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Liquefaction analysis of alluvial soil deposits in Bedsa south west of Cairo

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Abstract Bedsa is one of the districts in Dahshour that lays south west of Cairo and suffered from liquefaction during October 1992 earthquake, Egypt. The soil profile consists of alluvial river Nile deposits mainly sandy mud with low plasticity; the ground water is shallow. The earthquake hypocenter was 18 km far away with local magnitude 5.8; the fault length was 13.8 km, as recorded by the Egyptian national seismological network (ENSN) at Helwan. The analysis used the empirical method introduced by the national center for earthquake engineering research (NCEER) based on field standard penetration of soil. It is found that the studied area can liquefy since there are saturated loose sandy silt layers at depth ranges from 7 to 14 m. The settlement is about 26 cm. The probability of liquefaction ranges between 40% and 100%. The presence of impermeable surface from medium cohesive silty clay acts as a plug resisting and trapping the upward flow of water during liquefaction, so fountain and spouts at weak points occurs. It is wise to use point bearing piles with foundation level deeper than 14 m beyond the liquefiable depth away from ground slopes, otherwise liquefaction improving techniques have to be applied in the area.

1. Introduction

Liquefaction was first initiated by Seed [1] through experimental studies on sand samples. It is the process of reduction of shear strength for low plastic loose cohesionless soil. Pore pressure buildup due to static or cyclic stress applications. The soil looses contact between its grains and upward flow of water takes place. If the magnitude of pore-water pressure generated equals the total vertical stress, the effective stress becomes zero and the soil is said to have liquefied. The possibility of its occurrence depends on the initial void ratio or relative density of sand and the confining pressure (Seed [1]). Formation of sand boils and mud-spouts at the ground surface by seepage of water through ground cracks or in some cases by the development of quick sand conditions over substantial areas (Seed and Idriss [2]). Housner and Jennings [3] discussed the formation of sand boils in terms of soil porosity, permeability, elasticity, and degree of consolidation. Sand boils were attributed to non-homogeneity in permeability near the ground surface. Scott and Zuckerman [4] presented both experimental and analytical studies on the mechanics of liquefaction and sand boil formation in sandy soil deposits. They found that the presence of silt or a similar fine grained layer at the surface (above

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the liquefied layer) is conducive to the generation of sand boils. In contrast to "piping", sand boils were observed to propagate from the source of pressure to the outlet by a mechanism of cavity formation. Adalier [5] also demonstrated that stratified soil profiles are conducive to sand boil formation. It was shown that low permeability and cohesion of an overlying upper layer may lead to the formation of large sand boils, as the extruded water mainly travels through cracks and weak zones within this upper layer.

Cyclic testing of a wide range of soils found to liquefy in Adapazari during the Kocaeli earthquake confirmed that these fine-grained soils were susceptible to liquefaction. It is not the amount of "clay-size" particles in the soil; rather, it is the amount and type of clay minerals in the soil that best indicate liquefaction susceptibility (Bray et al. [6]).

Fig. 1 shows recommendation given by Bray et al. [6] and Seed et al. [7] according to atterberg limits for soil to liquefy and that plasticity index appears to be a better indicator of liquefaction susceptibility.

– Loose soils with PI < 12 and w_c/LL > 0.85 were susceptible to liquefaction.
– Loose soil with 12 < PI < 18 and w_c/LL > 0.8 were systematically more resistant to liquefaction.
– Soils with PI > 18 tested at low effective confining stresses were not susceptible to liquefaction.
– The location of a soil on the Casagrande plasticity chart and, or in combination with, the use of the "C" descriptor, (USCS) (e.g. CH, CL, SC, and GC) are considered as non-liquefiable.
– Liquefiable fine-grained soils should have LL < 35 and plot below the A-line or have PI < 7.
– Seed et al. [7] stated that soils with LL < 37 and PI < 12 are potentially liquefiable, and those with 37 < LL < 47 and 12 < PI < 20 require laboratory testing.

Ishihara [8] studied other factors which control liquefaction and/or cyclic mobility such as:

Confining pressure, initial static shear stress and stress-path.

Plito [9] found that soils with LL < 25 and PI < 7 are liquefiable, and soils with 25 < LL < 35 and 7 < PI < 10

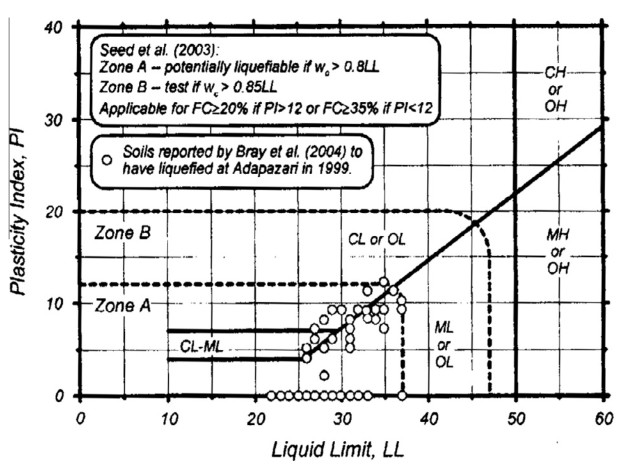

Figure 1 Atterberg limits of fine-grained soil reported by Bray et al. [6] to have "liquefied" at 12 building sites during the 1999 Kocaeli earthquake and recommendations by Seed et al. [7].

are potentially liquefiable, and soils with 35 < LL < 50 and 10 < PI < 15 are susceptible to cyclic mobility. Cyclic mobility of clay may depend upon plasticity index, w_c/LL ratio, Initial static shear stress, confining pressure, and stress path.

Several recent earthquakes indicate that many cohesive soils had liquefied. These cohesive soils had clay fraction less than 20%, liquid limit between 21% and 35%, plasticity index between 4% and 14% and water content more than 90% of their liquid limit. Kishida [10] reported liquefaction of soils with up to 70% fines and 10% clay fraction during Mino-Owar earthquake. Andrews and Martin [11] evaluate liquefactions of fine-grained soils as given in Table 1

Ishihara et al. [12] had set up a criterion to stipulate a threshold value for the thickness of a non-liquefiable surface layer to avoid ground damage due to liquefaction, as shown in Fig. 2. Although this figure is believed to be speculative and should not be used for design purposes, it provides initial guidance in this matter for sites having a buried liquefiable sand layer with a standard penetration resistance of less than 10 blows per foot (0.3 m). It should also be noted that even though the thickness of a non-liquefiable surface layer exceeds the threshold thickness shown in Fig. 2, the ground surface may still experience some settlement which may be undesirable for certain settlement-sensitive structures. Like all of the empirical curves, this figure is based on just three case histories, may need to be modified as more data become available.

In order to induce extensive damage at level ground surface from liquefaction, the liquefied soil layer must be thick enough so that the resulting uplift pressure and amount of water expelled from the liquefied layer can result in ground rupture such as sand boiling and fissuring (Ishihara et al. [12]; Dobry [13]). If the liquefied sand layer is thin and buried within a soil profile, the presence of a non-liquefiable surface layer may prevent the effects of the at-depth liquefaction from reaching the surface.

Fig. 3 shows the fault mechanism of 12 October 1992 earthquake southwest of Cairo, Egypt. It occurred on Monday at 15:09 local tim. It was a damaging earthquake of magnitude M_w = 5.8 and took place in Dahshour region, about 18 km SW of downtown Cairo at coordinates 29.77 N, 31.07 E and was followed by a sequence of aftershocks (Kamal et al. [14]).

The earthquake area lies in the northern part of the western desert tectonic zone, which forms part of the African plate. The focal depth was 23 km. The only earthquake that had occurred in this region is the 4.9 M_s event October 1920 at 29.5°N, 31.3°E, and the only known earthquake during this historical period had occurred in August 1847 A.D. and destroyed 3000 houses and 42 mosques in Cairo and Northern Egypt (Kebeasy et al. [15]).

Fig. 4 shows large sand-boil craters that had occurred in agricultural field at locations 2.5 km away from the Nile, and 1.0 km west of El-Beleda village (Elgamal et al. [16]).

Throughout centuries, the Nile River flooded the plains along its path every summer until the construction of the Aswan High Dam in 1971, so the age of sediments can occur in late Holocene. Table 2 shows evaluation of liquefaction according to age of deposits (Yould and Perkins [17]).

Natural deposits of alluvial and fluvial origins generally have soil grains in the state of loose packing which are young, weak and free from added strength due to cementation aging.

Youd and Hoose [18] stated that, as a rule of thumb, alluvial deposits older than late Pleistocene (10,000–130,000 years)