GEOTECHNICAL AND SLOPE STABILITY MANUAL

JULY 2019

ENGINEERING DEPARTMENT

2222 WEST 14400 SOUTH

BLUFFDALE, UTAH 84065

TABLE OF CONTENTS

1. GENERAL

A. INTRODUCTION

This manual includes the minimum standards and required format for geotechnical reports submitted to the City of Bluffdale. The standards and requirements are to guide engineers performing geotechnical work in the City of Bluffdale. Requirements in this manual ultimately expedite project approval. Any deviation from these standards must be approved by the City Engineer in writing. The appropriate scope of a geotechnical report is a function of the type of project or proposed land use, the soil/geologic conditions of the project site, and type of permit or approval sought. The geotechnical consultant is responsible for targeting the scope of their investigation, testing, analyses, and documentation to meet these standards as they apply to the project.

The two controlling faults that would most affect the City of Bluffdale are the Salt Lake City and Provo segments of the Wasatch fault zone (WFZ). Repeated Holocene movement has been well documented along both segments (Black and others, 2003). Studies along the Provo segment of the WFZ indicate a recurrence interval of approximately 1,150 years (Olig and others, 2007) with the most recent event being about 500 to 650 years ago (Black and others, 2003, Olig and others, 2007). Studies along the Salt Lake City segment of the WFZ indicate a recurrence interval of about 1,300 years (Lund, 2005). Based on the paleoseismic record of the Salt Lake City segment and assuming a time-dependent model, McCalpin (2002) estimates a conditional probability (using a log-normal renewal model) of 16.5% in the 100 years (8.25% in the next 50 years) for a M>7 surface –faulting earthquake. Therefore, using a time-dependent rather than Poisson or random model for earthquake recurrence, the likelihood of a large surface-faulting earthquake on the Salt Lake City segment of the WFZ is relatively high and therefore the Salt Lake City segment is considered the primary controlling fault for deterministic analyses.

In regards to design ground accelerations for seismic slope-stability the City of Bluffdale requires a probabilistic approach to determining the likelihood that different levels of ground motion will be exceeded at a particular site within a given time period. In order to more closely represent the seismic characteristics of the WFZ and better capture this possible high likelihood of a surface-faulting earthquake on the Salt Lake City segment, provide ground motion parameters for seismic slope stability analyses based on the peak accelerations with a 2.0 percent probability in 50 years (2,475 year return period). Peak bedrock ground motions can be readily obtained via the internet from any number of second party calculators that utilize the United States Geological Survey (USGS) National Seismic Maps. Adjust PGAs obtained from the web for effects of soil/rock (site class) conditions in accordance with Seed and others (2001). Site specific response analysis may also be used to develop PGA values as long as the procedures, input data, and results are thoroughly documented and deemed acceptable by the City.

B. DEFINITIONS

ACTIVE FAULT: A fault displaying evidence of displacement along one or more of its traces during Holocene time, which is approximately ten thousand (10,000) years ago to the present.

BUILDABLE AREA: Based on an accepted geotechnical/engineering geology report, the portion of a site not impacted by geologic hazards, or the portion of a site where it is concluded that the identified geologic hazards should be mitigated to a level where risk to human life, property and city infrastructure are reduced and where structures may be safely sited.

CITY: The political and administrative body that conducts the affairs of the incorporated local organizations including but not limited to the mayor, city council city manager and those representatives.

CRITICAL FACILITIES: Essential, hazardous, special occupancy facilities, and occupancy categories III and IV as defined in the currently adopted International Building Code(IBB,IBC) and lifelines, such as major utility, transportation, and communication facilities and their connections to critical facilities.

DEBRIS FLOW: A slurry of rock, soil, organic material, and water transported in an extremely fast and destructive flow that flows down channels and onto and across alluvial fans; including a continuum of sedimentation events and processes, including debris flows, debris floods, mudflows, clear water floods, and alluvial fan flooding.

ENGINEERING GEOLOGIST: A Utah-licensed geologist, who, through education, training, and experience, is competent in applying geologic data, geologic techniques, and geologic principles. The City of Bluffdale requires that pertinent experience be submitted prior to work. A minimum of 5 years' experience is required for any Engineering Geologist working within the City of Bluffdale.

ESSENTIAL FACILITY: Buildings and other structures intended to remain operational in the event of an adverse geologic event.

FAULT: A fracture in the earth's crust forming a boundary between rock or soil masses that have moved relative to each other.

FAULT SCARP: A steep slope or cliff formed by movement along a fault.

FAULT SETBACK: An area on either side of a fault within which structures for human occupancy or critical facilities or their structural supports are not permitted.

GEOLOGIC HAZARD: A surface fault rupture, liquefaction, slope stability, landslide, debris flow, and rockfall that may present a risk to life or property.

GEOLOGIC HAZARD STUDY AREA: A potentially hazardous area as shown on the geologic hazard study area maps within which hazard investigations are required prior to development.

GEOTECHNICAL ENGINEER: A professional, Utah-licensed engineer who, through education, training and experience, is competent in the field of geotechnical engineering.

GOVERNING BODY: The city council, or a designee of the city council.

LANDSLIDE: The downslope movement of a mass of soil, surficial deposits or bedrock, including a continuum of processes between landslides, earth flows, debris flows and debris avalanches, and rockfalls.

LIQUEFACTION: A process by which certain water-saturated soils lose bearing strength because of earthquake related ground shaking and subsequent increase of groundwater pore pressure. Liquefaction typically occurs in cohesionless silt, sand, and fine-grained gravel deposits of Holocene to late Pleistocene age in areas where the groundwater is shallower than about 50 feet.

NON-BUILDABLE AREA: That portion of a site which a geologic hazards report has identified a non-buildable area and where the siting of critical facilities is not permitted.

SETBACK: An area within which support of critical facilities is not permitted.

SLOPE STABILITY: The resistance of a natural or artificial slope or other inclined surface to failure by land sliding, usually assessed under both static and dynamic (earthquake induced) conditions.

STRUCTURE DESIGNED FOR HUMAN OCCUPANCY: Any residential dwelling or any other structure used or intended for supporting or sheltering any use or occupancy, which is expected to have an occupancy rate of at least two thousand

(2,000) person hours per year, but does not include an accessory building.

C. MINIMUM QUALIFICATIONS OF THE LICENSED PROFESIONAL

Submit engineering – geology investigations and accompanying geologic-hazard evaluations and studies that are prepared only by qualified Utah licensed professional geologist (Utah Code, Title 58-76-10) and/or by a qualified professional geologist and professional engineer (Utah Code, Title 58-22-302) working as a team. Submit all reports stamped and signed in blue ink by the professional who worked on the report or is responsible for the reports. Studies and reports without a stamp will be reported to the State Division of Occupational and Professional Licensing (DOPL).

2. GEOLOGIC HAZARDS STUDY REQUIREMENTS

A. GEOLOGIC HAZARDS STUDY AREA MAPS

Geologic Special Study Maps are available on the City of Bluffdale's website. Geologic hazards study area maps are prepared using the best available scientific information but are generalized and designed only to indicate areas where hazards may exist and where geologic hazards studies are required. Because the geologic hazards study area maps are prepared at a non-site-specific scale, hazards may exist that are not shown on the geologic hazards study area maps. As requested by the city, provide additional studies in areas outside the geologic hazards map that show potential geotechnical hazards.

B. GIS AVAILABLE MAPS

1. Liquefaction Potential Map
2. Slope Hazard Map
3. Landslide Hazard Map
4. Debris Flow Hazards on Alluvial Fans Map
5. Bluffdale City Hillshade Map
6. Jordan Narrows 1:24,000 Geologic Quadrangle Map

C. GEOTECHNICAL REPORT CONTENT

Each geologic hazard is site-specific. As part of the Geotechnical report, identify all known or suspected potential geologic hazards, originating on site or off site, whether previously identified or previously unrecognized, that may affect the subject property. Include the original or wet signature and professional seal, both in blue ink, of the qualified professional. On all reports include both professionals' original seal and signature in blue ink for reports prepared by Professional Geologists and Engineers.

1. **Purpose**: Clearly identify the purpose of the geotechnical investigation. Indicate if the investigation is intended to be comprehensive or if it addresses a specific permit (i.e., grading plan).

2. **Site Description:** Describe the site location and access. Provide a description of the physiographic (geomorphology), vegetation, and significant cultural (man-made) features of the site. Describe natural and manufactured slope height and gradient (or ratio). Reference to an index map that uses a topographic base may reduce the need for lengthy descriptions.

3. **Proposed Development:** Provide a general description of the proposed project. Refer to the plans addressed by the investigation and present the anticipated maximum cuts and fills at the site.

4. **Previous Studies:** List, describe, and provide relevant published and unpublished literature pertinent to the geologic or geotechnical aspects of the site.

5. **Scope of Investigation:** Describe the research, field exploration, laboratory testing, and analyses conducted. Provide details of the methods and procedures used in the investigation in the body of the report.

6. **Geologic/Geotechnical Site Conditions:** Describe the geologic and/or geotechnical conditions of the site. The emphasis of this section should reflect the Geologic Hazard Category. If groundwater is encountered at the subject site at an elevation within 5 feet of the planned bottom of footings, piezometers are required to provide accurate groundwater elevation. The number of piezometers will be determined by the Geotechnical Engineer. Piezometers must be allowed to equilibrate for a minimum of 24 hours prior to reading.

7. **Geologic/ Geotechnical Analysis**: Describe and discuss site or project specific geologic or geotechnical analyses. For slope stability focused reports, describe analyses that were conducted and discuss the results.

8. **Infiltration Test Results:** Planned retention basins must have the native soil below the proposed basin identified according to (USCS) (ASTM D2487, ASTM D4318). Use the table below for the design infiltration rate. Provide hydraulic conductivity testing of in situ soils according to ASTM D5856 if applicant believes in situ soils differ from this table. The results must be accepted by the city engineer. **A Safety Factor of 2.5 is required for the infiltration rates listed in this table.**

NRCS hydrologic soil group	Typical soil texture	Saturated infiltration rate(mm/h)*	Saturated infiltration rate (in/h)*	Porosity	Field capacity
A	Sand	200	8.0	0.437	0.062
A	Loamy sand	50	2.0	0.437	0.105
B	Sandy loam	25	1.0	0.453	0.190
B	Loam	12.7*	0.5	0.463	0.232
C	Silt loam	6.3*	0.25	0.501	0.284
C	Sandy clay loam	3.8	0.15	0.398	0.244
D	Clay loam and silty clay loam	<2.3	<0.09	0.465	0.325
D	Clay	<1.3	<0.05	0.475	0.378

*Values recommended for screening and selection only, as actual infiltration rates may vary significantly within each soil group. Soils must meet drain time requirements listed in the City of Bluffdale Storm Water Design Standards Manual.

9. **Conclusions:** Provide a conclusion section that addresses the suitability of the site for the intended use. Summarize all hazardous or damaging geologic or geotechnical conditions that can impact the proposed development. Support the conclusions and opinions with facts and/or experience. Provide the rational for experienced based judgments.

10. **Recommendations**: Provide project specific recommendations targeting the type of permit that is sought. For environmental review, provide recommendations to mitigate or avoid geologic hazards. For land disturbance permits, provide grading and erosional recommendations. In the geotechnical report for building lots or areas include foundation and design recommendations. Provide comprehensive recommendations for all phases of the permit process. Update recommendations if additional exploration, testing, or analyses are recommended to address the proposed project.

11. **Illustrations:** Use only clear pictures clear and legible. Define all symbols in a legend and include a graphic scale and north arrow on all maps. For all illustrations of geotechnical reports include an index map (site location map), regional geologic map, geological or geotechnical maps, and cross sections of existing and proposed grading. Site location map should include elevations of explorations.

12. **Logs of Exploratory Excavations:** Present logs for all exploratory excavations. Logs are required to include

    1. Project identification and or job description and exploration number.
    2. Method of drilling and/or sampling employed.
    3. Date of start and completion of boring.
    4. Latitude and Longitude of explorations.
    4. Sheet number and total number of log sheets.
    5. Definition of all symbols.
    6. Description of each layer encountered, and sample obtained; including information pertaining to color, strength, moisture content, composition, and degree of compactness.
    7. Depth at which obstacles were encountered in advancing the boring or test pit
    8. Number of blows in six-inch increments required to drive sampler during Standard Penetration Test.
    9. Reason for abandoning boring in the event specified depth was not reached.
    10. Groundwater measurement data.

13. **Geotechnical Test Data:** Perform in situ and/or laboratory testing to characterize the physical geotechnical parameters of the earth materials affecting the proposed development. Reference ASTM/AASHTO standards utilized during preparation of report. Provide the test data results in tabular format and plots as deemed appropriate. Provided data that is representative of site conditions and t substantiates the geotechnical parameters used for analyses.

14. **Authentication**: Wet sign and seal all geotechnical reports in accordance with Section 1-A of this manual submitted to the City of Bluffdale.

D. REQUIREMENTS FOR GEOTECHNICIAL REPORTS

Include on the geotechnical reports all potential geologic hazards of a site proposed for development with focus on the geologic hazards implied by the geologic hazard category of the site as shown on the Bluffdale Special Study Maps.

1. Standards of Exploration and Testing:

Development/Improvement Type	Number of/Frequency of Borings/Test Pits	Depth of Borings /Test Pits	Laboratory Testing
Residential	8 test pits for the first 20 acres and one test pit per every five acres thereafter	4-ft below the footing elevation	Classify each soil unit using (USCS) (ASTMD2487, ASTM D422, ASTM D4318) One-Dimensional Consolidation (ASTM D2435) for fine-grained soils
High Density Residential/Commercial Building > 2 stories	1 borehole per 200 linear feet of exterior strip footing	20 feet (unless shallower depths are approved by City Engineer). 50-ft for liquefaction hazard assessment.	Classify each soil unit using (USCS) (ASTMD2487, ASTM D422, ASTM D4318) One-Dimensional Consolidation (ASTM D2435) for fine-grained soils
High Density Residential/Commercial Buildings < 2 stories	1 borehole per 200 linear feet of exterior strip footing	20 feet (unless shallower depths are approved by City Engineer). One boring to at least 50-ft for liquefaction hazard assessment.	Classify each soil unit using (USCS) (ASTMD2487, ASTM D422, ASTM D4318) One-Dimensional Consolidation (ASTM D2435) for fine-grained soils
Retaining Structure	Borings spaced every 100 to 200 ft. Some borings should be at the front of and some in back of the wall face. Test pits may be used if retaining wall height is less than or equal to 10 feet.	Extend borings/test pits to depth of 0.75 to 1.5 times wall height. When stratum indicates potential deep stability or settlement problem, extend borings to hard stratum (material exceeding 50 blows per 6 inches of penetration).	Classify each soil unit using (USCS) (ASTMD2487, ASTM D422, ASTM D4318) Direct Shear or Triaxial Shear Test (ASTM D3080, ASTM D4767) on each soil unit
Bridge Approach Embankments over Soft Ground	When approach embankments are to be placed over soft ground, a minimum of one borings required to be made at each embankment to determine the problems associated with stability and settlement of the embankment. Typically, test borings taken for the approach embankments are located at the proposed abutment locations to serve a dual function.	Extend borings into competent material (material suitable to support the anticipated loading conditions) and to a depth where added stresses due to embankment load is less than 10% of existing effective overburden stress or 10 ft into bedrock if encountered at a shallower depth Additional shallow explorations (hand auger holes) taken at approach embankment locations to determine depth and extent of unsuitable surface soils or topsoil	Classify each soil unit using (USCS) (ASTMD2487, ASTM D422, ASTM D4318) Direct Shear or Triaxial Shear Test (ASTM D3080, ASTM D4767) on each soil unit One-Dimensional Consolidation Test (ASTM D2435)
Roadway Embankments and Pavement Cross Section	Borings typically spaced every 200 ft (erratic conditions) to 400 ft (uniform conditions) with at least one boring taken in each separate landform. For high cuts and fills, take 3 borings along a line perpendicular to centerline or planned slope face to establish geologic cross-section for analysis.	Twice the embankment height	Classify each soil unit using (USCS) (ASTMD2487, ASTM D422, ASTM D4318) California Bearing Ratio (CBR) (AASHTO T193) One-Dimensional Consolidation Test (ASTM D2435) for fine-grained native subgrade soils
Landslides	3 borings along a line perpendicular to centerline or planned slope face to establish geologic cross-section for analysis. For active slide, place at least one boring each above and below sliding area	Extend borings to an elevation below active or potential failure surface and into hard stratum, or to a depth for which failure is unlikely because of geometry of cross-section. Slope inclinometers used to locate the depth of an active slide must extend below base of slide.	Classify each soil unit using (USCS) (ASTMD2487, ASTM D422, ASTM D4318) Residual Direct Shear or Ring Shear Test (ASTM WK3822, ASTM D6467) of sheared soils Direct Shear or Triaxial Shear test (ASTM D3080, ASTM D4767) for non-sheared soils
Cut Slopes	Every 200 to 600 feet, depending on conditions. One for every cut exceeding 15 feet in depth.	15 feet below final bottom of cut elevation.	Classify each soil unit using (USCS) (ASTMD2487, ASTM D422, ASTM D4318) Residual Direct Shear or Ring Shear Test (ASTM WK3822, ASTM D6467) of sheared soils Direct Shear or Triaxial Shear test (ASTM D3080, ASTM D4767) for non-sheared soils

2. Liquefaction:

Map all areas in the development where conditions are present for liquefaction during an earthquake with a magnitude 6.0 on the Richter Scale or larger. Show where all sandy soils deposits are and where the water table is in the zone where external loads from building footings are located.

The City of Bluffdale requires a site-specific liquefaction investigation to be performed prior to approval of a project based on the land-use/liquefaction potential for the facilities listed below.

Type of Facility
Critical facilities (essential facilities, hazardous facilities, and special occupancy structures)
Category III and IV in Table 1604.58 of the most recently adopted edition of the IBC.
Industrial and commercial buildings.

a. **Subsurface Explorations:** Conduct subsurface explorations that consist of drilled borings and/or cone penetration tests (CPTs). Determine the soil stratigraphy, groundwater level, and indices that could be used to evaluate the potential for liquefaction by either in-situ testing or by laboratory testing of soil samples. Borings and CPT soundings must penetrate a minimum of 50 feet below final ground surface. Liquefaction has been known to occur during earthquakes at deeper depths than 50 feet (15 m) given the proper conditions such as low-density granular soils, presence of ground water, and sufficient cycles of earthquake ground motion. When a structure will have subterranean construction or deep foundations, the depth should extend to a minimum of 20 feet below the lowest expected foundation level (bottom of caisson or pile) or 50 feet below the ground surface, whichever is deeper. Take samples at a maximum of 5 foot spacing. Preform grain-size analysis, hydrometer tests, and Atterberg Limits Test for saturated cohesionless soils where the SPT (N60) values are less than 15, or where CPT tip resistances are below 60 tsf, further evaluate their potential for permanent ground displacement (Youd et al., 2002) and other forms of liquefaction-induced ground failure and settlement. Several correlations make use of the energy corrected Standard Penetration Test blow count, denoted as N60 where 60 is the percentage of the theoretical free-fall hammer energy. Measured blow counts may additionally be adjusted to an effective overburden pressure of 100 kPa which produces the N1,60 value. In some cases various other factors that influence the SPT results can be taken into consideration when calculating N1,60 such as bore-hole diameter, rod length etc.. Extend the depth of the investigation to a depth that is a minimum of 20 feet below the lowest expected foundation level (e,g, caisson bottom or pile tip) or 50 feet below the existing ground surface or lowest finish grade, whichever is deeper, where a structure may have subterranean construction or deep foundations (e.g., caissons or piles). Soils that behave like clays and do not undergo severe strength loss during ground shaking are considered non susceptible to liquefaction.

b. Evaluation of Liquefaction Hazards: The liquefaction study area map is based on broad regional studies and does not replace site-specific studies.

Soil liquefaction is caused by strong seismic ground shaking where saturated cohesionless, granular soil undergoes a significant loss in shear strength that can result in settlement and permanent ground displacement. Surface effects of liquefaction include settlement, bearing capacity failure, ground oscillations, lateral spread and flow failures. Soil liquefaction can occur in clean sands, silty sands, and sandy silt, non-plastic silts and gravelly soils. The following conditions must be present for liquefaction to occur:

a. Soils is submerged below the water table
b. Soils is loose to moderately dense
c. Ground shaking is relatively intense, and
d. The duration of the shaking generate seismically-induced pore water pressure and lose their shearing resistance.

Use the following screening to determine if the above conditions exist and further quantitative evaluation of liquefaction hazard is required:

a. For soil materials that are located above the level of the groundwater, a quantitative assessment of seismically induced settlement is required.
b. If the corrected standard penetration blow count is greater than or equal to 33 in all samples with a sufficient number of tests (blow counts obtained at 5-foot maximum intervals), liquefaction assessments are not required. If cone penetration test soundings are made, the corrected cone penetration test tip resistance, qc1N should be greater than or equal to 180 in all soundings in sand materials, otherwise liquefaction assessments are needed.
c. If plastic soils (PI>20) materials are encountered during site explorations, those materials may be considered non-liquefiable and no analysis of their liquefaction potential is necessary.
d. If "bedrock" or similar lithified formational material underlies the site, those materials need not be considered liquefiable and no analysis of their liquefaction potential is necessary.

If the screening investigation clearly shows the absence of liquefaction hazards at a project site and the City concurs, the screening investigation will satisfy the site investigation report requirement for liquefaction hazards. If not, a quantitative evaluation is required to assess the liquefaction hazards.

c. **MITIGATION OF LIQUEFACTION HAZARDS:** As stated in SP 117, in the presence of strong ground motion, liquefaction hazards are likely to occur in saturated cohesionless soils. Mitigation must provide suitable levels of protection with regard to potential large lateral spread or flow failures, and more localized problems including bearing failure, settlements, and limited lateral displacements. The choice of mitigation methods will depend on the extent of liquefaction and the related consequences. Also, mitigation cost will be based on consideration based on an acceptable level of risk. Youd (1998) has suggested that structural mitigation for liquefaction hazards may be acceptable where small lateral displacements (say less than 1 foot or 0.3 meter) and vertical settlement (say less than 4 inches or 10 centimeters) are predicted. Youd cites evidence that houses and small buildings with reinforced perimeter footings and connected grade beams have performed well in Japan, and similar performance should be expected in the United States.

3. Slope Stability:

Follow the minimum standards presented herein and the Guidelines for Evaluating Landslide Hazards in Utah (Hylland,1996) for slope stability. Perform quantitative slope stability analysis for all sites located within the

Slope Stability Special Study Map and for all cut, fill and natural slopes whose gradient exceeds two horizontal to one vertical (2:1) and for all slopes that expose incompetent bedrock or unfavorable geologic structure such as unsupported bedding or that contain evidence of prior instability or landslide activity.

a. **Factors of Safety**

The minimum acceptable static factor of safety is 1.5 for both global and surficial slope stability. The minimum acceptable factor of safety for a calibrated pseudostatic analysis is 1.0. Acceptable methods of analyzation include Bishops Simplified Method of Slices or the Janbu Simplified Method. Other methods of analysis may be considered with the approval of the City Engineer or City Consultant.

Methods for analysis tools use various versions of the method. Depict, illustrate and graph all subsurface geologic and groundwater conditions on geologic cross sections which must be utilized by the geotechnical engineer for the slope stability analyses. If on-site sewage or storm water disposal exists or is proposed, the slope stability analyses must include the effects of the effluent plume on slope stability.

Submit the results of any slope stability analyses with pertinent backup documentation (i.e., calculations, computer output, etc.). Place input/output data in the project appendix. Printouts of input data, output data (if requested), and graphical plots must be submitted for each computer-aided slope stability analysis. In addition, input data files may be requested to facilitate the City's review.

4. Landslide Hazard:

Preform Landslide evaluations during the feasibility phase of hillside developments. Where landslides are present or suspected, provide subsurface exploration to determine the basic geometry and stability of the landslide mass and the required stabilization measures. When determining the depth of geologic exploration consider the regional geologic structure, the likely failure mode of the suspected failure and past geomorphic conditions. Provide a landslide hazard investigation for all new buildings for human occupancy and for modified International Building Code (IBC) Risk Category II(a), II(b), III, and IV facilities (International Code Council (ICC), 2014a)) that are proposed on slopes. At the request of the City Engineer, more data may be required.

5. Debris-Flow Hazard:

Conduct a debris flow hazard investigation when developing on active alluvial fans where Holocene debris deposition has occurred. Use quantitative and objective procedures to estimate the location and recurrence of flows, assess their impacts, and provide recommendations for risk-reduction measures if necessary. The hazard investigation must consider the intended land use because site usage has direct bearing on the degree of risk to people and structures. Reports submitted to the City of Bluffdale must include:

a. **Interpretation of Remote-Sensing Imagery**. Interpret and describe the results of the most current remote-sensing imagery, including stereoscopic aerial photographs, lidar, and other remote-sensing data when available. List source, date, flight-line numbers, and scale of aerial photos or other imagery used.

b. **Subsurface Investigation**: Use test pits, trenches, and natural exposures in subsurface explorations when obtaining sedimentologic and stratigraphic information regarding previous debris flows. The type, number, and spacing of excavations depend on the purpose and scale of the hazard investigation, geologic complexity, rate of down-fan and across-fan transitions in flow type and thickness, and anticipated risk-reduction measures. Provide deeper excavations in the proximal fan areas due to thicker deposits.

c. **Complete an Alluvial Fan Evaluation:** Provide a site-scale geologic map showing areas of Holocene-ages deposition and other surficial deposits, including older debris-flow and alluvial-fan deposits and their relative age. Include test pit and trench logs at 1 inch = 5 feet scale showing descriptions of geologic units, layer thicknesses, maximum grain sizes, and interpretation of flow types. Show basis for design flow-volume estimates (deposit thickness and area estimates). Provide a range of estimates based on maximum, average, and minimum thickness and area estimates. Indicate runout distance, spatial extent, thickness, flow type, and deposit characteristics of historical flows, if present. Provide mitigation age estimates for the deposits or other evidence used to estimate the frequency of past debris flows. Evaluate the debris-flow hazard based on anticipated probability of occurrence and volume, flow type, flow depth, deposition area, runout, gradation of debris, flow impact forces, and stream-flow inundation and sediment burial depth

d. **Drainage Basin and Channel Evaluation**: Include a vicinity geologic map (1:24,000 scale) on a topographic base of the drainage basin showing bedrock and surficial geology, including shallow landslides (debris slides) and a measurement of drainage-basin morphologic parameters. Provide an estimate of the susceptibility of the drainage basin to shallow landsliding, likely landslide volume(s), and volume of historical landslides, if present. Provide an estimate of the susceptibility of the drainage basin slopes to erosion. Include a longitudinal channel profile, showing gradients from headwaters to the alluvial fan. Include cross-channel profiles and a map showing their locations. Provide a basis for channel volume estimates including initial debris slides, total feeder channel length, length of channel lined by bedrock, cross-channel profiles, and estimated volume of channel sediment available for sediment bulking including estimated bulking rate(s) in cubic yards per linear foot of channel.

REFERENCES

Bishop, A. W., 1955 The use of slip circle in the stability analysis of earth slopes, *Gèotechnique*, 5(1), 7-17

Blake, T. F., Hollingsworth, R. A., and Stewart, J. P., editors, 2002. Recommended Procedures for Implementation of DMG Special Publication 117 Guidelines for Analyzing and Mitigating Landslide Hazards in California, Southern California Earthquake Center, University of Southern California, available at http://www.scec.org/resources/catalog/ hazardmitigation.html

Bowman, S.D., and Lund, W.R, editors, Guidelines for Investigating Geologic Hazards and Preparing Engineering-Geology Reports, With a Suggested Approach to Geologic-Hazard Ordinances in Utah, 2016.

Hylland M.D., (1996) Guidelines for Evaluating Landslide Hazards in Utah, Utah Geological Survey Circular 92.

Martin, G.R., and Lew, M., editors, 1999, Recommended procedures for implementation of DMG Special Publication 117, Guidelines for analyzing and mitigating liquefaction in California: Los Angeles, Southern California Earthquake Center, 63 p.

Southern California Earthquake Center (1999), Recommended Procedures for Implementation of DMG Special Publication 117, Guidelines for Analyzing and Mitigating Liquefaction Hazards in California, Martin, G. R. and Lew, M. Co-Chairs and Editors, University of Southern California, March 1999.

Stewart and others.,2003 A Screen Analysis Procedure for Seismic Sope Stability, Earthquake Spectra, 19(3) ISSN 8755-2930.

Youd, T, L, Hansen, C. M. and Bartlett S.F., (2002), Revised Multilinear Regression Equations for Prediction of Lateral Spread Displacement. Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 2002 Vol. 128: 1007- 1017.

Youd, T. L. and Perkins, D. M., (1987), Mapping of liquefaction induced ground failure potential. Journal of Geotechnical Engineering, ASCE, 1987, Vol. 104 :433-446.

Bishop, A. W., 1955 The use of slip circle in the stability analysis of earth slopes, *Geotechnique*, 5(1), 7-17