Liquefaction Basics

By Marshall Lew, Ph.D., G.E. and Martin B. Hudson, Ph.D., G.E.

Would it shock you to see a building that has sunk 5 feet into the ground? Would it shock you to see a building that has tilted by more than 20 degrees? Soil liquefaction has resulted in spectacular damage during earthquakes to buildings and other structures. Buildings and other structures have settled differentially, severely tilted, and even ripped apart because of liquefaction. As seismic design levels have greatly increased in most of the U.S. due to recent design code changes, liquefaction hazard deserves attention and consideration for all construction.

What is Liquefaction?

Liquefaction is a phenomenon caused by earthquake shaking or other rapid loading in which an otherwise normal soil behaves like a fluid, losing some or all of its strength and stiffness. Liquefaction only occurs in soils already saturated before the earthquake strikes.

One has to look at how the particles of soil interact with each other to understand liquefaction. The water in-between soil particles always exerts some amount of pressure on the particles, influencing how tightly the particles themselves are pressed together. The net pressure between soil particles at a particular point in the soil is referred to as the effective overburden pressure (equal to the total vertical pressure minus the water pressure). Prior to an earthquake, the static water pressure in the soil is relatively low. However, earthquake shaking can cause the soil to attempt to compress, which will in turn cause the water pressure to increase. In the extreme, the water pressure will become equal to or greater than the total vertical pressure, thus reducing the effective overburden pressure to zero. This means that there is no longer any force between soil particles. As the strength of sandy soils is directly proportional to the effective overburden pressure, those soils will thus lose their shear strength and the soil particles can readily move with respect to each other.

Liquefaction can occur most commonly in sandy and silty soils. Also, the soils that are looser have a greater propensity to compress due to shaking and are thus more susceptible to liquefaction. Soils containing clays are not generally believed to be prone to liquefy.

Photo courtesy of Dr. Robert May

Effects of Liquefaction

As the water pressure increases during ground shaking as a result of an earthquake, the ground water may find its way to the ground surface through cracks and vents in the ground to relieve the excess pore pressures. This results in soil particles being carried with the water to the ground surface in what are commonly referred to as "sand boils," looking like small volcanoes with the carried particles stacked up outside of the cracks and vents.

Liquefaction can also cause ground deformations. These ground deformations can be expressed in the form of ground settlement as the loose soils become more compact after the pore pressures dissipate. Liquefaction can also cause excessive ground oscillations, caused by shaking of unliquefied soils above a deeper liquefied soil layer. In addition, liquefaction can result in lateral spreading or flow slides, caused by a surficial layer of soils on a slope (even a very gentle slope) moving downslope over a liquefied soil layer.

Significant damage can occur to structures supported on soils that liquefy. As liquefied soils lose strength, buildings supported on spread footings can lose bearing capacity and settle or tilt. Buried structures extending below the water can literally "float" out of the ground due to the increased pore water pressures. Waterfront structures, such as dock or quay walls, would experience greater lateral pressures and may tilt or fail. Buried utilities can be subjected to differential movements along their alignments, and ruptures can occur where the utilities make connections with structures that may move or settle differentially with the utilities.

Evaluation of Liquefaction Potential

Areas that may be prone to liquefaction hazard are those that may be subjected to moderate to very strong ground shaking, have young alluvial deposits consisting of sand and silt, and have shallow ground water (within 50 feet of the ground surface). Young deposits would be of Holocene to late Pleistocene in age.

Geotechnical professionals generally use subsurface exploration techniques to evaluate the potential for liquefaction. The most common technique is to use the Standard Penetration Test blow count (commonly referred to as the "N-value"). Researchers have developed liquefaction prediction techniques using the expected seismic stresses in the soil from a given design earthquake, and the N-value soil resistance. If the N-value is great enough, liquefaction would not be expected to occur for a given seismic stress. For sandy soils at sites in the most seismically active areas of the United States, the N-value would generally need to be greater than 30 to not have liquefaction. Liquefaction prediction techniques have also been developed based on correlations with Cone Penetration Tests (CPTs). CPTs are becoming more preferred by Geotechnical professionals as they provide essentially continuous soundings of the soil profile, whereas N-values can only provide discreet resistance values at intervals of several feet.

Current evaluation techniques can also predict the magnitude of liquefaction-induced settlement. Evaluation techniques are also available to analyze the magnitude of lateral spreading if there are ground slopes.

We have a liquefaction problem, so what?

If it is determined that there is a liquefaction potential at a site, what can you do about it? Generally, it is not good engineering practice to ignore the problem; you may end up talking with your attorneys later if an earthquake occurs. It would be good engineering practice to provide for mitigation of the liquefaction potential. There are two approaches to mitigate against liquefaction: *soil improvement* and *foundation-based mitigation*.

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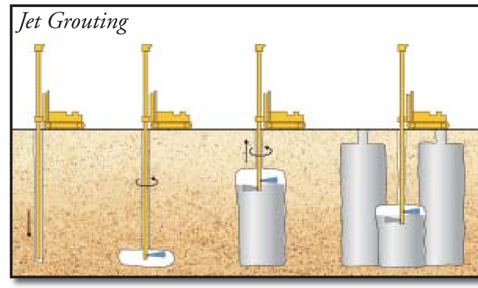
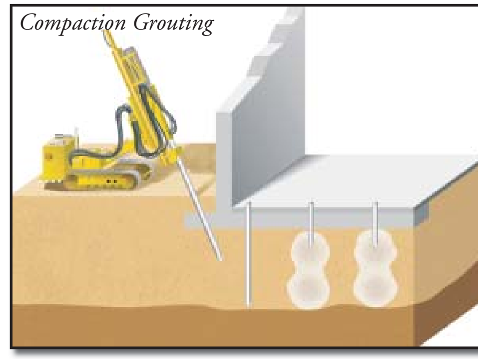
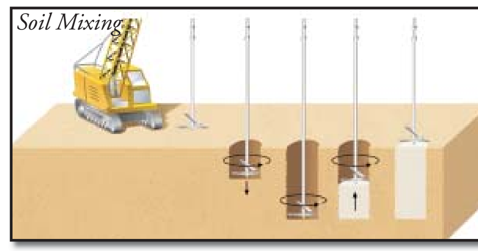


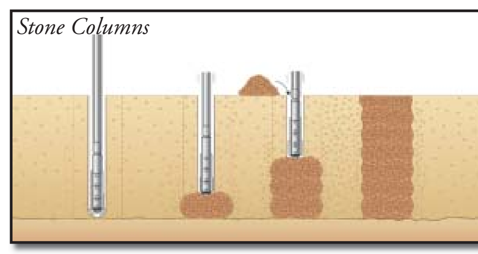
Jet Grouting



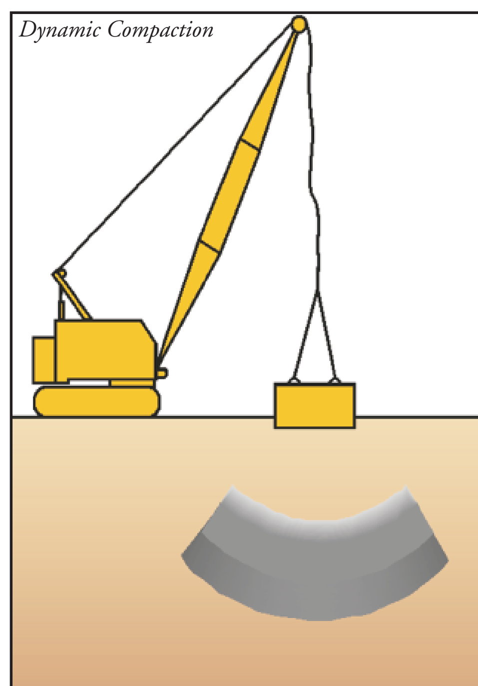
Compaction Grouting



Soil Mixing



Stone Columns



Dynamic Compaction

Soil Improvement

Soil mitigation options can be characterized as densification, drainage, reinforcement, mixing, or replacement. The implementation of these techniques may be designed to fully, or partially, eliminate the liquefaction potential, depending on the amount of deformation that the structure can tolerate.

The most widely used techniques for in-situ densification of liquefiable soils are vibro-compaction, vibro-replacement (also known as vibro-stone columns), deep dynamic compaction, and compaction (pressure) grouting. Vibro-compaction and vibro-replacement techniques use similar equipment, but use different backfill material to achieve densification of soils at depth. In vibro-compaction, a sand backfill is generally used; in vibro-replacement, stone (gravel) is used as backfill material. These methods are effective when there are few silts or clays.

Deep dynamic compaction involves the use of impact energy on the ground surface to densify and compact subsurface soils. Displacement or compaction grouting involves the use of low slump, mortar-type grout pumped into the ground under pressure to densify loose soils by displacement. Hardening and/or mixing techniques seek to reduce the void space in the liquefiable soil by introducing grout materials either through permeation, mixing mechanically, or jetting. Known as permeation grouting, soil mixing, and jet grouting, these procedures also help cement the soil particles together. Permeation grouting involves the injection of low viscosity liquid grout into the pore spaces of granular soils. Jet grouting creates hardened soils to replace liquefiable soils with soil-cement. Deep soil-mixing is a technique involving mixing of cementitious materials into the in-place soils using a hollow-stem-auger and paddle arrangement.

With regard to drainage techniques for liquefaction mitigation, only permanent dewatering (lowering of the ground-water table) works satisfactorily. The use of gravel or prefabricated drains, installed without soil densification, is unlikely to provide pore pressure relief during strong earthquakes and may not prevent excessive settlement.

Foundation-Based Mitigation

Foundation-based mitigation should be designed to protect the structure from liquefaction-induced deformations, recognizing that the structural solution will have little or no improvement on the soil properties that cause liquefaction. The appropriate means of structural mitigation may depend on the magnitude and type of soil deformation expected.

The most common types of structural mitigation against liquefaction would be support of the structure on a mat foundation or piles. If a mat foundation were used, it would need to be sufficiently stiff to accommodate the total and differential settlements due to liquefaction. It may be possible to re-level the structure after a liquefaction event. Deep piles extending into stable unliquefied soils could be used to support the structure, however, the piles would need to be designed to neglect the capacity in the liquefied soils and would also be subjected to downdrag forces due to settlement of the liquefied soils. Deep piles would also need to be able to resist lateral forces if lateral spreading were also a concern.

Summary

Liquefaction is a seismic hazard that deserves attention in design of new construction and evaluation of existing construction. The consequences of liquefaction can be dramatic and costly. The hazard can be evaluated by geotechnical professionals and there are mitigation technologies, using soil improvement and/or structural hardening, to reduce the risks associated with liquefaction.■

*For additional geotechnical information please contact Hyward Baker Inc., Baltimore, Maryland 800-456-6548 • **www.HaywardBaker.com**.*

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