GUIDELINES FOR EVALUATING LANDSLIDE HAZARDS IN UTAH

edited by
Michael D. Hylland
Utah Geological Survey

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UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES

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GUIDELINES FOR EVALUATING LANDSLIDE HAZARDS IN UTAH

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INTRODUCTION

The following guidelines were developed by the Utah Geological Survey (UGS) to assist geologists and geotechnical engineers in performing landslide-hazard studies and to help technical reviewers critically evaluate the conclusions and recommendations in hazard-evaluation reports. The guidelines address evaluating the potential for rotational and translational slides (classification after Varnes, 1978) and, to a limited extent, liquefaction-induced slope failures (for example, lateral spreads) in both previously failed and unfailed slopes. The guidelines do not address evaluating the potential for other types of mass movement such as rock falls or debris flows. These guidelines were modeled after *Guidelines for Evaluating Surface Fault Rupture Hazards in Utah* (Utah Section of the Association of Engineering Geologists, 1987) which, in turn, were patterned after a series of guidelines developed by the California Division of Mines and Geology (Slosson, 1984).

Landslide hazards involve both natural and development-induced variables. Site conditions must be evaluated in terms of proposed site modifications such as structure size and placement, cutting and filling, and changes in ground-water conditions. Existing landslides can represent either presently stable slopes or unstable slopes that are actively moving or that may be easily reactivated. Project budget and time constraints, as well as technical limitations of sampling and testing, can hinder accurate data collection and analysis. The evaluation of seismic slope stability can be particularly complex and requires specialized expertise. These and other factors make landslide-hazard evaluation a complex task.

A valid landslide-hazard evaluation must address all pertinent conditions that could affect, or be affected by, the proposed development. This can only be accomplished through the proper identification and interpretation of significant site-specific geologic conditions and processes. The landslide investigator has the responsibility to design a study that is complete and cost effective, to be familiar with and apply appropriate investigation tools, to use proper judgement, and to present valid conclusions and recommendations supported by adequate data and sound interpretations. Accordingly, landslide-hazard studies must be performed by qualified, experienced engineering geologists and/or geotechnical engineers. An interdisciplinary approach is generally advisable and is necessary for detailed studies in complex or high-risk situations.

These guidelines, which address site-specific landslide-hazard evaluations and associated reports, are general and must be applied with flexibility. The guidelines do not describe all available evaluation techniques, nor do they suggest including all topics or techniques on every project. The level of study needed for a particular project depends on several factors, including: site-specific geologic, geotechnical, and hydrogeologic conditions; the type of proposed development; and the level of risk acceptable to property owners and permitting agencies. The UGS recommends appropriate disclosure of any identified landslide hazard and the existence of hazard-evaluation reports for all projects where a landslide hazard has been evaluated.

HAZARD-EVALUATION GUIDELINES

The following guidelines are presented for three levels of landslide-hazard evaluation: (1) geologic evaluations, (2) preliminary geotechnical-engineering evaluations, and (3) detailed geotechnical-engineering evaluations. In general, a geologic evaluation is performed by an engineering geologist. A geotechnical-engineering evaluation is an extension of the geologic evaluation and is primarily a quantitative slope-stability analysis. This analysis is generally performed by a geotechnical engineer with input from an engineering geologist.

Geologic Evaluations

The primary purpose of a geologic evaluation is to determine the hazard potential relative to proposed development and the need for geotechnical-engineering studies. In general, a geologic evaluation should address site geologic conditions that relate to slope stability such as topography, the nature and distribution of soil and rock, landforms, hydrogeology, and existing landslides. The study should extend beyond the subject site boundaries as necessary to adequately characterize the hazard.

Important background information for a geologic evaluation often can be obtained from existing maps and previous reports. The UGS maintains a computerized geologic-hazards bibliography on its public-access computer that includes landslide references. The bibliography is also available on disk (Harty and others, 1992). Published UGS landslide information includes a statewide (1:500,000-scale) map (Harty, 1991) as well as 30 X 60-minute (1:100,000-scale) quadrangles for the entire state. Additionally, landslide information is available on larger scale (typically 1:24,000) maps and in reports that have been completed for numerous cities and counties throughout the state by the UGS and others, many of which are listed in the geologic-hazards bibliography.

Review of stereoscopic aerial photographs is a powerful investigative tool for a geologic evaluation. Such a review can provide critical information pertaining to landforms, landslide features such as scarps and deposits, vegetation indicative of shallow ground water (phreatophytes), and changes in land use. Review of photos of different scales is useful to evaluate potentially significant regional (area-wide) and local (site) conditions. In general, photos of 1:40,000-scale or smaller are useful only to identify regional features (for example, large Pleistocene landslide complexes), whereas photos of 1:30,000-scale or larger are needed to identify local features. Also, review of the oldest and most recent photos available is useful to evaluate changes in conditions over time.

A geologic evaluation must include a site visit to document surface and shallow subsurface conditions such as topography, type and relative strength of soil and rock, nature and orientation of planar features such as bedding or fractures, ground-water depth, and active erosion, as well as evidence for existing landslides such as scarps, hummocky topography, and disturbed vegetation (for example, "jackstrawed" trees). For existing landslides, the type, age, and cause of movement need to be evaluated. Investigators are strongly encouraged to map the site surficial geology in as much detail as possible, placing special emphasis on landslide features and geologic units of known landslide susceptibility. Surficial geology should be mapped on a detailed site topographic base map if possible, but features such as slope inclination, height, and aspect can be schematically illustrated on the geologic map if a detailed topographic base map is not available. The geologic map should also show areas of surface water and evidence for shallow ground water (such as phreatophytes, springs, or modern tufa deposits). Surficial observations should be supplemented by subsurface exploration using a backhoe, drill rig, and/or hand tools such as a shovel, auger, or probe rod. Additional considerations pertaining to documentation of site conditions are presented below under "REPORT GUIDELINES."

Numerous tools and techniques are available to facilitate the efficient and accurate collection and presentation of field data for a geologic evaluation. Soil (unconsolidated material) can be classified using a system such as the Unified Soil Classification System (USCS); American Society for Testing and Materials (ASTM) method D 2488 (Visual-Manual Procedure) can be used for field classification and ASTM method D 2487 can be used for laboratory classification. Rock can be classified using a system such as the Rock Mass Rating (RMR) System (or Geomechanics Classification; Bieniawski, 1988), Unified Rock Classification System (Williamson, 1984), or other appropriate system. Both soil and rock also can be classified using the GLQ classification system (Keaton, 1984). The method described by Williamson and others (1991) for constructing field-developed cross sections can facilitate topographic profiling and subsurface interpretation. Approximate landslide age can be estimated using a system such as that developed by McCalpin (1984). Comprehensive information for landslide identification and investigation is provided in Schuster and Krizek (1978), Hall and others (1994), and Turner and Schuster (1996).

Pertinent data and conclusions must be adequately documented in a written report. The report should note distinctions between observed and inferred features and relationships, and between measured and estimated values. Although geologic evaluations will generally result in a qualitative hazard assessment (for example, low, moderate, or high), the report should clearly state if a hazard exists and comment on development feasibility and implications relative to landsliding. If a hazard is found and the proposed development is considered feasible, the report should either clearly state the extent of the hazard and give justification for accepting the risk, or recommend appropriate hazard-reduction measures or a more detailed study. Kockelman (1986), Rogers (1992), and Turner and Schuster (1996) describe numerous techniques for reducing landslide hazards. Hazard-reduction measures (for example, building setbacks or special foundations) must be based on supportable data such as measured/estimated slope inclination and height, thickness and physical properties of slope materials, ground-water depth, and projections of stable slopes. The basis for all conclusions and recommendations must be presented so that a technical reviewer can evaluate their validity. Detailed considerations for reports are provided below under "REPORT GUIDELINES."

Preliminary Geotechnical-Engineering Evaluations

A preliminary geotechnical-engineering evaluation may be performed if the results of a geologic evaluation alone do not provide a high degree of confidence in slope stability or hazard-reduction measures, but the expense of a detailed geotechnical-engineering evaluation (as discussed below) is not warranted due to circumstances such as a perceived low level of risk or difficulties in obtaining representative geotechnical field data. Preliminary geotechnical-engineering evaluations may be particularly warranted where geologic studies identify landslides or landslide-prone geologic units at the site. A preliminary geotechnical-engineering evaluation may also be performed in conjunction with a geologic evaluation.

A preliminary geotechnical-engineering evaluation includes a quantitative slope-stability (factor-of-safety) analysis of existing and proposed slopes. The analysis requires measured profiles of existing slopes, but other input parameters (for example, shear strength and ground-water levels) may be estimated using appropriate values deduced from site observations, published or other existing information, and geologic/engineering judgement.

A preliminary geotechnical-engineering evaluation should address both static and seismic slope stability. Background and general guidelines for static and seismic slope-stability analyses presented below under "Detailed Geotechnical-Engineering Evaluations" also apply to preliminary geotechnical-engineering evaluations, except that certain input parameters are estimated in a preliminary study rather than measured. Because of the uncertainties associated with using estimated parameters in a preliminary geotechnical-engineering evaluation, the UGS recommends a static factor of safety (FS) $\geq$ 1.5 using low-range strength values and conservative ground-water levels. A dynamic (seismic) FS can be determined using a pseudostatic analysis under appropriate conditions. For a dynamic FS, the UGS recommends using an appropriate earthquake coefficient (for example, some percentage of a probabilistic peak horizontal ground acceleration [PGA]) with a FS $\geq$ 1, again using low-range strength values and conservative ground-water levels. Alternatively, a pseudostatic analysis can be used to estimate a yield acceleration which can then be compared to the PGA to evaluate seismic slope stability.

The results of a preliminary geotechnical slope-stability analysis must be validated by adequate documentation and justification of input parameters, and all supporting data for conclusions and recommendations must be included in the report to allow for a critical technical review.

Detailed Geotechnical-Engineering Evaluations

A detailed geotechnical-engineering evaluation generally should be performed when a geologic evaluation indicates a hazard exists but the data are insufficient to adequately characterize the hazard or demonstrate the effectiveness of hazard-reduction measures, and where the results of a preliminary geotechnical-engineering evaluation would not provide an adequate level of confidence relative to the proposed development. The need to complete a detailed geotechnical-engineering evaluation will be determined based on the critical nature of the proposed development, site-specific consequences of slope failure, level of hazard, and level of risk acceptable to property owners and permitting agencies.

A detailed geotechnical-engineering evaluation, which involves a quantitative slope-stability analysis, requires subsurface exploration, geotechnical laboratory testing, topographic profiling, and construction of geologic cross sections. A deformation analysis may also be necessary, and some detailed evaluations may include slope-movement monitoring. The results of a geologic evaluation should be used to assist in developing the scope of a detailed geotechnical-engineering evaluation. The results of the detailed evaluation must be validated by adequate documentation of appropriate input parameters and assumptions, and all supporting data for conclusions and recommendations must be included in the report to allow for a critical technical review.

The subsurface-exploration program of a detailed geotechnical-engineering evaluation should be designed to obtain and characterize samples of subsurface materials, determine depth to ground water and, where appropriate, locate landslide slip surfaces. If a landslide is present, subsurface exploration must be of sufficient scope, within practical limits and constraints, to determine slide geometry with relative confidence. At a minimum, a "best estimate" of the slide geometry should be made and appropriate analyses performed using the best-estimate geometry.

Subsurface exploration will generally require the use of heavy equipment such as backhoes or drill rigs. Trench or boring data can be supplemented with data from geophysical surveys using such methods as seismic refraction or electrical resistivity. Geotechnical laboratory testing should be performed on samples to evaluate pertinent physical and engineering characteristics such as unit weight, moisture content, plasticity, angle of internal friction, and cohesion intercept. At least one geologic cross section should be constructed through the slope(s) of concern to evaluate subsurface geologic conditions relative to the topographic profile. Cross sections should extend at least to the maximum postulated depth of potential slip surfaces and be at an appropriate scale (generally between 1:120 [1 inch = 10 feet] and 1:600 [1 inch = 50 feet]) for the size of the slope, type of proposed development, and purpose of investigation. Existing landslides can be monitored using photogrammetric methods, ground surveys, inclinometers, or extensometers.

Both preliminary and detailed geotechnical-engineering evaluations should include static and seismic analyses of the stability of existing and proposed slopes using undrained or total shear-strength parameters, under existing and development-induced conditions, and considering the likely range of ground-water conditions. A slope-stability evaluation addressing post-earthquake conditions may be warranted in some cases. Numerous computer software packages are available for quantitative slope-stability analysis, including deterministic and probabilistic soil- and rock-slope models.

Static Slope-Stability Analysis

Quantitative slope-stability analyses are typically accomplished with a limit-equilibrium technique wherein the ratio of resisting forces to driving forces is known as the factor of safety (FS). For general guidelines, the UGS recommends a static FS $\geq$ 1.5 for peak-strength conditions and/or where site characteristics and engineering properties of the materials involved are well understood. A higher FS is warranted where these conditions are not well understood. For existing landslides where measured residual-strength parameters are used, a minimum FS = 1.3 is acceptable.

Seismic Slope-Stability Analysis

In general, seismic slope-stability analyses should address overall mass stability as well as the potential for strength loss (for example, sensitive clays or liquefiable soils) or significant pore-pressure build-up. Where slope materials are subject to strength loss or pore-pressure build-up, the level of investigation and degree of care taken should be increased. A post-earthquake stability analysis should also be completed in these cases.

The earthquake parameter (typically ground acceleration) may be determined using either deterministic or probabilistic methods. Generalized probabilistic maps showing peak horizontal ground acceleration (PGA) (Youngs and others, 1987; Algermissen and others, 1990) and spectral acceleration (Frankel and others, in press), which include accelerations associated with various earthquake return times and exceedance probabilities, are available for the Utah area. The level of probabilistic ground acceleration (that is, return time or exceedance probability) used for evaluating seismic slope stability should be appropriate to the type of proposed development and anticipated duration of site land use. In general, a developed site will remain in continuous use beyond the design life of an individual structure or facility at the site, such that seismic site-design levels commonly should exceed building-design levels.

A pseudostatic analysis can be used to determine either a dynamic FS or a yield acceleration. For a dynamic FS, the UGS recommends using an appropriate earthquake coefficient (for example, some percentage of the PGA) with a FS $\geq$ 1. Justification must be provided to support the earthquake coefficient chosen. Alternatively, the yield acceleration of a potential landslide can be estimated from the static FS and geometry of the potential slip surface having the lowest FS (Newmark, 1965).

Where a pseudostatic analysis indicates apparent mass stability, a deformation (ground-displacement) analysis generally will not be necessary. However, where a pseudostatic analysis indicates instability (dynamic FS < 1, or expected site PGA ≥ yield acceleration), a deformation analysis may be used to evaluate the amount of expected ground displacement. Also, a pseudostatic analysis may not provide meaningful results where high ground accelerations are expected and/or slope materials are subject to strength loss or significant pore-pressure build-up. A deformation analysis should be completed under these conditions. Various deformation-analysis techniques are available, including the sliding-block (Newmark, 1965) and finite-element (Desai and Abel, 1972) techniques. Jibson (1993) presents a simplified method for estimating Newmark displacements using critical acceleration (analogous to yield acceleration) and Arias intensity (which can be estimated from moment magnitude and earthquake source distance [Wilson and Keefer, 1985]), eliminating the need for an earthquake acceleration-time history. Glaser (1994) summarizes various techniques for determining ground displacement at sites subject to liquefaction, including an empirical technique developed by Bartlett and Youd (1992) for lateral spreading. The results of a deformation analysis may be used as a basis for establishing building setbacks or to provide justification and design information for proposed structures within the potential zone of deformation. Acceptable deformation criteria will vary widely from site to site and will depend on the type and structural characteristics of the proposed development.

For sites subject to material strength loss or significant pore-pressure build-up, a post-earthquake stability analysis should be completed in addition to a deformation analysis. For a post-earthquake analysis, the UGS recommends a static FS ≥ 1.2 considering residual undrained shear strength in liquefied zones and shear-strength loss due to pore-pressure build-up in nonliquefied zones.

REPORT GUIDELINES

General information for preparing geologic site-evaluation reports is presented in *Guidelines for Preparing Engineering Geologic Reports in Utah* (Utah Section of the Association of Engineering Geologists [AEG], 1986). The following report guidelines, which are intended to supplement the AEG guidelines, represent the minimum level of information needed to adequately evaluate landslide hazard, provide a basis for recommending hazard-reduction measures, and allow for critical review of conclusions and recommendations. Although the scope and evaluation techniques used in landslide-hazard studies will vary depending on site conditions and the type of proposed development, certain information must be collected and presented in a report to permit technical reviewers to assess the reliability and interpretation of the data. The following list, which also appears on the report-review checklist included in the appendix, summarizes this essential information.

1. Reference materials used for the analysis (such as reports, maps, and aerial photographs) should be listed, including scale and publication date.

2. A vicinity map (such as part of a 1:24,000-scale U.S. Geological Survey topographic quadrangle map) should show the location of the site relative to surrounding physical features.

3. One or more site maps at a scale suitable for site planning should show:

   a. proposed development (to the extent known),

   b. topography and/or slope,

   c. geology,

   d. locations of subsurface explorations and cross sections,

   e. surface water and evidence of shallow ground water (such as streams, ponds, springs, bogs),

   f. features associated with existing and/or suspected landslides (such as scarps, deposits, hummocky ground), and

   g. recommended building setbacks, non-buildable areas, or other site-design features to reduce hazards.

4. Site conditions should be described with emphasis on existing slope stability, based on observation and/or measurement of:

   a. slope inclination and height,

   b. slope-material type, density/consistency of soil, degree of weathering or induration of rock, relative strength of material, and relative slope-failure susceptibility of material,

   c. orientation, spacing, and physical characteristics of planar features within soil or rock (such as bedding, fabric, partings, or fractures),

   d. surface- and ground-water conditions,

   e. vegetation conditions including type, size, and relative age of disturbed vegetation (such as leaning or "jackstrawed" trees), presence or absence of phreatophytes, or other pertinent conditions,

   f. scarps, ground cracks, hummocks, depressions, or other geomorphic features of suspected landslide origin, and alternative hypotheses of possible non-landslide origins,

g. active surficial processes potentially oversteepening or undercutting slopes (such as stream incision, erosion, or slope retreat), and

h. any other pertinent features or circumstances.

5. Existing landslides should be described with consideration given to the items listed in (4) above and:

   a. failed geologic units, including physical characteristics such as chaotic texture, fissures, slickensides, or fracture voids,

   b. type of slope failure (for example, shallow debris slide, deep-seated slump, lateral spread),

   c. scarp characteristics (such as height, length, inclination, and freshness),

   d. estimated age of movement and basis for estimate, and

   e. if possible, likely cause(s) of slope failure.

6. Where appropriate, the characteristics, locations, and implications of nearby (off-site) landslides in similar geologic conditions should be discussed.

7. Where appropriate, the elements of a geotechnical-engineering evaluation should be described. Depending on the project scope, the evaluation may include some or all of the following:

   a. characterization of subsurface materials and ground-water conditions, with documentation for estimated parameters (preliminary evaluation) or logs of explorations and summaries of field tests and results (detailed evaluation),

   b. laboratory soil or rock tests, with summaries of methods and results,

   c. construction of topographic profiles and geologic cross sections at a scale suitable for the analysis,

   d. static slope-stability evaluation listing analysis methods, assumptions, input parameters, results, and computer software used,

e. seismic slope-stability evaluation (including consideration of appropriate input ground motions, effects of ground motions on material shear-strength and pore-pressure parameters, and liquefaction potential) listing analysis methods, assumptions, input parameters, results, and computer software used, and

f. post-earthquake stability analysis, as appropriate.

8. Conclusions regarding the landslide hazard should include consideration of:

a. possible effects on slope stability from the proposed development associated with landscape irrigation, on-site wastewater disposal, slope modifications, or other factors,

b. implications for slope stability associated with possible impacts to or from adjacent properties, and

c. the possibility that the hazard precludes some or all development potential.

9. Appropriate recommendations should be given relating to hazard reduction, additional study, or acceptance of risk.

The report must be signed by the engineering geologist and/or geotechnical engineer who conducted the study. The state of Utah presently does not have a statutory definition of an engineering geologist. However, some local governments define the minimum qualifications of geologists who can perform geologic-hazards studies. Current registration as an engineering geologist in another state may be used in support of demonstrating qualifications. All reports associated with a geotechnical-engineering evaluation must be stamped by a Professional Engineer.

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APPENDIX

Checklist for the Review of Landslide-Hazard Reports

The purpose of the report-review checklist on the following pages is to provide an index for evaluating the adequacy of site-specific landslide-hazard reports. The checklist will be used by the UGS and its geotechnical-engineering advisors for technical reviews requested by local-government agencies. The investigator need not submit a copy of the checklist with the landslide-hazard report. Rather, the investigator should refer to the checklist and guidelines to complete an adequate study and report that contains the necessary supporting data to facilitate objective review and approval. The UGS will complete the checklist during the technical review process, indicate if the report is adequate or if additional data are needed, and return copies of the checklist to the investigator and agency that requested the report review.

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CHECKLIST FOR THE REVIEW OF LANDSLIDE-HAZARD REPORTS

Report Author(s) ____________________ Date Of Report ____________

Title Of Report ______________________________________

UGS File No. __________ Requesting Agency ______________ County __________

USGS 7.5' Quad(s) (BLM No.) ______________ Sec., T., R. ______________ SLBM UBM

Adequacy Codes: A = adequate; **N** = not necessary; **D** = additional data, analysis, or justification needed

SUBJECT[1]	Adequacy of Report	**COMMENTS** (attach additional sheets if necessary)
1. List of reference materials used		
2. Vicinity map		
3. Site-planning map at suitable scale, showing:		
3a. proposed development		
3b. topography		
3c. geology		
3d. subsurface exploration and cross section locations		
3e. surface water		
3f. landslide features		
3g. hazard-reduction features		
4. Description of site conditions:		
4a. slopes		
4b. slope materials		
4c. subsurface planar features		
4d. surface/ground water		
4e. vegetation		
4f. suspected landslide features		
4g. surficial processes		
4h. other		

(table continued)

[1] *Refer to UGS Circular 92, "Guidelines for Evaluating Landslide Hazards in Utah" (1996, M.D. Hylland [editor]) for supplemental information.*

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SUBJECT	Adequacy of Report	**COMMENTS** (attach additional sheets if necessary)
5. Description of existing landslides, including items in (4) above, and:		
5a. failed unit(s)		
5b. failure type(s)		
5c. scarp characteristics		
5d. age(s) of failure		
5e. cause(s) of failure		
6. Implications of nearby landslides		
7. Geotechnical-engineering evaluation:		
7a. subsurface materials/ground-water characterization		
7b. laboratory testing		
7c. profiles/cross sections		
7d. static slope-stability analysis		
7e. seismic slope-stability analysis		
• input ground motions		
• effects on shear strength and pore pressures		
• liquefaction potential		
7f. post-earthquake stability analysis		
8. Conclusions regarding hazard		
9. Recommendations		

Additional comments:

Reviewed By ______________________________ Date Reviewed ______________