IMPACT OF SOIL LIQUEFACTION ON TRANSPORTATION FACILITIES

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Liquefaction usually occurs when a vibration or cyclic loading causes saturated, loose, cohesionless soils to temporarily lose most or all of their shear strength and take on the properties of a viscous fluid. Cohesionless soils include naturally occurring sand, gravel, and silt deposits that do not contain significant clay or cementitious bonds between the particles. Fills made up of mine tailings and other types of particulate waste materials from manufacturing may also be cohesionless and thus potentially susceptible to liquefaction.

The structure of loose, cohesionless soils often tends to collapse when subjected to vibration. When the voids are saturated, the collapse of the structure shifts some or all of the weight of the overlying soils onto the water in the voids, causing the water pressure between the grains to increase and the contact friction between the particles to decrease. This excessive pore water pressure usually takes time to dissipate, so there may be an extended period during which the soil grains are essentially floating on the pore water. When this occurs, a soil that is normally quite stable and safe may experience a damaging or catastrophic failure.

Kobe Geotechnical Collection, Earthquake Engineering Research Center, University of California, Berkeley

Lateral spreading caused a 1.2–2 m drop of paved surface and flooding in Kobe, Japan.

Liquefaction is often a concern in the planning and design of transportation systems in earthquake-prone regions, in particular with regard to earthquake loads. Yet decisions about relocation, mitigation, or design modifications to accommodate liquefaction are difficult because of the uncertainty involved in predicting liquefaction and its effects on transportation systems or facilities. The cost of such measures is often quite high, and owners are sometimes faced with the undesirable choice of doing nothing about potential liquefaction and accepting the risk of failure.

Liquefaction-Related Failures

Liquefaction of soil can result in various types of failure, including flow failures, lateral spreads, ground oscillation, loss of bearing strength, settlement, and increased lateral pressure on retaining walls (*1*). Some of these failures are shown schematically in Figure 1.

- **Flow failures** can involve dramatic and catastrophic slope failures. In such cases, the failing soil may rapidly traverse many meters to kilometers.
- Although less dramatic, **lateral spreads** are more common than flow failures and cause much damage to pipelines, roadways, and other structures. Lateral spreads occur when the soil beneath gently sloping ground liquefies. This causes the overburden to spread in the down-slope direction, opening transverse cracks in the surface.
- **Ground oscillation** occurs when loss of shear strength in the soil column decouples the overlying soil from deeper deposits, resulting in excessive relative movement between the layers.
- **Loss of bearing strength** occurs when the shear strength in a liquefied zone beneath or around

a foundation approaches zero, causing a bearing capacity failure.

◆ **Settlement** is common in most types of liquefaction failure, but when ground conditions are level with no nearby structure or slope, settlement may be the only failure that occurs. This failure can also be damaging to pipelines, roadways, and other transportation facilities.

◆ If soil adjacent to a retaining wall or similar structure liquefies, **increased lateral pressure on the wall** results, leading to excessive deformation or outright failure.

Impacts on Transportation Facilities

Saturated and loose, cohesionless soils are frequently encountered in the flood plains of rivers and streams and along shores or coastlines that must be traversed by a transportation facility or byway. Liquefiable saturated fill that has been hydraulically placed from dredging may also underlie or join parts of the transportation infrastructure. Thus highways, railroads, piers, and other transportation facilities often must cross or bear on deposits susceptible to liquefaction.

Poorly compacted wall backfills for piers and bridge abutments can also liquefy and exert increased lateral stress on the wall, causing excessive lateral deformation or failure. In fact, settlement, lateral deformation, or outright failure of pier or quay walls is one of the most frequent structural impacts of liquefaction. Another common liquefaction-related impact is loss of a bridge span or spans due to movement of a bridge abutment or support during lateral spreading.

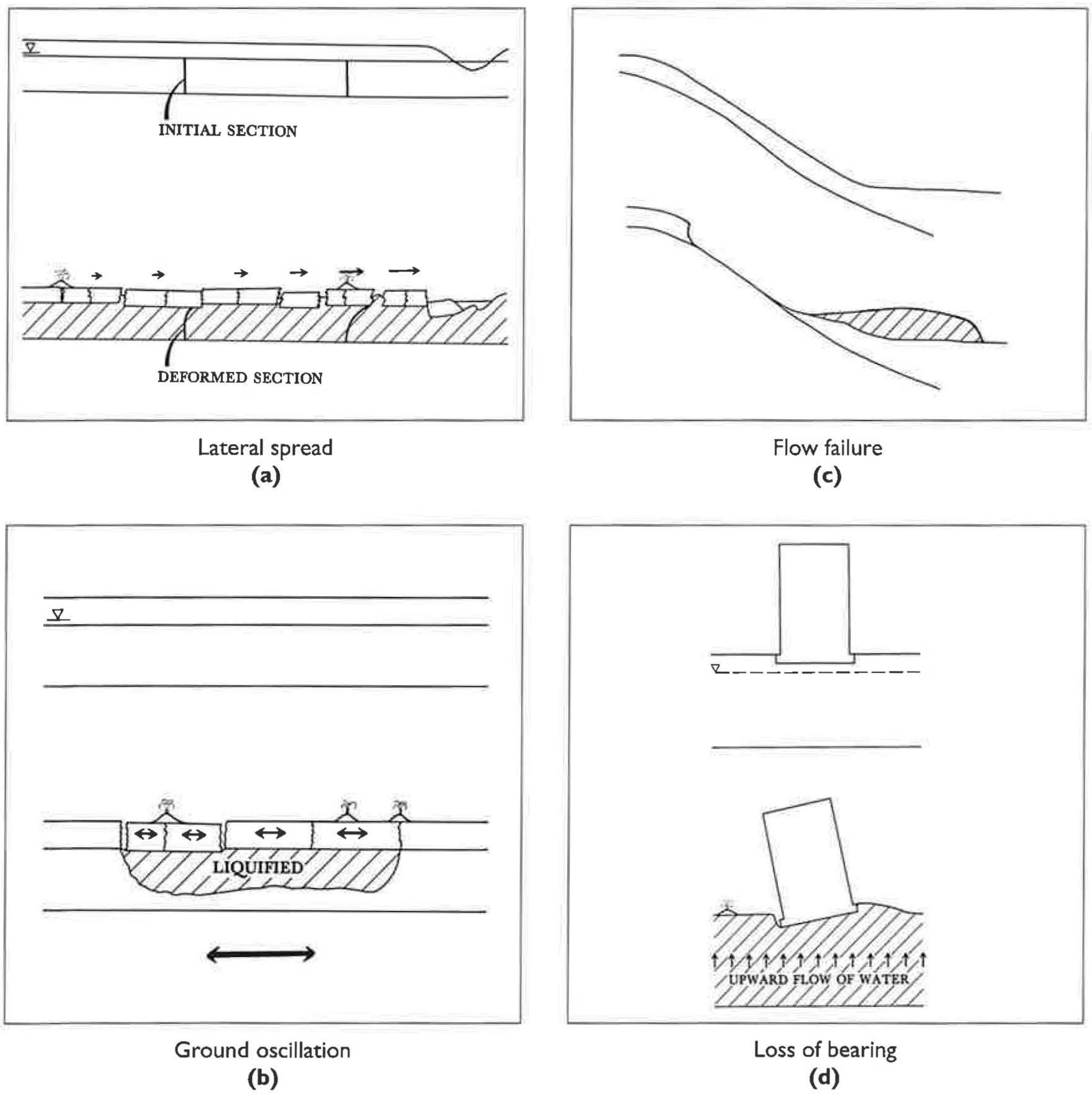

FIGURE 1 Liquefaction of soil can result in various types of failure, including (*a*) lateral spread, (*b*) ground oscillation, (*c*) flow failure, and (*d*) loss of bearing.

Loss of bridge decks and deck buckling due to liquefaction-induced ground oscillation or lateral spread near Honshu, Japan.

Prediction and Response

Prediction of the liquefaction behavior of a soil is difficult. Liquefaction potential normally varies significantly from point to point in a deposit. Yet drilling, sampling, and in situ testing generally involve evaluating only a small percentage of the soils on a site. In locations where only isolated liquefiable zones exist, it is thus likely that those zones will not be encountered in an exploration. Moreover, when liquefiable zones are identified in an exploration, assessment of the loading that will cause liquefaction and the extent of the resulting failure is difficult under the best of circumstances. In many projects, simply recognizing that there is a potential for liquefaction is insufficient for making a decision to relocate a structure or mitigate the liquefiable soils.

If liquefiable soils are found on a site, the choices are to relocate the project, do nothing and assume the risk of failure, design the system for the occurrence of liquefaction, or mitigate the liquefiable soils. In selecting the best of these options for a given case, one must consider not only engineering design, but also the importance of the facility as a lifeline, the cost of repair should liquefaction occur, and the impact should the facility be lost for an extended period. As noted, designing a system or structure to tolerate some liquefaction-induced ground failure or mitigating liquefiable soils can be costly, so the option of doing nothing and assuming risk may be the best choice for the owners of some facilities.

Designing a facility so it can tolerate some liquefaction-induced movements may involve use of deep foundations that extend beyond the liquefaction zone and will span the soils if they liquefy, additional structural reinforcement so minor movements will be tolerated, or design of a mat foundation that would span liquefied zones and maintain structural integrity. Mitigation of liquefiable soils usually includes construction techniques that densify or otherwise stabilize the soils. Techniques for soil modification include grouting; groundwater dewatering; and compaction using vibration, impulse loads, displacement piles, or stone columns.

Reference

1. Youd, T. L. Liquefaction, Ground Failure and Consequent Damage During the 22 April 1991 Costa Rica Earthquake. *Proceedings of the NSF/UCR U.S.-Costa Rica Workshop on the Costa Rica Earthquakes of 1990–1991: Effects on Soils and Structures.* Earthquake Engineering Research Institute, Oakland, California, 1992.

Related Websites

Multidisciplinary Center for Earthquake Engineering Research:
http://mceer.eng.buffalo.edu

The Liquefaction Web Site:
http://www.liquefaction.com

Earthquake Engineering Research Institute:
http://www.eeri.org

University of Washington Liquefaction Web Site:
http://www.ce.washington.edu/~liquefaction/html/main.html

Mid America Earthquake Center:
http://mae.ce.uiuc.edu/index.html