

EXPLANATION

H High Susceptibility - Geologic units that consist of well-sorted sands, silty sands, and gravels where Natural Resources Conservation Service (NRCS) and/or geotechnical data indicate depth to groundwater is ≤ 30 feet.

L₁ Liquefaction-Susceptibility Zone₁ - Geologic units with textural characteristics of the high-susceptibility category, but geotechnical data on groundwater conditions are lacking. However, these units are mapped by the NRCS as poorly drained soils (low-moderate permeability) that may develop shallow groundwater locally when rates of water application exceed the soil's drainage capacity. Because these soils naturally drain slowly, they may remain wet for most of the year, even though water is applied only during the growing season. Permanent shallow groundwater is possible following urbanization.

L₂ Liquefaction-Susceptibility Zone₂ - Geologic units with textural characteristics of the high-susceptibility category, but geotechnical and NRCS groundwater information is lacking.

INTRODUCTION

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, silt sand, and sandy silt soils (Youd and Idriss, 1997). All of the following conditions are required for liquefaction to occur:

- The soils must be below the water table.
- The soils must be loose to moderately dense.
- 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 rigid 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 spread, and (4) flow failure (Youd, 1978, 1984; Tinsley and others, 1985; figure 1). 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 depths 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 subsistence 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.

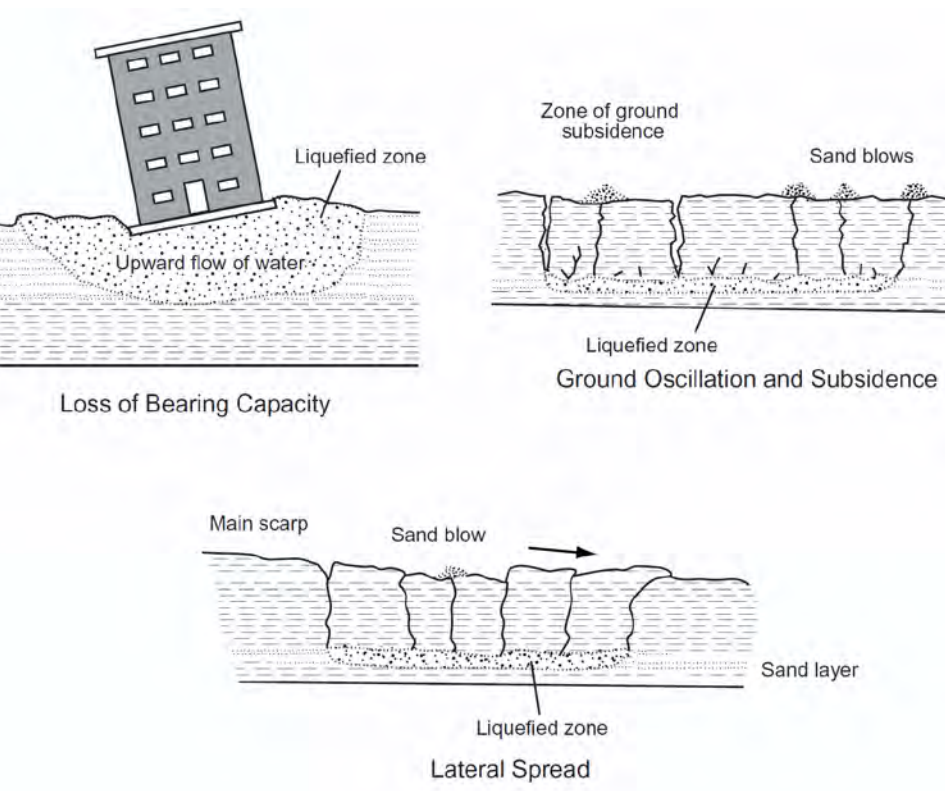


Figure 1. Four principal types of liquefaction-induced ground failure; arrows indicate direction of movement (modified from Youd, 1984; Harty and Lowe, 2003).

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 clayed. 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.

SOURCES OF INFORMATION

Sources of information used to evaluate liquefaction susceptibility in the State Route 9 Corridor Geologic-Hazard Study Area (SR-9 study area) include (1) the four Utah Geological Survey (UGS) 1:24,000-scale geologic quadrangle maps that cover the study area (Virgin Hayden and Sable, 2008; Springdale West (Willis and others, 2002); Springdale East (Doelling and others, 2002); and Smithsonian Butte (Moore and Sable, 2001)), (2) 40 geotechnical reports on file with the National Park Service (NPS), the Utah Department of Transportation (UDOT), and the towns of Springdale and Virgin, (3) 16 water-well drillers logs on file with the Utah Division of Water Rights, (4) the occurrence of wet, or potentially wet soils mapped by the Natural Resources Conservation Service (NRCS) (formerly Soil Conservation Service) (Mortensen and others, 1977), (5) *Engineering Geologic Map Folio, Springdale, Washington County, Utah* (Solomon, 1996), (6) *Geologic Hazards and Adverse Construction Conditions, St. George-Hurricane Metropolitan Area, Washington County, Utah* (Lund and others, 2008b), and (7) *Geologic Hazards of the Zion National Park Geologic-Hazard Study Area, Washington and Kane Counties, Utah* (Lund and others, 2010). Geotechnical and groundwater data are limited in both amount and distribution, and are generally available only where development has already occurred. Consequently, depth to groundwater information is not available for much of the SR-9 study area, including many areas where development may occur in the future.

HISTORICAL LIQUEFACTION IN SOUTHWESTERN UTAH

The September 2, 1992, M 5.8 St. George earthquake produced liquefaction in saturated sand deposits along the Virgin River (Black and others, 1995). The earthquake's epicenter was in Washington Fields east of St. George, and the earthquake possibly was the result of movement on the Hurricane fault (Pechmann and others, 1995). Liquefaction occurred along the river from approximately 1 mile south of Bloomington to approximately 4 miles west of Hurricane (Black and others, 1995). The affected geologic deposits consisted of well-sorted, modern channel sands covered by thin layers of silt and clay from overbank flooding. Observed liquefaction features included lateral spreads (figure 2), caved stream banks, and sand blows (figure 3). Lateral spreads were the most common feature (17 recorded); the largest was 200 feet long and 66 feet wide, and had total lateral movement of about 19 inches (Black and others, 1995). The greatest distance reported by Black and others (1995) between a recognizable liquefaction feature and the earthquake epicenter was 10.6 miles. No facility damage due to liquefaction was documented from the St. George earthquake.



Figure 2. Lateral-spread cracking from liquefaction along the Virgin River resulting from the September 2, 1992, M 5.8 St. George earthquake. Folding shovel for scale (photo credit W.E. Mulvey).



Figure 3. Sand blows from liquefaction along the Virgin River resulting from the September 2, 1992, M 5.8 St. George earthquake. Scale card shows centimeters (left) and inches (right) (photo credit W.E. Mulvey).

SOURCES OF EARTHQUAKE GROUND SHAKING

Potential sources of strong earthquake ground shaking in the SR-9 study area include (1) the Hurricane fault less than 1 mile west of the study area (Lund and others, 1995), (2) the comparatively short normal-slip faults with very long recurrence intervals within or close to the study area (see Surface-Fault-Rupture Hazard map (plate 8)), (3) the Sevier fault about 15 miles east of the study area (Lund and others, 2008a), and (4) a random background earthquake with a magnitude below that required to produce surface rupture ($\sim$ M 6.5) that occurs either within or near the study area on an unrecognized fault. While all of these sources could potentially produce ground shaking, the shorter normal faults and the Sevier fault have very long recurrence intervals for moderate to large earthquakes, and have a low likelihood to produce ground shaking strong enough to cause liquefaction in the study area. However, the Hurricane fault shows evidence for large, surface-faulting earthquakes during the Holocene (Lund and others, 2007), and is an indicator of liquefaction susceptibility, with well-sorted, cohesionless sands generally being more susceptible to liquefaction than silty sands and sandy silts.

LIQUEFACTION HAZARD CLASSIFICATION

As first determining factors, we considered the age, textural characteristics (grain size and sorting), and cementation of unconsolidated geologic units as characterized by UGS mappers and the limited geotechnical database to classify unconsolidated geologic units as potentially liquefiable. Table 1 summarizes potentially liquefiable geologic deposits in the study area. Age is an important consideration for liquefaction hazard because the older the unit, generally the more consolidated or cemented it is and the less susceptible it becomes to liquefaction. The limited geotechnical data available within and near the study area come chiefly from lower Zion Canyon in the Zion National Park administrative area and from the towns of Springdale and Virgin. Review of these data showed that unconsolidated deposits (chiefly alluvium and colluvium) in valley-bottom areas typically consist of silty sand, clayey sand, sandy silt, silty clay, and silty clay with occasional lenses of cleaner sand, gravel, cobbles, and boulders. Laboratory consolidation test results show that some sand, silt, and clay deposits have low densities and are subject to collapse (see Collapsible-Soil Susceptibility map (plate 4)). Standard Penetration Test blow-count (N_{60}) data confirm the low density of many deposits. (N_{60} values of <10 blows per foot were not uncommon. An (N_{60}) value <15 in sandy soil is an indicator of liquefaction susceptibility, with well-sorted, cohesionless sands generally being more susceptible to liquefaction than silty sands and sandy silts.

We then compared units classified as potentially liquefiable with available groundwater information. Where depth to groundwater was ≤ 30 feet, we classified the liquefaction susceptibility of the corresponding geologic unit as high.

Due to a lack of groundwater information, we employ a numbered susceptibility ranking as opposed to a severity ranking for the remaining potentially liquefiable units in the

MAP SYMBOLS

- State highway
- Primary paved road
- Secondary paved road
- Improved road
- Unimproved road
- Trail
- Springdale municipal boundary
- Rockville municipal boundary
- Virgin municipal boundary
- La Verkin municipal boundary
- Apple Valley municipal boundary

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.

MAP LIMITATIONS

This map is based on limited geological, geotechnical, and hydrological data; a site-specific investigation is required to produce more detailed information. This map also depends on the quality of those data, which varies throughout the study area. The mapped boundaries of the Liquefaction-Susceptibility Zones 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 short-term fluctuations in groundwater levels can affect liquefaction hazard at a site. This map is not intended for use at scales other than the published scale, and is intended for use in general planning and design to indicate the need for site-specific investigations.

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