Chapter 5

Robert L. Schuster and
William J. Kockelman

PRINCIPLES OF LANDSLIDE HAZARD REDUCTION

1. INTRODUCTION

Careful development of hillside slopes can reduce economic and social losses due to slope failure by avoiding the hazards or by reducing the damage potential. Landslide risk can be reduced by four approaches (Kockelman 1986):

1. Restriction of development in landslide-prone areas;
2. Codes for excavation, grading, landscaping, and construction;
3. Physical measures (drainage, slope-geometry modification, and structures) to prevent or control landslides; and
4. Development of warning systems.

These methods of hazard mitigation, when used with modern technology, can greatly reduce losses due to landslides. Schuster and Leighton (1988) estimated that these methods could reduce landslide losses in California more than 90 percent. Slosson and Krohn (1982) stated that implementation of this methodology has already reduced landslide losses in the city of Los Angeles by 92 to 97 percent.

After a discussion of the aforementioned widely used approaches to landslide hazard reduction, the status of development of landslide insurance programs is reviewed. Although insurance will not reduce overall landslide hazards or costs directly, nonsubsidized landslide insurance does offer promise as a means of distributing landslide costs more widely and of reducing landslide losses for individual property owners. In addition, advice from insurance organizations can positively influence the users of land that is subject to landslide hazards.

Landslides often occur as elements of interrelated multiple natural-hazard processes in which an initial event triggers secondary events or in which two or more natural-hazard processes occur at the same time. Examples are combinations of volcanic eruptions, earthquakes, and landslides. The resulting multiple-hazard problems require a shift in perspective from mitigation of individual hazards, such as landslides, to a broader systems framework that takes into account the characteristics and effects of all the processes involved.

In recent years, risk assessment has become an important factor in landslide hazard reduction. Landslide risk assessment utilizing reliability methods in landslide susceptibility mapping, prediction, and mitigation is discussed in Chapter 6.

Optimal approaches to reduction of landslide hazards generally involve a carefully assembled mix of the above hazard-reduction strategies and techniques. To plan a coordinated and successful reduction program requires input and cooperation from engineers, geologists, planners, landowners and developers, lending organizations, insurance companies, and government entities.

2. PREREQUISITE INFORMATION

Successful landslide hazard-reduction programs in the United States commonly are based on the following factors (U.S. Geological Survey 1982):

1. An adequate base of technical information on the hazards and risks;
2. A technical community able to apply, and enlarge upon, this data base;
3. An able and concerned local government; and
4. A citizenry that realizes the value of and supports a program that promotes the health, safety, and general welfare of the community.

These same concepts apply to other countries, except that most national governments have a stronger role than that of the U.S. government.

The key to a successful landslide hazard-reduction program is awareness and understanding of the landslide problem within the geographic area involved. The work of Varnes (1978) and of Cruden and Varnes (Chap. 3 in this report) in describing and classifying mass movements and in reviewing the principles and practices of zonation as related to landslide hazards (Varnes et al. 1984) has been very helpful in this regard. Recognition and identification of landslides have been discussed in detail by Rib and Liang (1978), Hansen (1989), and Soeters and van Westen (Chap. 8 in this report).

Reliable landslide hazard maps are of significant value in establishing reduction programs. Ideally, these maps indicate where landslides have occurred in the past, the locations of landslide-susceptible areas, and the probability of future occurrences. Brabb (1984) presented examples of various types of landslide maps: inventory, susceptibility, loss evaluation, and risk determination. Of particular interest in reducing the costs of landslide hazard mapping is the use of computer techniques to produce digital maps; in much of the world, the geographic information system (GIS) approach is widely used for producing digital maps and for integrating information to develop, enhance, and complement such maps.

An important element in determining international landslide hazard distribution is the World Landslide Inventory, which is being conducted by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) Working Party on the World Landslide Inventory (WP/WLI) sponsored by the International Geotechnical Societies (1991). The Working Party, which was formed from the Commission on Landslides of the International Association of Engineering Geology, the Technical Committee on Landslides of the International Society for Soil Mechanics and Foundation Engineering, and representatives of the International Society for Rock Mechanics, assists United Nations agencies in understanding the worldwide distribution of landslides (WP/WLI 1990, 1991, 1993a,b). The five WP/WLI classes of landslide inventory cover a range that includes computer data banks with complete national coverage and systematic data capture (Cruden and Brown 1992). The *Directory of the World Landslide Inventory* (Brown et al. 1992) is a useful worldwide guide to the people and institutions that deal with landslide hazards on a regular basis.

The extent and economic significance of landslides in 136 countries and areas, including land beneath all of the oceans, were reported by Brabb and Harrod (1989). These reports have been an invaluable contribution to the International Decade for Natural Disaster Reduction.

Governmental organizations have reported on landslide hazard-reduction approaches that are of value to others attempting to develop plans for their own areas. For example, the state of Colorado, under the auspices of the Federal Emergency Management Agency (FEMA), published a report (Jochim et al. 1988) that aims to reduce landslide losses by

1. Identifying local governmental resources, plans, and programs that can assist in loss reduction;
2. Determining unmet local needs that must be addressed to reduce losses;
3. Identifying and developing state agency capabilities and initiatives that can deal with unmet local needs;
4. Developing cost-effective projects that reasonably can be expected to reduce landslide losses;
5. Educating state and local officials and emergency-response personnel about landslide hazards and potential methods for loss reduction; and
6. Establishing means to provide a continuing governmental process to reduce losses.

This FEMA report will become part of the overall hazard mitigation plan for Colorado under the auspices of the Colorado Natural Hazards

Mitigation Council. Similar plans based on local needs were prepared for the city of Cincinnati, Ohio (Hamilton County Regional Planning Commission 1976), and Portola Valley, California (Mader et al. 1988). In addition, Hamilton County, Ohio, prepared a report on the duties of the county's Earth Movement Task Force, which provides advice to those wishing to establish similar working groups (Hamilton County 1982). A succinct but comprehensive guidebook for state and local governments interested in reducing landslide losses was sponsored and published by FEMA (Wold and Jochim 1989).

An important aspect of the reduction of landslide hazards is collection and dissemination of landslide information for scientists, engineers, policy makers, and the public. An excellent national example of a public repository of information on landslide hazards is the U.S. Geological Survey's National Landslide Information Center (NLIC) in Golden, Colorado (Brown 1992). The NLIC maintains a multiple-entry data base to foster national and international exchange of landslide information among scientists, engineers, and decision makers. On an international level, the International Union of Forestry Research Organizations (IUFRO) carries out a worldwide exchange of information and assistance on a full spectrum of technical, biological, and economic measures for the control of landslides in mountainous areas.

3. MAJOR POLICY OPTIONS

Alternative management policy options are available to decision makers who are concerned with natural hazards (Petak and Atkisson 1982; Olshansky and Rogers 1987; Olshansky 1990). The three most fundamental options (Rossi et al. 1982) are to

1. Take no action at all,
2. Provide relief and rehabilitation assistance after disasters occur, or
3. Take action to contain or control hazards before serious damage occurs.

Before about 1950, the first two of these options dominated. However, as a result of technical and sociological advances, the concept of prevention of landslide disasters by appropriate land use development or structural retention is becoming increasingly important.

4. APPROACHES

Reduction of landslide hazards in the United States is achieved mainly by

1. Restricting development in landslide-prone areas, a function assisted by mapping landslide susceptibility;
2. Requiring that excavation, grading, landscaping, and construction activities not contribute to slope instability; and
3. Protecting existing development and population (property and structures as well as people and livestock) by physical control measures, such as drainage, slope-geometry modification, and protective barriers, or by monitoring and warning systems.

These techniques, which were discussed by Kockelman (1986), are used individually or in various combinations to reduce or eliminate losses due to existing or potential landslides. The first two methods can be promoted by public legislation. In the United States, such legislation commonly is under the jurisdiction of local governments. However, most other countries with major and continuing landslide losses have incorporated a strong federal or provincial role in dealing with all aspects of landslide hazard-reduction activities to ensure consistent standards of practice and application and to prevent unequal and inadequate performance at provincial, municipal, and private levels (Swanston and Schuster 1989). In the United States the federal government plays a less active role and functions primarily as a source of expertise, research support, and funding of state and local control works.

4.1 Restricting Development in Landslide-Prone Areas

One of the most effective and economical ways to reduce landslide losses is by land use planning to locate developments on stable ground and to dedicate landslide-prone areas to open space or to other low-intensity uses. This procedure, which commonly is known as avoidance, is accomplished by either or both of the following: (*a*) removing or converting existing development or (*b*) discouraging or regulating new development in unstable areas.

In the United States, restrictions on land use because of natural hazards generally are imposed and enforced by local governments by means of land use zoning districts and regulations. Some local governments in the United States have adopted ordinances that limit the amount of development in hillside areas (see Section 4.1.3). In many other countries, land use planning that leads to avoidance is a function of the national government. In Japan, which is widely and continually affected by severe landslide problems, land use regulation has not been a common feature of landslide hazard reduction for reasons related to the limited availability of land (Huffman 1986, 96).

4.1.1 Removing or Converting Existing Development

Recurring damage to existing development caused by landslides can be eliminated or reduced by evacuating the area or by converting existing structures or facilities to uses less vulnerable to slope failure. Permanent evacuation of the distressed area commonly requires public acquisition of the land and relocation of the inhabitants and their facilities.

Conversion of existing structures and facilities to uses that are less vulnerable to slope failure may be undertaken by individual property owners, by developers, or, in the case of public properties, by the government. The feasibility of successful conversion depends on the value and criticality of the facilities, their potential for triggering or resisting slope failure, whether they can be successfully retrofitted to resist slope movement, and the level of concern of their owners.

4.1.2 Discouraging New Development

Where feasible, the most effective method of reducing landslide losses is to discourage new development in landslide-prone areas (U.S. Geological Survey 1982). Methods that have been successful in the United States include the following:

- **Public information programs:** Because any program of land use control requires the support of a knowledgeable citizenry, the public must be informed of landslide hazards. Prudent citizens, when properly informed of the existence of hazards, ordinarily will support land use controls that minimize losses due to those hazards.
- **Disclosure of hazards to potential property purchasers:** Governments can discourage development in hazardous areas by enacting hazard disclosure laws that alert potential buyers to hazards (Kockelman 1986). For example, Santa Clara County, California, requires sellers of property within the county's landslide, fault-rupture, and flood zones to provide prospective purchasers with written statements of geologic hazard (Santa Clara County Board of Supervisors 1978).
- **Exclusion of public facilities:** Local governments can prohibit construction of public facilities, such as streets and water and sewer systems, in landslide-prone areas.
- **Warning signs:** Warning signs posted by local governments can alert prospective property owners or developers to potential hazards.
- **Tax credits and special assessments:** Tax credits can be applied to properties left undeveloped in hazardous areas. Conversely, special assessments can be levied on landslide-prone properties that lie within especially created assessment districts.
- **Financing policies:** Lending institutions can discourage development in landslide-prone areas by denying loans or by requiring insurance for construction or development in these areas.
- **Insurance costs:** The high cost of nonsubsidized insurance for development in hazardous areas can discourage such development and can encourage land uses that constitute lower risk.
- **Government acquisition:** Government agencies can promote avoidance by acquiring landslide-prone properties by purchase, condemnation, tax foreclosure, dedication, devise (will), or donation. The agencies are then able to control development on these properties for the public interest.
- **Public awareness of legal liabilities:** Property owners and developers can be made aware of liabilities they may have in regard to slope failure.

4.1.3 Regulating Development

To assume that development in landslide-prone areas can be discouraged indefinitely by the nonregulatory methods noted above is unrealistic. Thus, governmental regulation often is needed to prevent or control development of lands subject to landslide hazards. In the United States, restrictions on land use because of natural hazards are generally imposed and enforced by local governments by means of zoning districts and regulations. By means of land development regulations, a local government can prohibit or restrict development in landslide-prone areas. It can zone hazardous areas for open-space uses such as agriculture, grazing, forests, or parks. If development is allowed in areas subject to slope failure, the location or intensity of this development, or both, can be controlled to reduce the risk. Examples of regulations of land use in areas prone to landslide activity are discussed in Sections 4.1.3.1–4.1.3.3.

4.1.3.1 Land Use Zoning Regulations

Land use zoning provides direct benefits by limiting development in landslide-prone areas. Under zoning ordinances enacted and enforced by local governments, land use with the least danger of activating landslides includes parks, woodlands, nonirrigated agriculture, wildlife refuges, and recreation. In addition, these land uses result in relatively small economic losses if landslides do occur. Regulations can include provisions that prohibit specific land uses or operations that might cause slope failure, such as construction of roads or buildings, irrigation systems, storage or disposal of liquid wastes, and operation of off-road vehicles. Zoning regulations can also control the location and density of development in hillside areas.

To assist counties and municipalities in designing land use regulations in hillside areas in the state of Colorado, the Colorado Geological Survey prepared model regulations (Rogers et al. 1974) that permit the following land uses in designated landslide-prone areas:

1. Recreational uses that do not require permanent structures for human habitation, including parks, wildlife and nature preserves, picnic grounds, golf courses, and hunting, fishing, hiking, and skiing areas that do not result in high population concentrations;
2. Low-density agricultural uses, such as forestry, grazing, and truck-crop farming; and
3. Low-density and temporary commercial and industrial uses, such as parking areas and storage yards for portable equipment.

Colorado is currently attempting to set a national precedent in dealing with natural hazards (including landslides) by means of the Colorado Natural Hazards Mitigation Council (1992), an official statewide 300-member group composed of earth scientists, engineers, planners, and local and state policy makers whose goal is to formulate new policies regarding natural hazards in Colorado. A prime strategy of the council is to unify technical experts and policy makers on issue-directed hazard-reduction teams. These teams deal with hazards in areas that are politically responsive to innovative solutions. They prepare statewide plans based on these solutions, and the plans are used to develop policy directions for future state hazard legislation.

4.1.3.2 Subdivision Regulations

Regulating the design of subdivisions (planned local units of land designed with streets, sidewalks, sewerage, etc., in preparation for building homes) is another means of controlling development of landslide-prone areas. Subdivision design and zoning regulations must be based upon geotechnical information.

4.1.3.3 Sewage-Disposal Regulations

Residential sewage-disposal systems that rely on ground absorption (septic-tank systems, leaching fields, and seepage beds and pits) can saturate the surrounding soil and rock and cause slope failure. Thus, the design and installation of these systems must be regulated in landslide-prone areas.

4.1.4 Implementing Avoidance as Landslide Hazard-Reduction Measure

In the United States, implementation of avoidance procedures has met with mixed success in landslide hazard reduction. In some areas, particularly in California, restriction of development in landslide-prone areas has been extensive, and avoidance programs generally have been successful in reducing landslide losses. However, in many states that have landslide-susceptible areas, there are no widely accepted procedures or regulations for considering landslides as part of the land use planning process (Committee on Ground Failure Hazards 1985).

Land use zoning probably has been the most effective means of regulating development. For example, in San Mateo County, California, a landslide-susceptibility map has been in use since 1975 to control the density of development (Brabb et al. 1972). On the basis of this map, the San Mateo County Board of Supervisors (1973) enacted legislation that restricts development in those areas most susceptible to landslides to one dwelling unit per 40 acres (approximately 16 ha) (Figure 5-1). Until 1982, all of the new landslides (mostly slips, slumps, and slides) that occurred in San Mateo County were in areas already mapped as landslides or in areas judged highly susceptible to landsliding. Thus, the zoning procedure was an outstanding success at that point. However, in 1982, under conditions of exceedingly heavy rainfall, thousands of debris flows occurred in areas where few had been observed previously (Brabb 1984). Thus, the 1972 map had accurately predicted the locations of future deep-seated landslides, but was not successful for debris flows. The new debris flows had not been expected because the landslide-susceptibility map was based on interpretation of aerial photographs that showed evidence of only deep-seated landslides.

Another approach to zoning has been used in Fairfax County, Virginia, where maps used for zoning purposes outline various degrees of hazard in different geologic materials (Obermeier 1979). Developers are required to obtain professional engineering advice for sites to be developed in specific geologic materials. The result has been a "drastic reduction in landslides" (Dallaire 1976).

The best examples of removal or conversion of existing development as a tool in the reduction of landslide losses have been those in which developments have been wholly or partly destroyed by slope failures, and, as a reaction to those losses, a decision has been made to replace the original development with a land use less prone to slope-failure damage. Such efforts commonly have been only partially successful because of the resistance of property owners, developers, or even the communities themselves. An excellent example of such partial success is provided by the city of Anchorage, Alaska, which received heavy damage from soil slides that were triggered by the 1964 Alaska earthquake. As a result of the earthquake, a scientific and engineering task force was established by the federal government to assess the damage, to evaluate future hazards, and to make recommendations that would minimize the impact of any future earthquake or landslide activity.

Especially interesting are land-planning decisions related to the three largest slope failures: the Turnagain Heights, Fourth Avenue, and L Street landslides (Mader et al. 1980). The mixed success of the task force's land use recommendations for these areas is illustrated by the cases discussed in Sections 4.1.4.1–4.1.4.3.

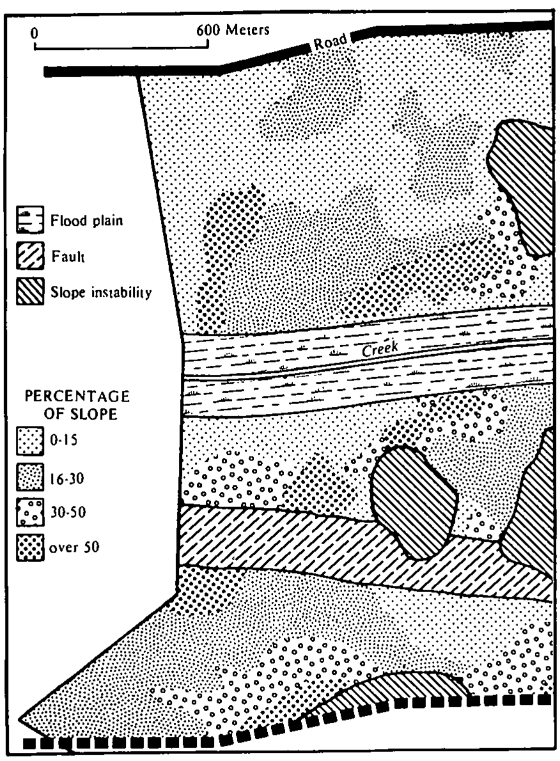

FIGURE 5-1 Hypothetical property in San Mateo County, California, showing seismic and other geologic constraints. Dwelling units in slope-instability zones are limited to one per 16 ha. Similar lower densities in floodplains and fault-rupture zones are required by San Mateo County Board of Supervisors (1973) (Kockelman and Brabb 1979).

4.1.4.1 Turnagain Heights Landslide

The Turnagain Heights slide was the largest and most spectacular of the 1964 slope failures, covering 53 ha and destroying 75 homes (Figure 5-2). The Alaska State Housing Authority prepared a redevelopment plan for the landslide area calling for park and recreation uses (Mader et al. 1980). However, only the economically least desirable part of the landslide was actually developed as a park. The Anchorage City Council voted against the plan and allowed applications for residential building permits in the landslide area (Selkregg et al. 1970). In 1977 controversy over the issue of rebuilding on parts of the Turnagain Heights landslide led to appointment of the Anchorage Geotechnical Advisory Commission. This commission consistently advised the local government not to allow development on the landslide unless the long-term stability of the slope could be assured. However, a few houses have since been built adjacent to or on the slide. The private property owners believed that compensation at postdisaster values was not sufficient inducement to relocate. In addition, local residents seemed to believe that because a catastrophe had only recently occurred, another would not take place at the same location during their lifetimes.

4.1.4.2 Fourth Avenue Landslide

This landslide was a single 15-ha block that moved horizontally about 5 m, destroying a significant part of Anchorage's central business district (Figure 5-3). The task force recommended that future developments in the Fourth Avenue landslide area be limited to parks, parking lots, and light structures no more than two stories high (Hansen et al. 1966). The recommended restrictions were incorporated into an urban renewal plan that was relatively successful because much of the land belonged to the federal government and thus was easily controlled (Mader et al. 1980).

4.1.4.3 L Street Landslide

The study by the task force showed that this 29-ha block slide and considerable adjacent hillside land constituted a significant continuing hazard. Thus, the same land use recommendations were made as for the Fourth Avenue landslide. However, the recommendations were ignored for the L Street area. About one year after the earthquake, the Anchorage City Council decided to rezone the area to permit higher residential densities, and by 1980 extensive new construction, including five new high-rise buildings, had taken place on or adjacent to the 1964 landslide (Mader et al. 1980). As was the case for the Turnagain Heights landslide, the main reason for the partial success in controlling redevelopment of the L Street landslide area was the resistance of property owners to less-intensive redevelopment.

4.2 Developing Excavation, Construction, and Grading Codes

Excavation, construction, and grading codes have been developed to ensure that construction in landslide-prone areas is planned and conducted in a manner that will not impair the stability of hillside slopes. These ordinances commonly

1. Require a permit before slopes are scraped, excavated, filled, or cut;
2. Regulate (including control of design, construction, inspection, and maintenance), minimize, or prohibit excavation and fill;
3. Control disruption of drainage and vegetation; and
4. Provide for proper design, construction, inspection, and maintenance of surface and subsurface drains.

FIGURE 5-2 *(top)* Damaged houses on Turnagain Heights landslide, Anchorage, Alaska, triggered by March 27, 1964, Alaska earthquake. U.S. GEOLOGICAL SURVEY

FIGURE 5-3 *(bottom)* Collapse of Fourth Avenue, Anchorage, Alaska, due to landslide triggered by Alaska earthquake of March 27, 1964. U.S. ARMY

In the United States there is no nationwide uniform code to ensure standardization of the foregoing criteria. Instead, in dealing with stability of hillside slopes on private lands, state and local government agencies apply design and construction criteria that fit the needs of their specific jurisdictions. The federal government usually has not participated directly in the formulation and enforcement of these codes. However, it has influenced the engineering profession by development of the codes used by government agencies in their own construction programs on federal projects. Federal standards for excavation and grading—such as those used by the U.S. Army Corps of Engineers, the Bureau of Reclamation, and the USDA Forest Service, each of which is in charge of major construction activities—often are used by other organizations in both the public and private sectors (Committee on Ground Failure Hazards 1985).

The development of excavation and grading ordinances related to geologic hazards originated in the United States shortly after World War II. At that time the accelerating demand for residential building sites in southern California because of a rapidly expanding population intensified development of hillside and mountain slopes (Scullin 1983, 14). In addition, improved earth-moving technology made development of slope areas economically feasible. The resulting poorly organized development combined with unusually heavy rainfall in southern California in the early 1950s resulted in significant landslide activity and major economic losses (Jahns 1969). As a result, the city of Los Angeles in 1952 adopted the first grading ordinance in the United States. The 1952 code was far from perfect, and during the following 10-year period, hillside developers in southern California faced many difficulties in applying and modifying it. However, this original code formed the basis for all subsequent codes adopted by local governments throughout the United States.

This early work in southern California led the International Conference on Building Officials in 1964 to develop Chapter 70 of the Uniform Building Code, which authorizes local governments to require that developers provide geotechnical reports on sites they intend to develop (Schuster and Leighton 1988). These reports are prepared by registered geotechnical engineers and certified engineering geologists. This code is still in effect (International Conference of Building Officials 1985); it has been adopted directly or used as a model by local governments in many countries.

Heavy rainfall in southern California in 1962 and 1969–1970 resulted in new major landslide losses and, as a result, in improvements to the 1952 code (Schuster and Leighton 1988). The 1962 storms and landslides resulted in more-sophisticated grading-code regulations that required

1. Geotechnical engineering and engineering geology input through the design and construction stages;
2. Definition of responsibilities of the design civil engineer, geotechnical engineer, and engineering geologist; and
3. Adequate subsurface exploration.

The 1969–1970 landslides led to

1. Additional refinement of grading ordinances;
2. A more quantitative approach to the design of slopes, for example, use of soil strength parameters, safety factors, and slope-stability analysis;
3. Emphasis on mud flow–debris flow mitigation; and
4. Proper design of structures above and below natural slopes.

The city of Los Angeles has provided an impressive example of the effective use of excavation and grading codes as deterrents to landslide activity and damage in the development of hillside slopes. The Los Angeles loss-reduction program relies heavily on regulations that require specific evaluations of landslide potential by engineering geologists and geotechnical engineers before construction as well as inspection of grading operations during construction. As noted above, controls on hillside grading and development in Los Angeles were almost nonexistent before 1952. In 1952, following severely damaging winter storms, a grading code was adopted that instituted procedures for safe development of hillsides; these grading regulations were significantly improved in 1963. The benefits resulting from these regulations were illustrated by the distribution of landslide damage in Los Angeles during severe storms in 1968–1969 and 1978. During the storms of 1968–1969, for a comparable number of building sites, the damage to sites developed before institution of grading codes in 1952 was nearly 10 times as great as damage to sites developed after 1963 (Slosson 1969). Similar results were observed after the 1978 storm (Table 5-1).

4.3 Protecting Existing Development

In spite of the avoidance and regulatory techniques presented above, development of hillside and mountain slopes that are subject to slope failure will continue. Thus, land use planning programs should include physical techniques to protect property, structures, and people in landslide-prone areas. These protective measures can be divided into (*a*) physical methods of control of unstable slopes and (*b*) monitoring and warning systems. These measures are introduced here and described in detail in Chapters 10, 11, 17, and 18.

Table 5-1
Relationship Between Modern Grading Codes and Slope Failures for Los Angeles Building Sites from Catastrophic February 1978 Southern California Storm (Slosson and Krohn 1979)

Building Code in Effect	No. of Sites Developed	No. of Site Failures	Percentage of Site Failures	Damage Costs ($)
Pre-1963 (premodern code)	37,000	2,790	7.5	40–49 million
Post-1963 (modern code)	30,000	210	0.7	1–2 million

4.3.1 Physical Controls

The most commonly used physical methods for control of unstable slopes are as follows:

1. **Drainage:** Because of its high stabilization efficiency in relation to cost, drainage of surface water and groundwater is the most widely used, and generally the most successful, slope-stabilization method (Committee on Ground Failure Hazards 1985).
2. **Slope modification:** Stability of a slope can be increased by removing all or part of the landslide mass.
3. **Earth buttresses:** Earth-buttress counterforts placed at the toes of potential slope failures are often successful in preventing failure. In California this is the most common mechanical (as contrasted to hydrologic) method of landslide control (Committee on Ground Failure Hazards 1985).
4. **Restraining structures:** When Methods 1 through 3 will not ensure slope stability by themselves, structural controls, such as retaining walls, piles, caissons, or rock anchors, commonly are used to prevent or control slope movement. In most cases restraining structures are used in conjunction with any or all of the following: drainage, slope modification, and construction of earth counterfort berms. Properly designed restraining structures are useful in preventing or controlling slumps and slips, particularly where lack of space precludes slope modification. However, use of restraining structures should be limited to control of small landslides because they seldom are successful on large ones.

All of these physical control methods have been discussed at length in the landslide literature [e.g., by Veder (1981), Holtz and Schuster (Chap. 17 in this report), and Wyllie and Norrish (Chap. 18 in this report)]. Their principal shortcoming is relatively high cost, which restricts effective usage to those sites for which avoidance is not feasible. Thus, they are most commonly used where landslide costs are high because of high population densities and property values.

4.3.2 Monitoring and Warning Systems

Landslide-prone hillside slopes can be monitored to provide warning of slope movement to downslope residents. Monitoring techniques include field observation and the use of extensometers, tiltmeters, piezometers, electrical fences, and trip wires. Recent innovations in monitoring devices include acoustic instruments, television, guided radar, laser beams, and vibration meters. Data from these devices can be telemetered to central receiving stations.

One of the most significant areas of recent landslide research is the development of real-time warning systems for landslides triggered by major storms. Such a system has been developed for the San Francisco Bay region, California, by the U.S. Geological Survey in cooperation with the National Weather Service. The procedure is based on (*a*) empirical and theoretical relations between rainfall intensity and duration and landslide initiation, (*b*) geologic determination of areas susceptible to landslides, (*c*) real-time monitoring of a regional network of telemetering rain gauges, and (*d*) National Weather Service precipitation forecasts (Keefer et al. 1987). The procedure was used to issue over public television and radio stations the first regional public warnings in the United States during the storms of February 12–21, 1986, which produced 800 mm of rainfall in the San Francisco

Bay region. According to eyewitness accounts of landslide occurrence, the warnings accurately predicted the times of major landslide events. Although analysis after the storms suggested that modifications to and additional development of the system are needed, it can be used as a prototype for systems in other landslide-prone areas.

The Territory of Hong Kong also relies on a rainfall-monitoring system for identifying periods of high landslide potential. This system is maintained by the Geotechnical Control Office (GCO) within the Engineering Department of the Hong Kong government (Geotechnical Control Office 1985). During heavy rainstorms, the GCO operates on an emergency basis to provide advice on remedial measures for landslides.

Landslide monitoring systems also have been developed in other countries, notably Japan, New Zealand, and the alpine countries of Europe. Ancient landslides that may be reactivated by the filling of Clyde Reservoir on the Clutha River on the South Island of New Zealand were being monitored at more than 2,000 points (as of July 1991) by means of piezometers, inclinometers, survey points, and flow measurements; many more monitoring installations are planned (Gillon et al. 1992). In the aftermath of the catastrophic 1987 Val Pola rock avalanche, which dammed the Adda River in northern Italy, the Italian Department of Civil Defense installed an on-line monitoring system on both the unstable slope and the landslide dam (Cambiaghi and Schuster 1989). This system included down-hole inclinometers, Invar-wire extensometers, an acoustic monitoring system, rain gauges, ultrasonic hydrometers, and thermometers. Data obtained by these instruments were transmitted by radio to a computer system operated by the local government; these data provided real-time analysis of applicable risk scenarios for the downvalley populace and for construction crews operating beneath the unstable slopes.

Monitoring and warning systems are installed primarily to protect lives and property, not to prevent landslides. However, these systems often provide warning of slope movement in time to allow the construction of physical control measures that will reduce the immediate or long-term hazard.

5. LANDSLIDE INSURANCE

Although insurance programs are not intended to reduce landslide hazards directly as do the mitigative measures discussed above, they can reduce the impact of landslide losses on individual property owners by spreading these losses over a larger base (Schuster and Fleming 1986). In addition, the high cost of nonsubsidized insurance for development in landslide-prone areas can discourage such development and encourage lower-risk land uses. The use of insurance as a landslide hazard-reduction technique has the following advantages over other strategies (Olshansky and Rogers 1987; Olshansky 1990):

1. In theory, insurance provides equitable distribution of costs and benefits. If property owners in landslide-prone areas were to pay premiums reflecting their actual risk and if insurance were to fully compensate victims, costs and benefits would be equitably distributed.
2. Landslide insurance encourages hazard reduction if premium rates reflect not only the degree of natural hazard but also the quality of physical control measures.
3. Using insurance to reduce the impact of landslide hazards appeals to those opposed to government regulation because, as compared with the other approaches, it depends more on the private market than on government intervention.

The most successful application of insurance to landslide mitigation has been in New Zealand, where a national insurance program assists homeowners whose dwellings have been damaged by landslides or other natural hazards that could not within reason have been prevented or controlled by the homeowners. A disaster fund, accumulated from a surcharge to the national fire insurance program, reimburses property owners for losses (O'Riordan 1974). This natural-hazard insurance program is an outgrowth of New Zealand's Earthquake and War Damage Act of 1944.

Landslide insurance can be divided into two types, public and private. In the United States, public landslide insurance is available in certain circumstances through the National Flood Insurance Program (NFIP), which was created by the Housing and Urban Development Act of 1968. An amendment to this act extended the application to "mudslides" in 1969. However, the range of phenomena defined by the term *mudslide* was not made clear. As presently worded, the regulations include mudslides that are proximately caused or precipitated by accumulations of surface water or groundwater (Committee on Methodologies for Predicting Mudflow Areas 1982). The insurance on these "water-caused" landslides is provided by private insurance companies but is little used; however, it is underwritten and subsidized by the federal government.

FEMA, which administers the NFIP, has been unable to implement an effective mudslide insurance program, largely because of technical difficulties in defining *mudslide* and in mapping mudslide hazard zones (Olshansky and Rogers 1987). A possible solution to this dilemma would be to add all types of landslides to the NFIP. A bill proposing this solution was introduced in the U.S. House of Representatives in 1981. This bill would have immediately added landslide coverage to the nearly 2 million existing NFIP policies, and a new landslide mapping program would have been undertaken to provide data for the underwriters. However, FEMA opposed it because of its high cost and difficulty in administration. Partly as a result of this opposition, the bill was killed before reaching a vote by the House.

Yelverton (1973) reviewed U.S. experience in landslide insurance as a basis for proposing a national landslide insurance program. However, other than through the NFIP, landslide insurance generally is not available in the United States. Although the concept of private landslide insurance is an appealing one, it has certain drawbacks in practice, and the private sector does not appear to be interested in offering this coverage. The reluctance to provide landslide insurance is of long standing, partially based on several costly and highly publicized landslides along the California coast. In addition, private insurers hesitate to offer landslide coverage because of the problem of "adverse selection," which is the tendency for only those who are in hazardous areas to purchase insurance (Olshansky and Rogers 1987; Olshansky 1990).

Olshansky and Rogers summarized the need and general requirements for landslide insurance in the United States as follows:

> Insurance can equitably provide funds to compensate for landslide damage that will inevitably occur even when there are strict land use and grading controls. For insurance to be an effective solution, though, a comprehensive government landslide insurance fund is needed, or alternatively, some other form of government intervention is needed to induce or require private insurers to cover landslides. Controls on building, development, and property maintenance would need to accompany mandatory insurance. Insurance and appropriate government intervention can operate together, each filling a need not served by the other, and each improving the performance of the other in reducing landslides and compensating victims. (Olshansky and Rogers 1987, 992)

The cost of insurance can directly reduce landslide risk by discouraging development in hazardous areas or by encouraging land uses that are less subject to damage. Landslide insurance from private sources is costly for areas known to be susceptible to landslides because losses due to landslides lack the random nature necessary for a sound insurance program. In this respect, landslide areas are comparable with flood areas, and the statement by the American Insurance Association on flood insurance may be applicable:

> Flood insurance covering fixed-location properties in areas subject to recurrent floods cannot feasibly be written because of the virtual certainty of loss, its catastrophic nature, and the reluctance or inability of the public to pay the premium charge required to make the insurance self-sustaining. (American Insurance Association 1956)

Sound insurance programs at reasonable rates cannot be made available in known fault-rupture, flood, and landslide areas unless the premium costs are subsidized. Government subsidies to property owners and their mortgagers who suffer damage may lead to development in hazardous areas because the potential loss is indemnified. According to Miller (1977), after national flood insurance became available, lending institutions in 4 of the 15 communities studied reversed earlier restrictions on mortgages in hazardous coastal areas. On the basis of a survey of 1,203 local governments, Burby and French (1981, 84) concluded, "It often appears that the NFIP induces increased flood plain development. . . ." State and local officials interviewed by Kusler (1982, 36, footnote 55) argued that "bank financing would not have been available for much of the new development without flood insurance."

6. MULTIPLE-HAZARD REDUCTION

Typically, landslide hazard reduction is undertaken as an individual exercise. However, landslides often occur as elements of interrelated multiple natural-hazard processes in which an initial event triggers secondary events (Advisory Board on the Built Environment 1983; Advisory Committee on the International Decade for Natural Hazard Reduction 1987). In other cases, two or more natural-hazard processes, not directly related to each other but triggered by a common cause, may occur at the same time in the same or adjacent localities. Examples are the 1964 Alaska earthquake, which triggered tsunamis, local flooding, and many landslides, and the 1980 Mount St. Helens eruption, which led to major landslides, floods, and wildfires that consumed large tracts of timber.

Multiple-hazard problems require a shift of perspective from mitigation of separate hazards, such as landslides, to a broader systems framework that takes into account the characteristics of more than one hazard (Advisory Committee on the International Decade for Natural Hazard Reduction 1987). Therefore, in planning landslide hazard-reduction programs, attention should be paid to possible interrelationships between landslides and other hazards. Building-code requirements in one geographic area may deal individually with landslides, floods, earthquakes, and tornadoes, but the ideal requirement is one that takes into account all of these hazards. For example, a building moved from a floodplain to a hillside to avoid floods may be at increased risk from landslides or earthquakes. In such cases, the failure or loss of the building may be caused by several hazard mechanisms or modes. The planning of mitigation should consider all possible hazard modes. A probabilistic approach for estimating risks associated with multiple hazards is presented in Chapter 6 of this report. A discussion of multiple-hazard mapping—preparation, format, and limitations—was presented in the development planning primer prepared for the Organization of American States (1991, Chap. 6).

7. ELEMENTS OF NATIONAL PROGRAM

As noted earlier, Swanston and Schuster (1989) reviewed landslide hazard management strategies in several countries (Austria, Canada, France, Italy, Japan, New Zealand, Norway, the former Soviet Union, Sweden, and Switzerland) and in Hong Kong, where landslides constitute a major socioeconomic problem. On the basis of the collective experience from these areas and the United States, a successful unified national program of landslide hazard reduction conceivably would include the following key elements (Swanston and Schuster 1989):

1. Identification of a central organization for management of a national landslide loss-reduction program;
2. Establishment of limits of responsibility of federal, state and provincial, municipal, and private entities in dealing with landslide hazards;
3. A national effort to identify and map hazardous areas, define process characteristics, and determine degree of risk;
4. Development of guidelines for application of reduction techniques to identified hazards;
5. Development of minimum standards of application and professional practice (standards should be created by professional societies in collaboration with federal and national governments);
6. Regulation of minimum standards of application and professional practice (in conjunction with professional societies) through periodic review and upgrading of practice guidelines, building codes, and land use practices;
7. Strong support of federal and national government and university research dealing with process mechanics, reduction techniques, and warning systems;
8. Provision of a central clearing house for collection and distribution of publications and guidelines to professionals, agencies, and local governments; and
9. Relief and compensation programs through federal and national and private insurance funds.

Similarly, a comprehensive national program for landslide hazard reduction developed by the U.S. Geological Survey (1982) set forth goals and tasks for making landslide studies, evaluating and mapping the hazard (sometimes called "zonation"), disseminating the information to potential users, and subsequently evaluating the use of the information. Examples of the types and maps to be developed under such a program and lists of typical users and communication techniques were included in the program, which has yet to be actuated except in piecemeal fashion.

REFERENCES

ABBREVIATIONS

UNESCO United Nations Educational, Scientific, and Cultural Organization

WP/WLI Working Party on the World Landslide Inventory (International Geotechnical Societies and UNESCO)

Advisory Board on the Built Environment. 1983. *Multiple Hazard Mitigation: Report of a Workshop on Mitigation Strategies for Communities Prone to Multiple Natural Hazards*. National Research Council, National Academy Press, Washington, D.C., 60 pp.

Advisory Committee on the International Decade for Natural Hazard Reduction. 1987. *Confronting Natural Disasters—An International Decade for Natural Hazard Reduction*. National Research Council, National Academy Press, Washington, D.C., 60 pp.

American Insurance Association. 1956. *Studies of Floods and Flood Damages, 1952–55*. New York, N.Y., 296 pp.

Brabb, E.E. 1984. Innovative Approaches to *Landslide Hazard and Risk Mapping*. Proc., Fourth International Symposium on Landslides, Canadian Geotechnical Society, Toronto, Canada, Vol. 1, pp. 307–323.

Brabb, E.E., and B.L. Harrod (eds.). 1989. *Landslides: Extent and Economic Significance*. Proc., 28th International Geological Congress: Symposium on Landslides, Washington, D.C., July 17, A.A. Balkema, Rotterdam, Netherlands, 385 pp.

Brabb, E.E., E.H. Pampeyan, and M.G. Bonilla. 1972. *Landslide Susceptibility in San Mateo County, California*. U.S. Geological Survey Miscellaneous Field Studies Map MF-360.

Brown, W.M. III. 1992. Information for Disaster Reduction: The National Landslide Information Center, U.S. Geological Survey. In *Landslides: Proc., Sixth International Symposium on Landslides* (D.H. Bell, ed.), Christchurch, New Zealand, Feb. 10–14, A.A. Balkema, Rotterdam, Netherlands, Vol. 2, pp. 891–892.

Brown, W.M. III, D.M. Cruden, and J.S. Denison. 1992. *The Directory of the World Landslide Inventory*. U.S. Geological Survey Open-File Report 92-427, 216 pp., Appendix 19 pp.

Burby, R.J., and S.P. French. 1981. Coping with Floods—The Land Use Management Paradox. *Journal of the American Planning Association*, Vol. 47, No. 3, pp. 289–300.

Cambiaghi, A., and R.L. Schuster. 1989. Landslide Damming and Environmental Protection—A Case Study from Northern Italy. In *Proc., Second International Symposium on Environmental Geotechnology* (H.Y. Fang and S. Pamukcu, eds.), Shanghai, May, Envo Publishing Company, Inc., Vol. 1, pp. 469–480.

Colorado Natural Hazards Mitigation Council. 1992. *Annual Report 1991–1992*. Office of Emergency Management, Golden, Colo., 55 pp.

Committee on Ground Failure Hazards. 1985. *Reducing Losses from Landsliding in the United States*. Commission on Engineering and Technical Systems, National Research Council, Washington, D.C., 41 pp.

Committee on Methodologies for Predicting Mudflow Areas. 1982. *Predicting a Methodology for Delineating Mudslide Hazard areas for the National Flood Insurance Program*. National Research Council, Washington, D.C., 35 pp.

Cruden, D.M., and W.M. Brown III. 1992. Progress Towards the World Landslide Inventory. In *Landslides: Proc., Sixth International Symposium on Landslides* (D.H. Bell, ed.), Christchurch, New Zealand, Feb. 10–14, A.A. Balkema, Rotterdam, Netherlands, Vol. 1, pp. 59–64.

Dallaire, G. 1976. Consultants Reviewing Plans for Other Consultants in Fairfax County, Va.; Landslides Greatly Reduced. *Civil Engineering*, ASCE, Vol. 46, No. 9, pp. 77–79.

Geotechnical Control Office. 1985. *Description of the Geotechnical Control Office Engineering Development Department*. Hong Kong, 8 pp.

Gillon, M.D., P.F. Foster, G.T. Proffitt, and A.P. Smits. 1992. Monitoring of the Cromwell Gorge Landslides. In *Landslides: Proc., Sixth International Conference on Landslides* (D.H. Bell, ed.), Christchurch, New Zealand, Feb. 10–14, A.A. Balkema, Rotterdam, Netherlands, Vol. 2, pp. 1135–1140.

Hamilton County. 1982. *Earth Movement Task Force*. Hamilton County, City of Cincinnati, Ohio, 38 pp.

Hamilton County Regional Planning Commission. 1976. *Hillside Development Study—Hillside Development Plan and Strategy*. Regional Planning Commission, Hamilton County, Cincinnati, Ohio, 86 pp.

Hansen, A. 1989. Landslide Hazard Analysis. In *Slope Instability* (S. Brunsden and D.B. Prior, eds.), John Wiley & Sons, New York, pp. 523–595.

Hansen, W.R., E.B. Eckel, W.E. Schaen, R.E. Lyle, W. George, and G. Chance. 1966. *The Alaska Earthquake of March 27, 1964—Investigations and*

Reconstruction Effort. U.S. Geological Survey Professional Paper 541, 111 pp.

Huffman, J. 1986. *Government Liability and Disaster Mitigation—A Comparative Study*. University Press of America, Lanham, Md., 626 pp.

International Conference of Building Officials. 1985. *Uniform Building Code*. Whittier, Calif., 817 pp.

Jahns, R.H. 1969. Seventeen Years of Response by the City of Los Angeles to Geologic Hazards. In *Geologic Hazards and Public Problems* (R.A. Olson and M.M. Wallace, eds.), Conference Proceedings, May, Office of Emergency Preparedness, Washington, D.C., pp. 283–296.

Jochim, C.L., W.P. Rogers, J.O. Truby, R.L. Wold, Jr., G. Weber, and S.P. Brown. 1988. *Colorado Landslide Hazard Mitigation Plan*. Colorado Geological Survey, Department of Natural Resources, Denver, 149 pp.

Keefer, D.K., R.C. Wilson, R.K. Mark, E.E Brabb, W.M. Brown III, S.D. Ellen, E.L. Harp, G.F. Wieczorek, C.S. Alger, and R.S. Zatkin. 1987. Real-Time Landslide Warning during Heavy Rainfall. *Science*, Vol. 238, pp. 921–925.

Kockelman, W.J. 1986. Some Techniques for Reducing Landslide Hazards. *Bulletin of the Association of Engineering Geologists*, Vol. 23, No. 1, pp. 29–52.

Kockelman, W.J., and E.E. Brabb. 1979. Examples of Seismic Zonation in the San Francisco Bay Region. In *Progress on Seismic Zonation in the San Francisco Bay Region* (E.E. Brabb, ed.), U.S. Geological Survey Circular 807, pp. 73–84.

Kusler, J.A. 1982. *Regulation of Flood Hazard Areas to Reduce Flood Losses*. U.S. Water Resources Council, Washington, D.C., Vol. 3, 357 pp.

Mader, G.G., W.E. Spangle, and M.L. Blair. 1980. *Land Use Planning after Earthquakes*. William Spangle and Associates, Inc., Portola Valley, Calif., 24 pp.

Mader, G.G., T.C. Vlasic, and P.A. Gregory. 1988. *Geology and Planning: The Portola Valley Experience*. William Spangle and Associates, Inc., Portola Valley, Calif., 75 pp.

Miller, H.C. 1977. *Coastal Flood Hazards in the National Flood Insurance Program*. National Flood Insurance Program, Department of Housing and Urban Development, Washington, D.C., 58 pp.

Obermeier, S.F. 1979. *Slope Stability Map of Fairfax County, Virginia*. U.S. Geological Survey Miscellaneous Field Studies Map MF-1072.

Olshansky, R.B. 1990. *Landslide Hazard in the United States—Case Studies in Planning and Policy Development*. Garland Publishing, Inc., New York, 176 pp.

Olshansky, R.B., and J.D. Rogers. 1987. Unstable Ground: Landslide Policy in the United States. *Ecology Law Quarterly*, Vol. 13, No. 4, pp. 939–1006.

Organization of American States. 1991. *Primer on Natural Hazard Management in Integrated Regional Development Planning*. Department of Regional Development and Environment, Washington, D.C., 418 pp.

O'Riordan, T. 1974. The New Zealand Natural Hazard Insurance Scheme: Application to North America. In *Natural Hazards—Local, National, Global* (G.F. White, ed.), Oxford University Press, New York, pp. 217–219.

Petak, W.J., and A.A. Atkisson. 1982. *Natural Hazard Risk Assessment and Public Policy—Anticipating the Unexpected*. Springer-Verlag, New York, 489 pp.

Rib, H.T., and T. Liang. 1978. Recognition and Identification. In *Special Report 176: Landslides: Analysis and Control* (R.L. Schuster and R.J. Krizek, eds.), TRB, National Research Council, Washington, D.C., pp. 34–80.

Rogers, W.P., L.R. Ladwig, A.L. Hornbaker, S.D. Schwochow, S.S. Hart, D.C. Shelton, D.L. Sroggs, and J.M. Soule. 1974. Appendix: Model Geologic Hazard Area Control Regulations. In *Guidelines and Criteria for Identification and Land-use Controls of Geologic Hazard and Mineral Resource Areas*, Colorado Geological Survey, Denver, pp. 135–146.

Rossi, P.H., J.D. Wright, and E. Weber-Burdin. 1982. *Natural Hazards and Public Choice—The State and Local Politics of Hazard Mitigation*. Academic Press, New York, 337 pp.

San Mateo County Board of Supervisors. 1973. *Adding a Resource-Management District and Regulations to the County Zoning Ordinance*. Ordinance No. 2229. Redwood City, Calif., 24 pp.

Santa Clara County Board of Supervisors. 1978. *Geological Ordinance NS-1205.35: Santa Clara Code, Section C-12–600 ff*. San Jose, Calif.

Schuster, R.L., and R.W. Fleming. 1986. Economic Losses and Fatalities due to Landslides. *Bulletin of the Association of Engineering Geologists*, Vol. 23, No. 1, pp. 11–28.

Schuster, R.L., and F.B. Leighton. 1988. Regulations in California, U.S.A. In *Landslides and Mudflows* (E.A. Kozlovskii, ed.), UNESCO/UNEP, Moscow, Vol. 2, pp. 116–122.

Scullin, C.M. 1983. *Excavation and Grading Code Administration, Inspection, and Enforcement*. Prentice-Hall, Inc., Englewood Cliffs, N.J., 405 pp.

Selkregg, L., E.B. Crittenden, N. Williams, Jr. 1970. Urban Planning in the Reconstruction. In *The Great Alaska Earthquake of 1964—Human Ecology*, National Academy of Sciences, Washington, D.C., pp. 186–242.

Slosson, J.E. 1969. The Role of Engineering Geology in Urban Planning. In *The Governor's Conference on Environmental Geology*, Colorado Geological Survey Special Publication 1, Denver, pp. 8–15.

Slosson, J.E., and J.P. Krohn. 1979. AEG Building Code Review—Mudflow/Debris Flow Damage; February 1979 Storm—Los Angeles Area. *California Geology*, Vol. 32, No. 1, pp. 8–11.

Slosson, J.E., and J.P. Krohn. 1982. Southern California Landslides of 1978 and 1980. In *Storms, Floods, and Debris Flows in Southern California and Arizona, 1978 and 1980*, Proceedings of a Symposium, National Research Council and Environmental Quality Laboratory, California Institute of Technology, Pasadena, 17–18 Sept. 1980, National Academy Press, Washington, D.C., pp. 291–319.

Swanston, D.N., and R.L. Schuster. 1989. Long-Term Landslide Hazard Mitigation Programs: Structure and Experience from Other Countries. *Bulletin of the Association of Engineering Geologists*, Vol. 26, No. 1, pp. 109–133.

U.S. Geological Survey. 1982. *Goals and Tasks of the Landslide Part of a Ground-Failure Hazards Reduction Program*. U.S. Geological Survey Circular 880, 49 pp.

Varnes, D.J. 1978. Slope-Movement Types and Processes. In *Special Report 176: Landslides: Analysis and Control* (R.L. Schuster and R.J. Krizek, eds.), TRB, National Research Council, Washington, D.C., pp. 11–33.

Varnes, D.J., and International Association of Engineering Geology Commission on Landslides and Other Mass Movements on Slopes. 1984. *Landslide Hazard Zonation—A Review of the Principles and Practice*. UNESCO, Natural Hazards Series, No. 3, 63 pp.

Veder, C. 1981. *Landslides and Their Stabilization*. Springer-Verlag, New York, 247 pp.

Wold, R.L., Jr., and C.L. Jochim. 1989. *Landslide Loss Reduction: A Guide for State and Local Government Planning*. Earthquake Hazards Reduction Series 52. Federal Emergency Management Agency, Washington, D.C., Aug., 50 pp. (Also published as Colorado Geological Survey Special Publication 33, Denver, 50 pp.)

WP/WLI. 1990. A Suggested Method for Reporting a Landslide. *Bulletin of the International Association of Engineering Geology*, No. 41, pp. 5–12.

WP/WLI. 1991. A Suggested Method for a Landslide Summary. *Bulletin of the International Association of Engineering Geology*, No. 43, pp. 101–110.

WP/WLI. 1993a. A Suggested Method for Describing the Activity of a Landslide. *Bulletin of the International Association of Engineering Geology*, No. 47, pp. 53–57.

WP/WLI. 1993b. *Multilingual Landslide Glossary*. BiTech Publishers, Richmond, British Columbia, Canada, 59 pp.

Yelverton, C.A. 1973. Land Failure Insurance. In *Geology, Seismicity and Environmental Impact*, Association of Engineering Geologists, Brentwood, Tenn., pp. 15–20.