UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources
in cooperation with
National Park Service

LIQUEFACTION SUSCEPTIBILITY
ZION NATIONAL PARK GEOLOGIC-HAZARD STUDY AREA

By

William R. Lund, Tyler R. Knudsen, and David L. Sharrow

2010

This geologic-hazard map was funded by the Utah Geological Survey and the U.S. Department of the Interior, National Park Service. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

www.geology.utah.gov

Base map consists of U.S. Department of Agriculture 2006 National Agricultural Imagery Program natural color aerial photography and shaded relief generated from digital elevation data acquired from the Utah Automated Geographic Reference Center.

Universal Transverse Mercator Projection, zone 12
North American Datum of 1983

SYMBOLS

- Zion National Park Geologic-Hazard Study Area boundary
- Zion National Park boundary
- County boundary
- State highway
- Minor road
- Foot trail
- Existing park structure
- Area not studied

EXPLANATION

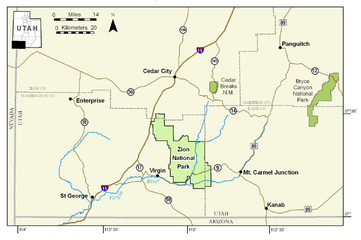
Liquefaction-Susceptibility Zone -- Areas where potentially liquefiable unconsolidated geologic units may also be saturated. Determining if a liquefaction hazard exists at a particular location requires acquiring site-specific information about soil texture and density, ground-water conditions, and the frequency and intensity of anticipated ground shaking.

Unconsolidated Geologic Deposits[1] that may be Susceptible to Liquefaction if Saturated

Stream and Terrace Alluvium	Alluvial Deposits	Eolian Deposits	Colluvial Deposits	Lacustrine Deposits
Qaly, Qath, Qat_2	Qaso, Qae, Qa, Qa_1, Qa_2, Qac, Qay, Qaec, Qaf, Qaf_1, Qaf_2, Qafy, Qafc, Qage, Qao, Qaeo	Qes, Qeq, Qre, Qer, Qed	Qc, Qce, Qces	Qla, Qlbc, Qls

[1]Refer to UGS geologic quadrangle maps (see Sources of Information and References in accompanying text) for descriptions of map units.

Map Location



SCALE 1:24,000

1 0.5 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 0.5 0 1 KILOMETER

12°9' TRUE NORTH / MAGNETIC NORTH

Approximate mean declination, 2009

DISCUSSION

Liquefaction and liquefaction-induced ground failure are major causes of earthquake damage (Keller and Blodgett, 2006). During liquefaction, a soil loses its strength and ability to support the weight of overlying structures or sediment. Soil liquefaction is caused by strong earthquake ground shaking where saturated, cohesionless, granular soil is transformed from a solid to a nearly liquid state. Soil liquefaction generally occurs in sand, silty sand, and sandy silt soils (Youd and Idriss, 1997). All of the following conditions are required for liquefaction to occur:

- The soils must be submerged below the water table.
- The soils must be loose/soft to moderately dense/stiff.
- The ground shaking must be intense.
- The duration of ground shaking must be sufficient for the soils to lose their shearing resistance.

Plastic or clay-rich soils having either a clay content greater than 15 percent, a liquid limit greater than 35 percent, or a moisture content less than 90 percent of the liquid limit are generally immune to liquefaction (Seed and Idriss, 1982; Youd and Gilstrap, 1999).

Four types of ground failure commonly result from liquefaction: (1) loss of bearing capacity, (2) ground oscillation and subsidence, (3) lateral spreading, and (4) flow failure (Youd, 1978, 1984; Tinsley and others, 1985). The expected mode of ground failure at a given site largely depends upon the ground-surface slope. Where slope inclination is less than 0.5 percent, liquefaction may cause damage in one of two ways. The first is the loss of bearing capacity and resulting deformation of soil beneath a structure, which causes the structure to settle or tilt. Differential settlement is commonly accompanied by cracking of foundations and damage to structures. Buoyant buried structures, such as underground storage or septic tanks, may also float upward under these conditions. The second results from liquefaction at depth below soil layers that do not liquefy. Under these conditions, blocks of the surficial, non-liquefied soil detach and oscillate back and forth on the liquefied layer. Damage to structures is caused by subsidence of the blocks, opening and closing of fissures between and within the blocks, and formation of sand blows as liquefied sand is ejected through the fissures from the underlying pressurized liquefied layer.

Lateral spreading may occur where the ground surface slopes from 0.5 to 5 percent, particularly near a "free face" such as a stream bank or cut slope. Lateral spreads are characterized by surficial soil blocks that are displaced laterally downslope as a result of liquefaction in a subsurface layer. Lateral spreading can cause significant damage to structures and may be particularly destructive to pipelines, utilities, bridges, roadways, and structures with shallow foundations.

Flow failures may occur where the ground surface slopes more than about 5 percent. Flow failures are composed chiefly of liquefied soil or blocks of intact material riding on a liquefied layer. Flow failures can cause soil masses to be displaced several miles and are the most catastrophic mode of liquefaction-induced ground failure.

For additional information about the liquefaction hazard in the Zion National Park Geologic-Hazard Study Area, refer to the Earthquake Hazards chapter in this report.

USING THIS MAP

This map shows areas where liquefaction may be possible in the Zion National Park Geologic-Hazard Study Area. The map is based on limited information about the textural characteristics of unconsolidated geologic units and the distribution and depth of ground water in the study area. The map does not integrate earthquake ground motions with material characteristics and depth to ground water, which is required to determine relative liquefaction potential in susceptible deposits. Consequently, the map does not differentiate ground-failure types or amounts, which are needed to fully assess the hazard and evaluate possible mitigation techniques.

This map is intended for general planning and design purposes to indicate where liquefaction hazards may exist and to assist in liquefaction-hazard investigations. In Utah, soil-test requirements are specified in chapter 18 (Soils and Foundations) of the IBC (International Code Council, 2009a) and chapter 4 (Foundations) of the IRC (International Code Council, 2009b), which are adopted statewide. IBC Section 1803.2 requires a geotechnical investigation be performed in accordance with IBC sections 1803.3 through 1803.5. Section 1803.3 requires an investigation to evaluate liquefaction, and Section 1803.5.11 requires a liquefaction evaluation for structures in Seismic Design Categories C through F (see Earthquake-Ground-Shaking Hazard section in chapter 5 of accompanying text). In general, seismic design categories in the Zion National Park Geologic-Hazard Study Area for structures built on unconsolidated materials fall into Seismic Design Categories C and D (see chapter 5, table 5.4), thus triggering the IBC requirement for a liquefaction investigation. Although the IRC does not specifically mention liquefaction, IRC Section R401.4 states that the local building official determines whether to require soil tests in areas likely to have expansive, compressive, shifting, or other unknown soil characteristics, such as liquefiable soils.

International Building Code seismic design categories are determined on a site-specific basis, and vary throughout the study area depending on IBC site class, maximum considered earthquake ground motions, and the IBC occupancy category of the proposed structure (see Earthquake Ground-Shaking Hazard section in chapter 5 of accompanying text). Because the risk to human life and the requirement that certain essential structures remain functional during natural or other disasters varies by occupancy category, we recommend the following levels of liquefaction-hazard investigation for the different IBC occupancy categories (see table below) in areas identified on this map as potentially liquefiable. Detailed (quantitative) subsurface investigations should be performed for Occupancy Category II, III, and IV structures, and reconnaissance (screening) investigations for Occupancy Category I structures. Additionally, a reconnaissance investigation should be performed for Occupancy Category II, III, and IV structures in areas mapped as not susceptible to liquefaction followed by a detailed investigation if a liquefaction hazard is determined to be present. Investigations are not recommended for Occupancy Category I structures in nonsusceptible areas. Martin and Lew (1999) provide guidelines for conducting both reconnaissance and detailed liquefaction investigations.

Recommended Requirements for Liquefaction-Hazard Investigations

Liquefaction Hazard	IBC Occupancy Category			
	I	II	III	IV
	Buildings and Other Structures that Represent a Low Hazard to Human Life in the Event of Failure (IBC)	All Other Buildings and Structures Except Those Listed in Categories I, III, and IV (Includes One- and Two-Family Dwellings and Townhouses) (IRC) (IBC)	Buildings and Other Structures that Represent a Substantial Hazard to Human Life in the Event of Failure	Buildings and Other Structures Designated as Essential Facilities (IBC)
Susceptible	Reconnaissance	Detailed[1]	Detailed[1]	Detailed[1]
Not Susceptible	None	Reconnaissance[2]	Reconnaissance[2]	Reconnaissance[2]

[1]Detailed evaluation necessary; a detailed liquefaction investigation should be interdisciplinary in nature and performed by qualified experienced geotechnical engineers and engineering geologists working as a team. [2]A reconnaissance investigation should be followed by a detailed investigation if a liquefaction hazard is determined to be present.

MAP LIMITATIONS

This map is based on limited geological, geotechnical, and hydrological data; a site-specific investigation is required to produce more detailed information. The map also depends on the quality of those data, which varies throughout the study area. The mapped boundaries of the Liquefaction-Susceptibility Zone are approximate and subject to change as new information becomes available. Liquefaction susceptibility at any particular site may be different than shown because of geologic and hydrologic variations within a map unit, gradational and approximate map-unit boundaries, and the map scale. Small, localized areas of liquefaction susceptibility may exist anywhere within the study area, but their identification is precluded because of limitations of either data or map scale. Seasonal and long-term fluctuations in ground-water levels can affect liquefaction hazard at a site. The map is not intended for use at scales other than the published scale, and is designed for use in general planning and design to indicate the need for site-specific studies.

HAZARD REDUCTION

Although potentially costly when not recognized and properly accommodated in project design, problems associated with liquefaction rarely are life threatening. As with most geologic hazards, early recognition and avoidance are the most effective ways to mitigate this hazard. However, avoidance may not always be a viable or cost-effective option and other techniques are available to reduce liquefaction hazards (National Research Council, 1985).

Liquefaction damage may be reduced either by using ground improvement methods to lower the liquefaction hazard (for example, compacting or replacing soil; installing drains or pumps to dissipate or lower the water table) or by designing structures to withstand liquefaction effects (using deep foundations or structural reinforcement). Existing structures threatened by liquefaction may be retrofitted to reduce the potential for damage. Because the cost of reducing liquefaction hazards for existing structures may be high relative to their value, and because liquefaction is generally not a life-threatening hazard, we consider it prudent, although not essential, to reduce liquefaction hazards for existing structures, unless significant ground deformation (lateral spreading) is anticipated and the structures fall into IBC Occupancy Categories III or IV, in which case retrofitting is recommended.

REFERENCES

International Code Council, 2009a, International building code: Country Club Hills, Illinois, 678 p.

International Code Council, 2009b, International residential code for one- and two-family dwellings: Country Club Hills, Illinois, 870 p.

Keller, E.A., and Blodgett, R.H., 2006, Natural hazards — Earth's processes as hazards, disasters, and catastrophes: Upper Saddle River, New Jersey, Pearson Prentice Hall, 395 p.

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

National Research Council, 1985, Liquefaction of soils during earthquakes: Washington, D.C., National Academy Press, 240 p.

Seed, H.B., and Idriss, I.M., 1982, Ground motion and soil liquefaction during earthquakes: Oakland, California, Earthquake Engineering Research Institute, 135 p.

Tinsley, J.C., Youd, T.L., Perkins, D.M., and Chen, A.T.F., 1985, Evaluating liquefaction potential, *in* Ziony, J.I., editor, Evaluating earthquake hazards in the Los Angeles region—an earth science perspective: U.S. Geological Survey Professional Paper 1360, p. 263-315.

Youd, T.L., 1978, Major cause of earthquake damage is ground failure: Civil Engineering, v. 48, p. 47-51.

Youd, T.L., 1984, Geologic effects—liquefaction and associated ground failure: U.S. Geological Survey Open-File Report 84-760, p. 210-232.

Youd, T.L., and Gilstrap, S.D., 1999, Liquefaction and deformation of silty and fine-grained soils, *in* Seco e Pinto, editor, Proceedings of the Second International Conference on Earthquake Geotechnical Engineering: Lisbon, Portugal, 21-25 June 1999, p. 1013-1020.

Youd, T.L., and Idriss, I.M., 1997, Summary report, *in* Proceedings of the NCEER workshop on evaluation of liquefaction resistance of soils, December 31, 1997: National Center for Earthquake Engineering Research Technical Report NCEER-07-0022, p. 40.