

Section II.

Evaluating and Communicating Landslide Hazard

Worldwide, information about landslides varies in its quantity and complexity and ranges in quality from detailed inventories of past landslides and resultant susceptibility and hazard maps to no information at all. People in some regions of the world have collective memories of past landslide events and know where slopes are unstable and (or) dangerous, and as a result, intuitively know where it is advantageous to build or not build. However, many areas are not readily obvious as to potential landslide hazard, and ground failure does not occur on any kind of regular basis. Also, some triggering mechanisms occur sporadically and have a gradual and cumulative effect and are not readily obvious.

Part A. Evaluating Landslide Hazards

There are many different means of assessing landslide hazard for an area; it is always advisable to consult with an expert for the most accurate assessment, although this is not always possible. Two types of landslide hazard evaluation, direct observation and the use of technological tools, are discussed here.

Observation and (or) inspection by local experts and (or) municipal officials, and property owners.

*For further reading:
References 1, 3, 4, 19, 20, 21, 25, 26,
36, 39, 42, and 44*

The following simple guide may assist individuals in observing and assessing a potential landslide hazard. It is important to note that some of these features can also be due to causes other than landslides, such as swelling soils.

Features that might indicate landslide movement:

- Springs, seeps, and wet or saturated ground in previously dry areas on or below slopes.
- Ground cracks—cracks in snow, ice, soil, or rock on or at the head of slopes.
- Sidewalks or slabs pulling away from structures if near a slope; soil pulling away from foundations.
- Offset fence lines, which were once straight or configured differently (see photograph in figure 22).
- Unusual bulges or elevation changes in the ground, pavements, paths, or sidewalks.
- Tilting telephone poles, trees, retaining walls, fences.
- Excessive tilting or cracking of concrete floors and foundations.
- Broken water lines and other underground utilities.
- Rapid increase or decrease in stream-water levels, possibly accompanied by increased turbidity (soil content clouding the water).
- Sticking doors and windows and visible open spaces, indicating walls and frames are shifting and deforming.
- Creaking, snapping, or popping noises from a house, building, or grove of trees (for example, roots snapping or breaking).
- Sunken or down-dropped roads or paths.

Note to Managers: It is important that governing bodies provide a means of keeping records, preferably in written format, about the occurrences of landslides, with photographs and (or) diagrams where possible. For areas of the world that do not already have laws or regulations that require disclosure of landslide hazards to property owners, it is important for villages, municipalities, or cities to establish some source of authority for hazard information. This need not be sophisticated or expensive but will provide a means to sustain landslide knowledge through time. Although some information may be politically sensitive, such as landowner rights, it is important that landslide information be made available, in some manner, to the general population.



Figure 36. Ground cracks. (Photograph courtesy of Utah Geological Survey.)



Figure 37. Sidewalk pulling away from house. (Photograph courtesy of Utah Geological Survey.)



Figure 38. Cracking of the foundation of a structure. (Photograph courtesy of Utah Geological Survey.)

Technological Tools for Evaluation of Landslides— Mapping, Remote Sensing, and Monitoring

One of the guiding principles of geology is that *the past is the key to the future*. In evaluating landslide hazards this means that future slope failures could occur as a result of the same geologic, geomorphic, and hydrologic situations that led to past and present failures. Based on this assumption, it is possible to estimate the types, frequency of occurrence, extent, and consequences of slope failures that may occur in the future. However, the absence of past events in a specific area does not preclude future failures. Human-induced conditions, such as changes in the natural topography or hydrologic conditions, can create or increase an area's susceptibility to slope failure.

In order to predict landslide hazards in an area, the conditions and processes that promote instability must be identified and their relative contributions to slope failure estimated, if possible. Useful conclusions concerning increased probability of landsliding can be drawn by combining geological analyses with knowledge of short- and long-term meteorological conditions. Current technology enables persons monitoring earth movements to define those areas most susceptible to landsliding and to issue warnings and “alerts” covering time spans of hours to days when meteorological conditions or thresholds known to increase or initiate certain types of landslides are met.

Map Analysis

Map analysis is usually one of the first steps in a landslide investigation. Necessary maps include bedrock and surficial geology, topography, soils, and if available, geomorphology maps. Using knowledge of geologic materials and processes, a trained person can obtain a general idea of landslide susceptibility from such maps. Appendix B at the end of this report contains a section on the various types of maps used in landslide analysis.

Aerial Reconnaissance

Analysis of aerial photography is a quick and valuable technique for identifying landslides, because it provides a three-dimensional overview of the terrain and indicates human activities as well as much geologic information to a trained person. In addition, the availability of many types of aerial imagery (satellite, infrared, radar, and so forth) makes aerial reconnaissance very versatile although cost-prohibitive in some cases.

Field Reconnaissance

Many of the more subtle signs of slope movement cannot be identified on maps or photographs. Indeed, if an area is heavily forested or has been urbanized, even major features may not be evident. Furthermore, landslide features change over time on an active slide. Thus, field reconnaissance is always mandatory to verify or detect landslide features, and to critically evaluate the potential instability of vulnerable slopes. It identifies areas with past landslides (which could indicate future likelihood of landslides) by using field mapping and laboratory testing of terrain through the sampling of soil and rock. Mapping and laboratory testing for example, may identify vulnerable clays or other susceptible soils and show where they exist and their size and extent.

Drilling

At most sites, drilling is necessary to determine the type of earth materials involved in the slide, the depth to the slip surface, and thus the thickness and geometry of the landslide mass, the water-table level, and the degree of disruption of the landslide materials. It also can provide suitable samples for age-dating and testing the engineering properties of landslide materials. Finally, drilling is needed for installation of some monitoring instruments and hydrologic observation wells. Note that drilling for information on stratigraphy, geology, water-table levels and for installation of instruments, for example, is also done for areas that have never had a landslide but for which the possibility exists.

Instrumentation

Sophisticated methods such as electronic distance measurement (EDM), instruments such as inclinometers, extensometers, strain meters, and piezometers (see Glossary for definitions of these instruments), and simple techniques, such as establishing control points by using stakes can all be used to determine the mechanics of landslide movement and to monitor and warn against impending slope failure.

Geophysical Studies

Geophysical techniques (measurement of soil's electrical conductivity/resistivity, or measurement of induced seismic behavior) can be used to determine some subsurface characteristics such as the depth to bedrock, stratigraphic layers, zones of saturation, and sometimes the ground-water table. It can also be used to determine texture, porosity, and degree of consolidation of subsurface materials and the geometry of the units involved. In most instances, such surface survey methods can best be used to supplement drilling information, spatially extending and interpolating data between boreholes. They can also offer an alternative if drilling is impossible. Downhole geophysical methods (nuclear, electrical, thermal, seismic) also can be applied to derive detailed measurements in a borehole. Monitoring of natural acoustic emissions from moving soil or rock has also been used in landslide studies.

Acoustic Imagery and Profiles

Profiles of lakebeds, river bottoms, and the sea floor can be obtained using acoustic techniques such as side-scan sonar and subbottom seismic profiling. Surveying of controlled grids, with accurate navigation, can yield three-dimensional perspectives of subaqueous geologic phenomena. Modern, high-resolution techniques are used routinely in offshore shelf areas to map geologic hazards for offshore engineering.

Computerized Landslide Terrain Analysis

In recent years, computer modeling of landslides has been used to determine the volume of landslide masses and changes in surface expression and cross section over time. This information is useful in calculating the potential for stream blockage, cost of landslide removal (based on volume), and type and mechanism of movement. Very promising methods are being developed that use digital elevation models (DEMs) to evaluate areas quickly for their susceptibility to landslide/debris-flow events. Computers also are being used to perform complex stability analyses. Software programs for these studies are readily available for personal computers.

See Appendix B for more information and images of map types.

*For further reading:
References 4, 15, 18, 24, 25, 39,
and 46*

Part B. Communicating Landslide Hazard

The successful translation of natural hazard information into a form useful for nontechnical users conveys the following three elements in one form or another:

- Likelihood of the occurrence of an event of a size and in a location that would cause casualties, damage, or disruption to an existing standard of safety.
- Expected location and extent of the effects of the event on the ground, structures or socioeconomic activity.
- Estimated severity of the effects on the ground, structures, or socioeconomic activity.

These elements are needed because engineers, planners, and decisionmakers usually will not be concerned with a potential hazard if its likelihood is rare, its location is unknown, or its severity is slight.

Unfortunately, these three pieces of information can come in different forms with many different names, some quantitative and precise, others qualitative and general. For a product to qualify as useful hazard information, the nontechnical user must be able to perceive likelihood, location, and severity of the hazard so that they become aware of the danger, can convey the risk to others, and can use the translated information directly to reduce a threat.

Safety Information

Safety is no doubt the first order of business for managers and municipal officials. People living in areas prone to fast-moving, deadly debris flows need information on the likelihood of the hazard; for example, when it is most dangerous to be in the path of potential debris flows (such as during heavy rainstorms) and at what point to evacuate and (or) cease walking or driving in a hazardous area. Safety information about slow-moving landslides is equally important as these types of landslides can damage and (or) break electrical and gas lines, creating an additional hazard of fire, electrocution, and gas fumes.

Building and Construction Information

This information is also valuable to communities, so that some of the causes of landslides might be avoided. This information is discussed in Section III, “Mitigation Concepts and Approaches.”

Safety, education, and building information can be made available to community residents in various ways. A list of building codes, building inspection processes, and potential areas where destabilization may cause landslide problems can be made available through the following:

Suggested Local Government Outreach for Landslide Hazard

- Newspaper bulletins/advertisements.
- Public-service brochures distributed door-to-door or displayed in public places.
- Community meeting discussions.
- Posters in public buildings and (or) marketplaces with as much visual information as possible.
- Media announcements through radio, television, loudspeakers, or other means.
- Public lectures by experts or other officials.
- Signs posted in immediate areas of hazards, informing people of the kind of hazard and warning them to be cautious. An example of this would be a sign warning of rockfall hazards along well-used footpaths.
- In areas where literacy rates are low, oral communications with graphics, photographs, and illustrations of hazards can be extremely effective. Pictures may take the place of a thousand words!
- Telephone book—In areas where phone service is widespread or accessible, municipal listings for engineering, emergency planning, and police or fire departments.
- Where possible a municipal Internet Web site is a useful source of safety information and contact phone numbers and emails for emergency personnel and engineering and (or) planning departments.
- Determine local landslide hazard problems through a working committee and (or) secure professional advice. State/Provincial or Federal geological surveys, university geology or engineering departments, and private geotechnical companies are sources of advice. Provide for a mapping program where possible, either within local government or contracted with professionals.
- Conduct public education and information programs through community meetings, city council, or other councils.
- Adopt and enforce appropriate land-use policies—discuss with landowners, developers, buyers, and sellers. One option is to require disclosure of geological hazards during property sales to ensure that the new buyer is aware of any problems.
- Monitor changes in unstable slopes and take appropriate actions (see “Mitigation” section of this handbook).
- Construct street and drainage projects that meet local safety needs and ordinances.
- Pursue public grant programs, government programs for infrastructure, and public works improvement projects.
- Be informed about insurance programs available and liability issues and know where local government responsibility lies for public safety and well-being.
- Have an emergency response plan for the community. Consult with neighboring towns and (or) communities that have plans and have used them in an emergency. Evaluate their effectiveness for your own situation.

Examples of Hazard Warning Signs

The following figures (figs. 39, 40, and 41) show examples of some simple warning signs that can be placed in hazardous areas. This information can also be used in emergency management policies for municipalities and (or) communities.

Please see Appendix B for samples of basic safety information for debris flow and other landslide hazards that are suitable for posting and distributing in public places.

*For further reading:
References 1, 6, 19, 21, 23, 24, 26,
36, and 41*

Figure 39. Example of a rockfall hazard sign.



Figure 40. A notice for cliff hazards, city of Wanneroo, Australia.



Figure 41. Sign along a highway in Virginia, USA.