SETTLEMENT OF SHALLOW FOOTING RESTED ON LIQUEFIABLE SAND: PHYSICAL MODELING

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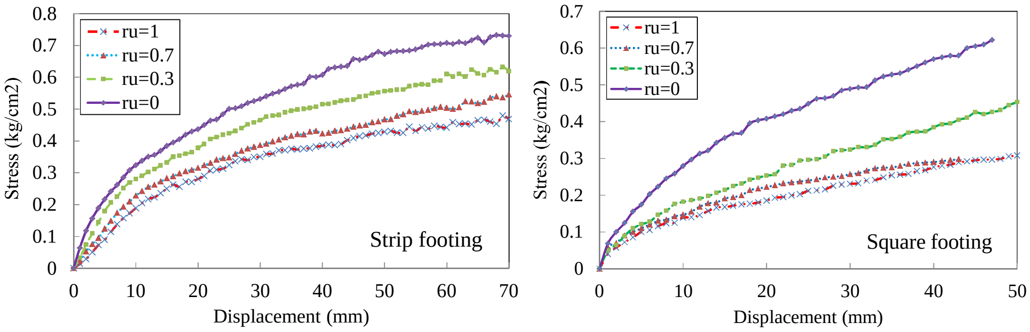
Keywords: Shallow Footing, Liquefaction, Shear Deformation, Pore Pressure, Physical Modeling

Earthquake-induced excess pore water pressure build-up and associated shear strength deterioration of liquefiable soils beneath shallow footings may result in bearing capacity degradation and seismic permanent settlement of such foundations. Numerous studies have been carried out to evaluate behavior of shallow foundations rested on liquefiable sand. Building settlements have been found to be related to foundation dimensions, the confining pressure and shear stress imposed by the buildings, building height/width (H/B) ratio and their adjacent structures, according to the observations in recent earthquakes (Liu and Dobry, 1997).

Shaking table and centrifuge studies of this problem have identified important factors involving shaking intensity, the liquefied soil's relative density and thickness and the building weight and width. Recent studies have also showed that shear deformation combined with localized volumetric strains during partially drained loading are dominant mechanisms (Dashti et al, 2010).

In this study, several physical model experiments involving shallow footing on fully and partially liquefied sand have been conducted to figure out mechanisms of liquefaction-induced settlements and bearing capacity degradation of buildings. Bulk samples of Babolsar sand were taken from the coastal regions of the Caspian Sea in Mazandaran Province of Iran and poured in dry state into a Plexiglas box fulfilled of distilled water. Earthquake waves can cause pore pressure build up in saturated sands but complete liquefaction always do not occur. However, excess pore pressure generation even in low to moderate extents can cause bearing capacity degradation and excessive settlements. In this study, various pore pressure ratios were generated via hydraulically conduction of distilled water through the base of the sand box in order to simulate partial and fully liquefaction conditions.

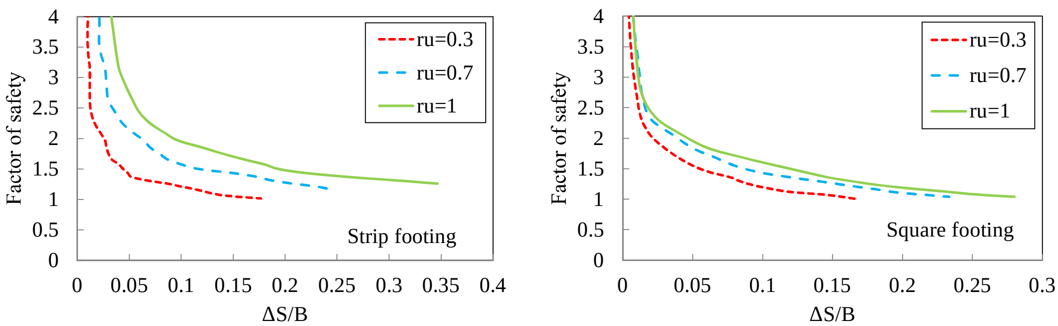
First series of the experiments were consisted of 1g tests in which stress – settlement curves of square and strip foundations were measured in various pore pressure ratios. As shown in Figure 1, bearing capacity decreases due to excess pore pressure development, but there is remarkable strength even in complete liquefaction which is referred as post-liquefaction strength of liquefied sand. Square foundations were more affected by excess pore pressure ratios than the strip ones. It was found that the conducted pore water pressure decreases with loading increment in the points located exactly beneath the foundation because of soil dilatancy and development of negative excess pore water pressure during the vertical loading of foundation. Fully liquefaction was never observed under the foundations. Excess pore pressure ratio was defined as the excess pore water pressure divided by initial vertical effective stress.



(a) (b)

Figure 1. Stress-settlement curves in various levels of r_u for (a) strip foundation (b) square foundation

Selection of bearing capacity safety factor is a challenging step in shallow foundation designs for engineers. However, recent studies have shown the important role of shear deformations in shallow foundations design. In the second test series of this experimental study, foundations were first loaded in the absence of excess pore water pressure to mimic pre-earthquake condition of foundations with predetermined bearing capacity safety factors. Subsequently, vertical settlements due to upward conduction of pore water pressure were measured and then vertical loading was increased up to complete bearing capacity failure. It is worth noting that only shear deformations have been assessed in this series because there is no volumetric deformation as r_u was kept constant during the tests. Figure 2 shows plots of normalized deformation (i.e. settlements normalized to foundation width) and safety factor of square and strip foundations.



(a) (b)

Figure 2. Curves of safety factor-normalized settlement for (a) strip foundation (b) square foundation

As seen in the figure, foundation settlement increases with safety factor reduction and liquefaction-induced settlements for safety factors larger than 3 and 2 are negligible for strip and square footings, respectively. Moreover, strip footing has experienced more settlement than square one in constant safety factor while square foundations were less affected by r_u. Results of this study, especially those presented in Figure 2, are limited to the sand type and conditions provided for the tests. Further experiments are required to confirm such charts for design purposes.

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