International Journal of
Research in Civil Engineering
and Technology

E-ISSN: 2707-8272
P-ISSN: 2707-8264
IJRCET 2023; 4(1): 30-33
Received: 30-10-2022
Accepted: 15-12-2022

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Study on liquefaction of soil using cyclic load mechanism and pore pressure dissipation

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Abstract

This report provides basic knowledge about the liquefaction of soil during a strong earthquake. The prediction of liquefaction and resulting displacements is a major concern for earth structures located in regions of moderate to high seismicity. The effect of these parameters was studied using excess pore pressure, lateral movement, and settlement time histories.

Seismic disturbances can cause a sudden decrease in soil volume, creating pore spaces that become filled with water. This build-up of pore water pressure in the soil can be dangerous, as it can lead to a loss of shear strength in the soil. When the pore water pressure becomes equal to the total stresses in the soil, the soil can no longer resist the forces acting on it. As a result, the foundation on the soil may experience a large settlement, which can cause significant damage to buildings and other structures. In addition, the upward flow of water mixed with soil particles under turbulent conditions can cause further damage. It is important to understand the potential effects of seismic disturbances on soil and to take appropriate measures to mitigate the risks. This may involve designing foundations that are able to withstand the effects of earthquakes or implementing measures to reduce the build-up of pore water pressure in the soil. By taking proactive steps to protect against seismic disturbances, it is possible to minimize the risks and ensure the safety of structures built on or near potentially unstable soil.

Keywords: Pore pressure dissipation, cyclic mobility, cyclic lateral spreading mechanism, densification rule, cyclic id

Introduction

One of the main reasons for the damage of soil structures due to earthquakes in saturated conditions is liquefaction. The simplest way of modeling liquefaction which is still used in practice is done by means of total stress analysis.

Liquefaction can be assessed from total or effective stress analysis. Effective stress analyses have been available for more than 25 years and are more fundamental. Triggering of liquefaction as well as post-liquefaction stability and resulting displacements can be considered in a single-time domain analysis. Most of the Northern part of India is coming under seismic zone IV or V.

The failure behavior is broadly divided into two categories; flow liquefaction and cyclic mobility. Flow liquefaction leads to huge instabilities and deformations which are driven by cyclic shear stresses. On the other hand, cyclic mobility is another phenomenon that causes large deformations known as lateral spreading, but in comparison flow liquefaction deformation produced by cyclic mobility is driven by both cyclic and static shear stresses.

Under earthquake and dynamic loading, the liquefaction phenomenon is common in loose saturated sands. In saturated sands, a longer drainage path and a lack of time between load increments contribute to the generation of excess pore pressure.

When seismic disturbances take place there is a sudden decrease in the volume of soil, this builds pore water pressure in the soil. A condition comes when this pore water pressure becomes equal to the total stresses, as a result of which soil loses of all its shear strength and a large settlement of foundation with vertical upward flow of water mixed with soil particles under turbulent conditions takes place.

Literature Review

A definition given by Sladen et al. (1985) states that “Liquefaction is a phenomenon wherein a mass of soil loses a large percentage of its shear resistance, when subjected to monotonic, cyclic, or shocking loading, and flows in a manner resembling a liquid until the shear stresses acting on the mass are as low as the reduced shear resistance”.

When dense saturated sands are subjected to static loading they have the tendency to progressively soften in undrained cyclic shear achieving limiting strains which is known as cyclic mobility (Castro 1975; Castro and Poulos 1979).

(Seed 1979) defines that Cyclic mobility should not be confused with liquefaction. Both can be distinguished from the very fact that liquefied soil displays no appreciable increase in shear resistance regardless of the magnitude of deformation.

Ahmed-W. ELGAMAL1 And Zhaohui YANG2 directed a study about the liquefaction of soil during an earthquake using excess pore pressure drop, sharp acceleration spikes and associated regain of shear strength and stiffness in the liquefied soil.

N. Y. ELWakkad1, KH. M. Heiza2and M. Elmahroky the objective of this paper is to determine the behavior of structural elements to cyclic loads are summarized.

The latest put forward by Robertson and Fear (1996); Cyclic Softening – Large deformations occurring during a cyclic load test to increase in pore water pressure that would tend to dilute in undrained, monotonic shear.

According to Selig and Chang (1981) and Robertson (1994). cyclic load may produce a reversal in the shear stress direction when the initial shear stress is low i.e, the stress path passes through a condition that is known as a state of zero shear stress.

Robertson (1994) termed this, “cyclic liquefaction”. It involves some deformation occurring while static shear stresses exceed the shear resistance of the soil (when the state of zero effective stress is approached). However, the deformations stop after cyclic loading ends as the tendency to expand quickly results in strain hardening.

As defined by the National Research Councils Committee on Earthquake Engineering (1985), soil liquefaction is defined as this phenomenon in which there is a loss of shearing resistance or the development of excessive strains as a result of transient or repeated disturbance of saturated cohesionless soils.

During cyclic mobility, the driving static shear stress is less than the residual shear resistance and deformations get accumulated only during cyclic loading. However, in layman‟s language, a soil failure resulting from cyclic mobility is referred to as liquefaction.

Objectives

The objective of the present research is to develop deterministic, probabilistic, and reliability-based models to evaluate the liquefaction potential of soil using liquefaction modeling, cyclic load test and cyclic load spreading mechanism, and densification rule also.

The scopes of the research are as follows:

- To determine liquefaction modeling of soil under monotonic or cyclic loading for loose soil to compact under shear loading.
- To study about Cyclic load test that describes the constitutive model.
- To study about cyclic lateral spreading mechanism considered to ground deformation resulting from soil liquefaction in earthquakes.
- To determine pore pressure dissipation and densification rule.

Research methodology

Liquefaction modeling

Liquefaction is defined as the loss of shear strength of soil under monotonic or cyclic loading, arising from a tendency for loose soil to compact under shear loading. The term “liquefaction” was originally coined by Mogami and Kubo (1953). Dilation plays an important role in the liquefaction process. As soil densifies under repeated shear cycles, grain rearrangement may be inhibited. Soil grains may then be forced to move up against adjacent soil particles, causing dilation to occur, the effective stress to increase and the pore pressure to decrease. Thus densification is a self-limiting process.

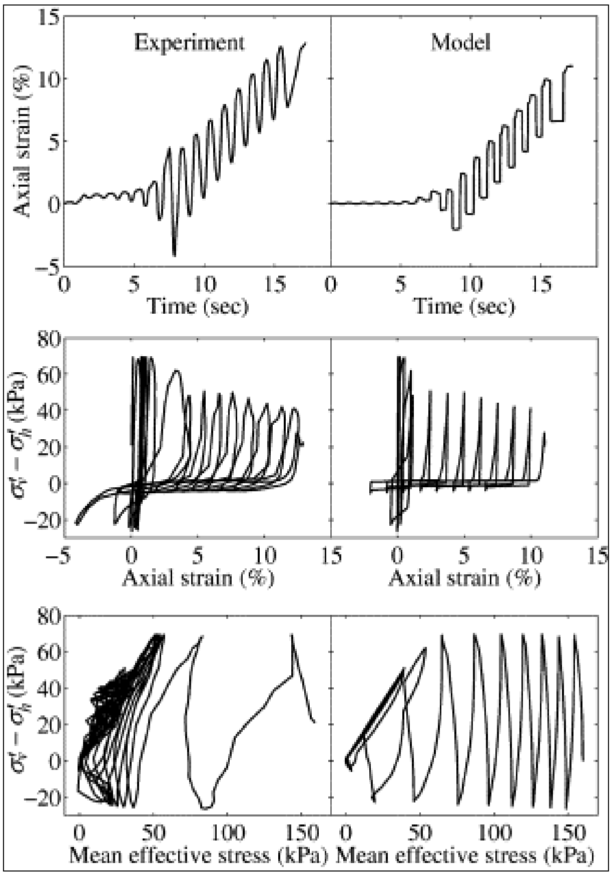

Fig 1: Mean effective stress

$$\frac{\Delta\mathcal{E}vd}{\Upsilon} = c1 \exp\left[-c2 \frac{\Delta\mathcal{E}vd}{\Upsilon}\right]$$

Where $\Delta\mathcal{E}vd$ is the increment of volume decrease, Υ is the cyclic shear strain, and c1 and c2 are constants dependent on the volumetric strain behavior of sand. These constants are derived from the relative density, Dr as:

$$c_1 = 7600(Dr)^{-2.5}$$

$$c_2 = \frac{0.4}{c1}$$

This definition is available in FLAC, as a built-in model that incorporates into the standard Mohr-Coulomb plasticity model.

Cyclic ID

A site amplification computer code (CYCLIC CODE) describes the constitutive model that is currently available for execution using commonly available Internet browsers such as Internet Explorer or Netscape Navigator.

In the level ground case, liquefaction is quickly reached in all but the deepest part of the stratum, and the high level of excess pore pressure remains throughout the shaking phase. This important buildup of excess pore pressure results in: i) loss of effective confining stress and shear strength, ii) degradation of shear stiffness, and iii) quick decrease and eventually the disappearance of lateral acceleration amplitude near the surface of the ground. It is also been observed that in the level ground case with uniform cycles of excitation, acceleration spikes are symmetric, with negligible permanent lateral deformation.

In the inclined stratum case, the soil is subjected to the same symmetric cyclic base excitation superposed on a static locked-in shear stress (due to the 4 degrees inclined self-weight component of the ground). The presence of this static driving force results in the accumulation of significant permanent lateral deformation (lateral spreading) in the down-slope direction and in a pattern of asymmetric acceleration spikes. Although excess pore pressure initially builds up much like the level ground case, post-liquefaction behavior is completely different. The p-q diagram shows strong soil dilatancy as the stress path travels along the failure (or phase-transformation) line during liquefaction. This pattern of cyclic mobility results in 1) an instantaneous increase of confining stress and shear strength, 2) corresponding pore pressure drops, 3) associated regain in shear stiffness, and 4) the appearance of asymmetric downslope acceleration spikes (a direct consequence of this stiff dilative shear stress-strain response) at the ground surface. Thus, the above dilative mechanism may prevent an otherwise excessive amount of lateral spreading from accumulating.

Cyclic Lateral Spreading Mechanism

Restricting the consideration to ground deformations resulting from soil liquefaction in earthquakes, liquefaction-induced lateral spreading has been defined as the "lateral displacement of large, surficial blocks of soil as a result of liquefaction in a subsurface layer" (Liquefaction... 1985). As described by Bartlett and Youd (1992a; 1992b), liquefaction-induced lateral spreading occurs on mild slopes of 0.3 to 5% underlain by loose sands and a shallow water table. Such soil deposits are prone to pore pressure generation, softening, and liquefaction during large earthquakes. If liquefaction occurs, the unsaturated overburdened soil can slide as intact blocks over the lower, liquefied deposit.

An illustration of the dilative-tendency mechanism observed in undrained cyclic laboratory tests is shown in Figure 1 [Arulmoli et al. 1992]. Similar response (Figure 1) was observed [Zeghal and Elgamal 1994] at the US Imperial County Wildlife Refuge site (1987 Superstition Hills earthquake records, see [Holzer et al. 1989]). Figure 1 depicts the mechanism of accumulation of cycle-by-cycle deformations. This cyclic mobility mechanism can significantly reduces the total accumulated shear strain due to liquefaction.

Pore Pressure Dissipation and Densification Rule

During the time cycle between successive impacts, the pore pressure generated dissipates with time and densification occurs concurrently. The equation for pore pressure dissipation with time is given as;

$$\frac{du}{dt} = Cr\left(\frac{\partial^2 u}{\partial r^2} + \frac{1}{r}\frac{\partial u}{\partial r}\right) + Cv\,\frac{\partial^2 u}{\partial z^2}$$

Here u= pore water pressure, Cr and Cv are the coefficient of consolidation in the radial and vertical directions. During consolidation, the volumetric densification of a soil element is given by;

$$\varepsilon v = \int m_v \,.\, \partial\sigma'$$

Where εv = volumetric strain, m_v= coefficient of volume compressibility, and σ' = effective stress.

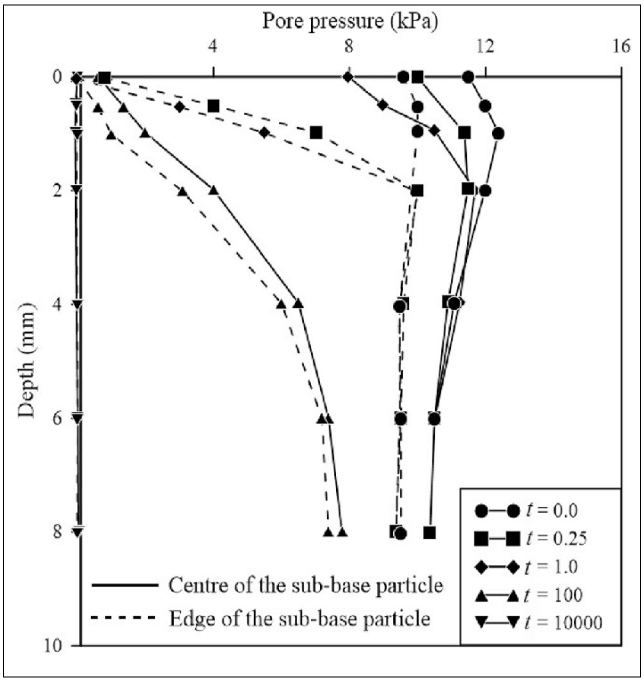

Fig 2: Depth Vs Pore Pressure

Conclusion

A new constitutive model is developed to model the cyclic shear behavior of liquefied soil. The underlying mechanisms are based on observed (medium-dense cohesionless soil) response during earthquakes, centrifuge experiments, and cyclic laboratory tests. The cyclic strain-based approach is less commonly used than the Cyclic stress-based approach as the cyclic strain amplitudes cannot be predicted as accurately as cyclic stress amplitudes, and due to the unavailability of equipment for cyclic strain-controlled testing. Though, the deterministic method of liquefaction potential is preferred by geotechnical professionals but, probabilistic evaluation is very much required in actual practice, which helps in taking risk-based design decisions. For making an unbiased evaluation of liquefaction potential, the uncertainty of the limit state boundary surface is to be determined for which rigorous reliability analyses are required.

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