairman, 1950, Application of geology to engineering practice: Geological Society of America Berkey Volume, 327 p.

Terzaghi, Karl; Peck, R. R., 1948, Soil mechanics in engineering practice: John Wiley and Sons, New York, 566 p.

Zaruba, Quido; Mencl, Vojtech, 1969, Landslides and their control: Elsevier Publishing Co., New York, 205 p.

POTENTIAL LAND USE PROBLEMS OF PUGET SOUND SHORE BLUFFS

By

D. W. Mintz
Department of Geography
and Regional Planning

R. S. Babcock
Department of Geology

T. A. Terich
Department of Geography
and Regional Planning

Western Washington State College
Bellingham, WA 98225

Department of Natural Resources
Division of Geology and Earth Resources
Information Circular 58, Engineering Geologic Studies

1976

CONTENTS

ILLUSTRATIONS

POTENTIAL LAND USE PROBLEMS OF PUGET SOUND SHORE BLUFFS

By

D. W. Mintz, R. S. Babcock, and T.A. Terich

INTRODUCTION

Cities and counties adjacent to Puget Sound now account for 65 percent of the state's population. Not surprisingly, a great number of residential homes and summer cottages have been built on or near the shore. The desirability of doing this is quite understandable: the esthetic enjoyment of water and mountain views; beach recreational opportunities; and, in some circles, an increased social prestige.

A shifting state population, rising personal income, and a diminishing amount of per-capita shoreline have had the effect of increasing the economic value of waterfront property. Relative to prices paid for other residential property, waterfront lots may be five to eight times more expensive. Because of the high dollar costs involved in acquiring waterfront property, people may understandably want to ensure that precautions are taken so their investment is not devalued, damaged, or lost because of geologic hazards.

This paper is presented as a guide to understanding the natural geologic processes that affect banks along the shoreline in Puget Sound. Such knowledge should allow landowners and land use planners to assess conditions affecting shoreline property and to take measures that would alleviate any potentially destructive situation. Most of the examples in this report have been drawn from Fidalgo Island in Skagit County; however, it is believed that the geologic characteristics of the island and the natural shoreline processes operating there are similar to those found throughout the Puget Sound area.

Real estate agents generally subdivide shoreline property into three categories: (1) high bank, (2) low bank, and (3) no bank waterfront. Although the last two categories are probably the most desirable, most of the Puget Sound shoreline is characterized by bluffs, with banks varying from several feet to more than 400 feet high. Thus, the discussion in this paper will center on the processes that operate through time to erode and degrade these higher bluffs. A knowledge of such processes may be important, not only to maintain property values but to protect human safety as well.

MATERIALS AND PROCESSES

BLUFF MATERIALS

Materials making up bluffs along the shoreline in the Puget Sound can be subdivided as follows:

Bedrock: Solid, jointed or fractured rock.

Clay-silt: Very fine particles deposited by glacial melt water in former river deltas and lake bottoms farthest from the source area (distal deposit).

Glacial till: Mixture of rock fragments embedded in a fine-grained matrix; commonly called boulder-clay or hardpan.

Outwash: Well-sorted layers of gravel, sand, or finer sediments deposited by glacial melt water, near the source area (proximal deposit).

Although bedrock sea cliffs are common in San Juan, Whatcom, and Skagit Counties, most of the Puget Sound shoreline consists of glacial till, outwash, clay-silt, and nonglacial clay-silt, or a composite of these. These materials were deposited during the last episodes of continental glaciation in this region, approximately 10,000 to 50,000 years or more ago. Unless a great deal of fracturing and(or) extensive weathering has occurred, bedrock sea cliffs represent much less of a stability problem than glacial deposits. In particular, outwash sand and gravel and the clay-silts are generally poorly to moderately compacted, and thus are highly susceptible to wave erosion and mass movement. The physical nature of glacial tills is highly variable, but most units are relatively well compacted and therefore more stable.

The engineering properties of bank materials, such as shear strength, permeability, or bearing capacity, may also place constraints on shoreline development. A good example is the so-called "quick-clay," which is commonly of glacial origin. The structure of this material is thought to resemble a "honeycomb" that retains large amounts of moisture without loss of cohesion. However, if the honeycomb structure is destroyed by ground vibrations, the quick-clay immediately converts to a liquid, which will flow if a slope is present. The devastation in the Turnagain Heights section of Anchorage during the 1964 Alaska earthquake is believed to be the result of such a quick-clay collapse.

MASS MOVEMENT PROCESSES

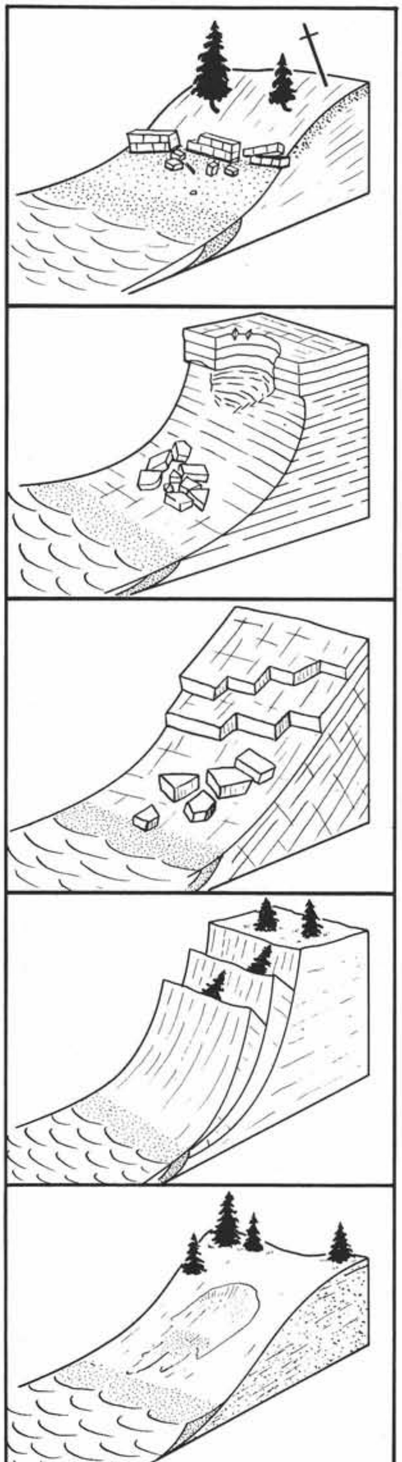
Besides the erosional effects of breaking waves or the runoff of surface water, shoreline bluffs are also subjected to the movement of materials downslope, under the influence of gravity. Such gravitational transport is generally called mass movement. Figure 1 shows the characteristics of several types of mass movement, subdivided according to the speed of motion involved.

Many bluffs that are quite stable when dry become highly susceptible to mass movement when enough water is present to lubricate slide surfaces or to produce a semiliquid mass from poorly compacted sediments. Thus, it is not surprising that many slope failures occur during or just after periods of heavy rain. Also, if water is present in bluff materials during a freeze-thaw cycle, the growth and melting of of ice crystals may have a considerable effect on slope stability.

Many bluffs in the Puget Sound region can be considered to be in a delicate state of balance with gravity. When this balance is disturbed by man or nature, mass movement may result. There are at least four categories of such disturbances.

> Undercutting removes the toe support of a bluff. This is most commonly due to wave erosion, but manmade excavations can have the same effect.
>
> Overloading the top of the bluff can have the same result as undercutting the lower toe-section. Thus, considerable care must be exercised in locating structures or landfill relative to the bluff's upper edge.
>
> Saturating bluff materials enhances instability, either by reducing cohesion or by increasing load due to the water's weight. Water is often inadvertantly introduced by septic tank drain fields, by watering lawns, or by leaking water mains and sewers.
>
> Vibration from earthquakes, blasting or heavy equipment operation may cause a loss of cohesion in bluff materials, resulting in mass movement.

PROCESSES | CHARACTERISTICS



CREEP

Imperceptibly slow downslope gliding of unconsolidated soil or rock. The movement may involve a particle-by-particle transfer or slow distortion of a larger mass of surficial material.

FALL

Extremely rapid movement of consolidated or unconsolidated material downward in a vertical or near-vertical path.

PLANAR SLIDE

Imperceptible to rapid movement of either consolidated or unconsolidated material along inclined surfaces defined by fractures or bedding planes. Introduction of water may facilitate movement either by increasing load or by lubricating slip planes.

SLUMP

Similar to planar slides except that movement occurs along internal slip surfaces, which are generally concave upward.

FLOW

Viscous downslope movement of distinctly bounded masses of unconsolidated surficial material. Rates of movement vary from a few feet per hour to several feet per second depending upon type of material, slope, water content, vegetation and other factors.

FIGURE 1.—Characteristics of several types of mass movement (modified from Longwell and others).

EFFECTS OF WAVES ON BEACHES AND BLUFFS

Wave attack is an important facet of the erosion-deposition cycle on the beach and bluff backshore. Waves erode the bluff by undercutting, and then transport the eroded material one way or another along the beach. The severity of erosion potential by waves can be understood when one briefly examines the origin, mechanisms, and processes of waves.

Waves are generated by wind blowing over the water. In general, the largest waves are generated by continuous high-wind velocities over a long, large body of deep water. The open-water distance over which wind blows is known as fetch. Because of the relatively short fetches and shallow waters in Puget Sound, maximum wave heights seldom exceed 4 to 5 feet. Because waves are generated by wind, the larger waves occur during the winter storms when wind speeds are correspondingly highest. If a storm should coincide with a high tide, waves will be able to attack at the upper reaches of the beach with more severity. Figure 2 illustrates the effects of a combination of high tide and relatively large waves working together to erode a bluff. In this case, however, the maximum wave heights were under two feet.

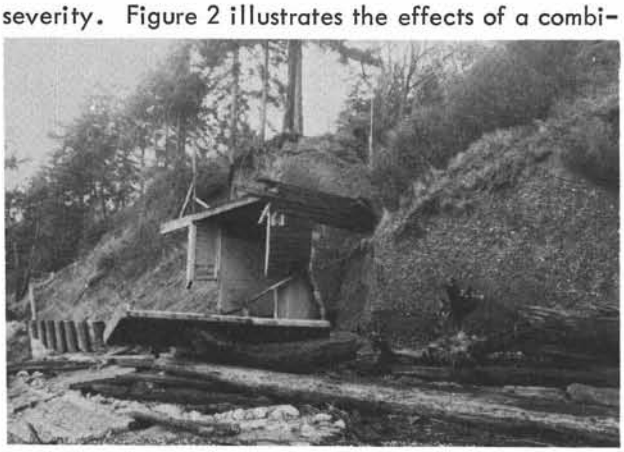


FIGURE 2.—Undercutting by wave attack. Establishing construction date may give one the rate of bluff retreat.

Waves are measured not only in terms of height, but also length and period. Wave length is the horizontal distance between two wave crests. Period is the time lapse between successive wave crests passing a fixed point. Wave period may either be expressed in terms of seconds, as the lapse time between two successive wave crests, or in terms of the number of crests passing a fixed point in one minute. Wave period is important, for given the same wave height, different wave periods cause different effects on a beach. Longer period waves on the order of 6 to 7 per minute tend to be "constructive" to a beach. These wave periods build up, or prograde the beach. Short period, steep waves, on the order of 12 to 14 per minute, are "destructive" and erode the beach. This erosion is due to increased, more continuous wave turbulence keeping material in suspension, and an increased volume of wave swash and backwash moving on the beach. Because of the short wind fetches in the Puget Sound, storm-driven wind waves have a short period and are very erosive. If high tides occur during a storm, then the effect of these waves will reach farther up the backshore.

The highly irregular nature of Puget Sound's shoreline, with its numerous islands, bays, and headlands, presents a variety of wind and wave exposures. Generally, those beaches and bluffs exposed to the relatively long fetches to the southwest, south, and southeast are most susceptible to intense wave attack from winter storms. On the other hand, beaches and bluffs with west, northwest and north exposures on the leeward side of the predominant storm direction are less likely to experience severe wave attack.

If one examines a beach in the summer and returns to it again in the winter, he might well wonder if it is indeed the same beach. The change in the physical nature of the beach is primarily the result of seasonal differences in wave attack. This difference is found in wave period, length, height, and direction. The small wave heights and longer period waves of summer drive sand onshore and build up the beach. The broad, gently inclining sand beach will extend from the surf up to a bluff or vegetation zone of the backshore. However, the higher, steeper and shorter period waves of winter quickly change the beach profile. Winter waves remove the sand accumulated in summer, and transport it either to deeper water or to another section of the beach. The result is that the winter beach is usually narrower, steeper, and rockier; quite different from the summer beach. The winter beach thus provides less of a natural buffer to incoming waves. This phenomenon, like the effect of high tide, enhances the impact of storm waves on the toe of a bluff.

Wave attack erodes beach-front property by three mechanisms.

1. Chemical-solution: The weathering action of the sea water dissolving intragranular bonding materials and carrying them away in solution.

2. Hydraulic plucking: Caused by water compressing air so that pressure of several thousands of pounds per square inch is bashing the erosional surface. This high pressure breaks apart almost any material—concrete included.

3. Wave scour: The result of material, such as sand and pebbles, abrading the erosional surface, much like a sand-blasting machine.

Resistance to erosion varies according to the geologic composition of the bluff. For example, the erosion of exposed bedrock cliffs (such as Chuckanut Drive in Whatcom County) is considerably less than that eroded from parts of the western side of Fidalgo Island, which are composed of poorly compacted gravel, sand, and clay-silts.

After material has been eroded by wave attack, it is removed from the beach by shore drift. Shore drift is the term that describes both the material carried along by waves on the beach, known as beach drift, and that carried by currents close to the shore, known as longshore drift. Once again, the rapidity and quantity of sediment movement on a beach is a function of the periods of incoming waves, their steepness and direction relative to the shoreline. Greater amounts of material tend to be moved when large waves with short periods (close together) and steep sides approach the beach at an angle of 45°. Because of shore drift, extreme care must be exercised when building jetties, docks, or seawalls. These structures will impede or stop shore drift causing the beaches to the lee side to be "starved" of beach material, and thus hasten bluff erosion because the beach buffer has been removed or lessened.

OVERVIEW

The understanding of bluff and beach processes is academic unless this knowledge can be applied in a functional way. Therefore, this unit discusses the general principles to keep in mind when acquiring water-front property and preparing it for house construction.

EROSION PROCESSES

First of all, an initial walk-around at the site can provide a great deal of information about active erosion processes and rates. Some features to look for are listed below:

Bluff materials: Is the bluff composed of bedrock, till, outwash, clay-silt, or a complex mixture of each? If the bluff is composed of different layers of material, is one obviously weaker than the others?

Bluff undercutting: Scour marks by wave attack; note where the high tide and storm waves have driven beach material and driftwood.

Debris flows: An unconsolidated mixture of bank material, vegetation, and water, with an irregular "oozed" appearance.

Manmade structures: Do any structures, such as bulkheads or steps, indicate that the shoreline is eroded? Are there any structures on either side of the property that cause the beach to be "starved" or void of sand and gravel? Figure 2 obviously indicates rapid bluff retreat.

Shore drift: Is the beach profile steep, indicating short-period, erosive waves? Is there an obvious direction of shore drift? What is the direction and length of fetch?

Slumping: Cracks in earth or terraces parallel to the bluff's edge; slump scars on face of bluff (fig. 3).

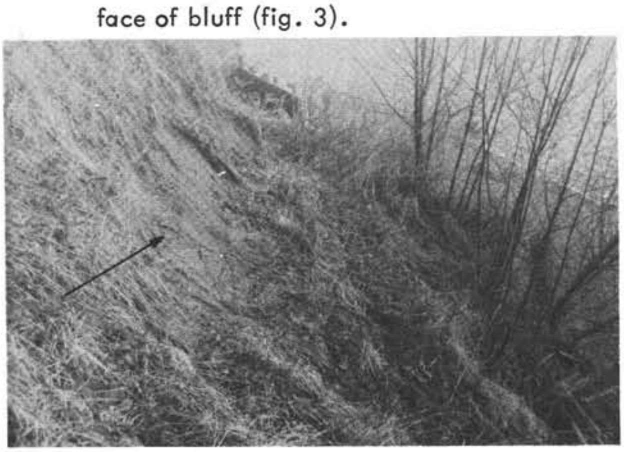


FIGURE 3.—Bluff slump scar.

Soil creep: Trees tilted downslope; overturning and tension cracks in retaining walls; especially note highly susceptible areas that have been disturbed by excavation or the dumping of fill. Figure 4 illustrates how soil creep has displaced a seawall.

Surface runoff: Look for rills or channels on top of the bluff or on the bluff face, plus small deltas and alluvial fans formed at the base of the bluff.

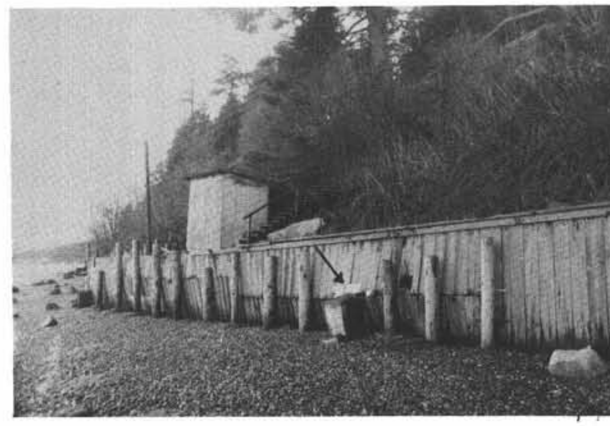


FIGURE 4.—Effects of soil creep.

Vegetation: Note whether vegetation has controlled surface runoff and stabilized the bank.

PREPARATION OF BUILDING SITE

After this walk-around, you will then have an idea of what natural processes are most active or that have the potential to erode the bluff. When preparing the site for building, the objective is to minimize and control activities that will increase the natural mass movement processes already at work.

Disturb the vegetation and natural slope as little as possible

The removal of vegetation or major regrading often results in a drastic change in surface runoff and the ground-water table. Such changes may result in the bluff establishing a new equilibrium with attendant slumping, flows, and surface gullying. The bluff's adjustment to this change can last for several years.

Ground cover should be introduced if possible on all exposed, raw earth

This includes exposed faces of the bluff. Common bank ivy as well as a host of other plants help to prevent surface erosion. Consult your local county extension agent or nursery for specific recommendations.

Take care in depositing fill material

If possible, excess excavation fill should be removed from the site rather than used for "leveling out" the lot. Fill removal decreases the load on the bluff, and also decreases the amount of unconsolidated material that is most vulnerable to creep and flow. Fill material should not be dumped over the bluff as this material may alter the natural vegetation, drainage, and compaction of the bluff face.

If the bluff is being undercut by wave attack, shore defense structures may be the only recourse

Breakwaters, seawalls and riprap are commonly used but considerable care must be taken to assure that such structures do not upset the natural shoreline equilibrium. Also, all structures must be periodically inspected and repaired. Figure 5 illustrates how the failure of even a small section of a wooden bulkhead resulted in rapid erosion of the bluff. Prior to construction, local planning or building department offices should be contacted for advice on construction techniques and shoreline regulation statutes.

FIGURE 5.—Effects of seawall failure.

Take care in the location of septic tanks and drainage systems

This is especially true on a complex bluff composed of both till and outwash layers together. Realize that the two materials respond quite differently to ground water. The different effects of ground water are most obvious in the adjustments of these materials to load, shrink-swell, and to freeze-thaw actions.

As of yet, there are no established rules for calculating safe set-back distances from a bluff

The rate of bluff retreat is an obvious clue, but not for preventing overloading and slumping. In short, build as far back as possible.

FIGURE 6.—Seawall subjected to wave attack and breaching from the side; slumping.

Finally, the bluff protection measures taken by one owner may be effectively negated by the neglect of another owner

Slumps, local water tables, and wave attack do not respect property lines. Therefore, collective action is often required of adjacent landowners. For example, a structurally sound and well designed seawall can be rendered useless by wave attack working on the next lot. Figure 6 illustrates how a wooden seawall has been breached from the side. In this case, slumping also resulted from undercutting. Again, prior to any collective action, consult with your local building or planning department.

If any of the previously described conditions exist on a site or if stability or other geologic problem is evident or suspected, contact an engineering geologist. In most cases a detailed engineering and geology report is recommended for individual site evaluations and investigations.

SELECTED REFERENCES

Recent Geologic History of Puget Sound

Easterbrook, D. J., 1969, Pleistocene chronology of the Puget Lowland and San Juan Islands, Washington: Geological Society of America Bulletin, v. 80, no. 11, p. 2273-2286.

McKee, Bates, 1972, Cascadia: McGraw-Hill Book Co., New York, 394 p.

Bluff Processes

Flawn, P. T., 1970, Environmental geology—Conservation, land-use planning, and resources management: Harper and Row, New York, 313 p. (especially note chapter 2).

Legget, P. T., 1962, Geology and engineering, 2nd edition: McGraw-Hill Book Co., New York, 884 p. (especially note chapter 11).

Longwell, C. R.; Flint, R. F.; Sanders, J. E., 1969, Physical geology: John Wiley and Sons, New York, 685 p.

Paige, Sidney, chairman, 1950, Application of geology to engineering practice: Geological Society of America Berkey Volume 327 p. (see chapter by K. Terzaghi on mechanism of landslides).

Beach and Wave Processes

Bascom, Willard, 1964, Waves and beaches—The dynamics of the ocean surface: Doubleday and Co., Garden City, New York, 267 p.

King, C. A. M., 1960, Beaches and coasts: E. Arnold, London, 403 p.

Shepard, F. P.; Wanless, H. R., 1971, Our changing coastline: McGraw-Hill Book Co., New York, 579 p.

Wiegel, R. L., 1964, Oceanographical engineering: Prentice-Hall, Englewood Cliffs, New Jersey, 532 p.

SEISMIC RISK

By

Ernest R. Artim
Department of Natural Resources
Division of Geology and Earth Resources
Olympia, WA 98504

Department of Natural Resources
Division of Geology and Earth Resources
Information Circular 58, Engineering Geologic Studies
1976

SEISMIC RISK

By

Ernest R. Artim

Seismic risk is defined as any risk associated with earthquakes. Seismic risk can be further defined as the likelihood of damage or injury from an earthquake within a given time interval. This time interval is called a design period for engineering structures, or it can be an arbitrary interval, such as the next 50 or 120 years. Some of the natural factors included in seismic risk determination are ground rupture, ground shaking, landslides caused by the earthquake, earth "lurches," differential settlement or land subsidence, liquefaction, tsunamis, and seiches. Seismic risk determination also includes human factors, such as dam, reservoir, or any other possible structural failures, emergency services, and public utilities.

The basic objective of planning related to acceptable seismic risk is to reduce the loss of life, injuries, and property damages resulting from seismic activity to an "acceptable" level. Since it is not possible, or practical, to eliminate all seismic risk to life and property, each community or region must decide what level of risk is acceptable for its goals. Acceptable risk can be defined as follows:

> The level of risk below which no specific action <u>by local government</u> is deemed to be necessary to protect life and property.

Because risk is a function of chance, there is an inherent degree of uncertainty in using risk as a basis for land use planning. However, land use planning decisions can be made if the risks are identified that may arise from potential geologic hazards, which are associated with any proposed or existing development, program, or structure, and compared with alternative risks. If risk reduction measures are enacted and enforced, the amount of damage to property and injury to life will be reduced over a given period of time. In this respect, risk can be a framework for land use decision making.

Every seismic hazard has an associated element of risk. This risk has two aspects: one is the chance that the hazard will in fact occur; and the other aspect is that, if the hazard does occur, the measures taken to alleviate the hazard will be sufficient to reduce the damage to life and property to some predetermined acceptable level. Unfortunately, at the present time, there are no available technological methods or capabilities to control or reduce the actual occurrence of seismic hazards. Ground shaking cannot be prevented, but its effects can be minimized; and tsunamis cannot be stopped from reaching coastal areas, but wise land use planning can reduce the exposure of life and property to the hazard.

In addition, although seismic hazards can be identified, at present the prediction of exactly when a given event will occur cannot be made with any significant degree of accuracy. The risk of occurrence of a seismic event is not necessarily a suitable basis for determining acceptable risk. In other words, it would not necessarily be "acceptable" to expose a school building with a 50-year life expectancy to a potentially destructive seismic hazard with a once-in-500-years activity expectancy (assuming no other hazards were present). The time of the actual seismic event would be only theoretical with prediction based on past activity; the actual seismic hazard could, in fact, occur tomorrow, next week, next year, or in a thousand years.

The most reasonable basis for determining acceptable risk is whether the preventive measures taken to reduce the damage to life and property will result in predetermined acceptable levels of damage. Each local jurisdiction should determine its own particular acceptable risk levels, based on local land uses and building types, and on local geologic conditions. However, there are some general guidelines that should prove helpful for local jurisdictions in determining acceptable levels of risk.

Emergency services and public utilities are required to provide vital services, especially during disasters, and seismic risk should be minimal. These emergency services and public utilities include the following:

1. Emergency facilities (hospitals, medical clinics, fire and police stations, post-earthquake aid stations, etc.).

2. Utilities (power plants, water and sewage facilities, gas storage tanks, telephone lines, electrical lines, natural gas lines, etc.).

3. Communication and transportation systems (such as telephone terminals, major highways, bridges, tunnels, overpasses and interchanges, railway stations, ferry terminals, evacuation routes, etc.).

4. Water retention structures (such as dams, reservoirs, etc., used for water storage).

There should be an explicit differentiation between the risk associated with voluntary presence and the risk associated with involuntary presence. Certain types of public and private buildings and land uses involve involuntary use, and there is no choice available to the individual whether or not to submit to a given level of risk. Thus, the level of acceptable risk in these instances should be quite low. Public and private buildings and land uses requiring involuntary occupancy include nursing homes, convalescent homes, mental hospitals, schools, jails, etc.

There should be an explicit differentiation between the risk associated with buildings of high occupancy rates and buildings associated with low occupancy rates. All other factors being equal, a high occupancy building (office building, for example) will expose many more people to a given seismic hazard than a low occupancy building (warehouse building, for example). Therefore, high occupancy buildings and land uses should be required to have a risk exposure less than those of low occupancy.

Occupancy rates can be determined by multiplying the average number of persons exposed by the average number of hours exposed during some selected period of time, and dividing that product by the number of hours in the period of computation selected.

Therefore:

Or= Occupancy rate

Pe= Average number of persons exposed

Te= Average number of hours exposed during some selected period of time

Ts= Total number of hours in the period of computation selected

$$Or = \frac{Pe \times Te}{Ts}$$

Exposed persons would include all those within the building, as well as those outside, that would be reasonably endangered if the building were to experience a major structural failure during seismic activity. For comparison, the following three samples are presented:

A single family dwelling with four occupants has an average of 2.8 persons (Pe) during a 24-hour period (Ts). The average number of hours of exposure is 15.75 hours (Te).

$$Or = \frac{2.8 \times 15.75}{24} = \frac{44.1}{24} = 1.84$$

An apartment building contains 400 occupants. The average number of persons in that apartment during a 24-hour period (Ts) is 200 (Pe). The average number of hours of exposure is 12 hours (Te).

$$Or = \frac{200 \times 12}{24} = \frac{2400}{24} = 100$$

A sports arena holds 10,000 persons. The average number of persons in that arena during a 24-hour period (Ts) is 1,250 (Pe). The average number of hours of exposure is 3 hours (Te).

$$Or = \frac{1250 \times 3}{24} = \frac{3750}{24} = 156$$

No local jurisdictions have as yet used occupancy rates as a measure of acceptable seismic risk. Thus, there are no quantitative measures of high, moderate, and low occupancy rates. However, in general, high occupancy rates do tend to be associated with certain kinds of buildings and land uses, including theaters, churches, large industrial and shopping centers, libraries, large motels and hotels, restaurants, large office buildings, etc.

The level of acceptable risk must be reasonable in terms of the cost of its achievement. Minimizing risk often results in higher costs, but at some balancing point a risk becomes acceptable. At this point, the public is no longer willing to pay to reduce the risk further. The cost need not be direct (potential damage to property or loss of life), but may be indirect (foregoing some projected future economic benefit by retaining the land in open space, if the potential for seismic risk is high).

Although each local jurisdiction must determine its own priorities in terms of how much it is willing to spend to reduce existing and potential seismic risks, two factors should be considered in evaluating the cost of achieving an acceptable level of risk:

1. The reduction of risk associated with the human element should be given highest priority. At a minimum, the risk of injury and loss of life due to seismic hazards should be no greater than the risk of injury or loss of life due to disease or due to accidents.

2. The level of risk with regard to property damage should be considered acceptable only if the potential damage, in monetary terms, is less than or equal to the cost of the measures proposed to be taken to mitigate the hazard (assuming that the risks to human life are satisfied). In other words, if an earthquake could cause $1 million worth of damage to existing structures, and a structural improvement program would cost only $500,000, then the cost of the earthquake risk would not be acceptable and the structural improvement program would be an acceptable cost.

The determination of acceptable risk is applicable not only to future planning decisions but also to the evaluation of the risks associated with existing buildings and land uses. High risks may be lowered to a level of acceptable risk by means of physical alteration (a structural hazard abatement program), relocation and(or) demolition of existing structures, and the change of use of structures (from high to low occupancy, or involuntary to voluntary presence, for example). Whatever course of action is taken, the cost of achieving the acceptable level of risk should be commensurate with the benefits gained.

The evaluation of the seriousness of seismic hazards and their associated risks are the technical judgments of professionals, based on a limited amount of information of the natural physical environment. Even with a substantial amount of basic data, it would not be easy to quantify technical judgment and experience into an easily understood format. Because of this, the concept of acceptable risk has not traditionally played an important, if any, role in land use planning decision making. Generally, a structure is considered "safe" if it conforms to certain required standards, and "unsafe" if it does not.

The problem involved in addressing the concept of acceptable risk is not so much a question of whether a structure or land use is "safe" but rather "how safe." Experts are not necessarily "wrong" if their recommendations on codes, regulations and risk levels prove to be insufficient during earthquakes. Their judgments were based on available information and experience. Each seismic event that occurs will yield new data that can be used by the experts in future recommendations.

Clearly then, the role of the engineer, geologist, planner, or other professional should not be to determine the level of acceptable risk. It is their function only to lay out the guidelines that will allow the elected officials who represent the public to make the final decisions.