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Soil Characterization in Super Soft, Sensitive Soils of Urmiyeh Lake

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Abstract

In the early 1980´s the Urmiyeh Causeway was constructed at the Urmiyeh Lake's narrowest part to connect the eastern part of Iran to the western area and Europe. Geotechnical investigations carried out the construction of associated 1260 m length Causeway Bridge. For design and analysis of 400 driven pipe piles, piezocone has been considered as a major tool and were performed in twelve locations along the bridge route to depths of 100 m below the lake-bed. Soils encountered include super soft and sensitive gray to dark gray and somewhere yellowish deposits known as 'Tabriz Marl.' which is visually classified as a high liquid limit silt and clay. This paper evaluates CPTu records presented on two CPTu soil classification methods. Results indicate that for soft sensitive deposits the mobilized pore pressure can be realized as a valuable parameter for soil behavior interpretation.

Keywords: Urmiyeh Lake, CPTu, Soil profiling, Sensitivity, Pore pressure

1. INTRODUCTION

Urmiyeh Lake is a closed basin among the surrounding mountains. The area of the Lake is approximately 5500 km^2, its length is about 140 km and the width varies from 15 to 50 km. The average depth of the lake is between 6 to 8 m while the maximum depth varies from 11 to 12 m. In the early 1980's, Tabriz-Urmiyeh Highway began construction for the purpose of connecting west part of Iran to Turkey and Europe. The distance of the existing road path between Tabriz and Urmiyeh cities would be shortened about from 300 km to 130 km, consequently leading to rapid access and efficient transit between Iran and Europe through Turkey.

The highway embankment in the lake was constructed, by rock fill quarried from the nearby mountains at the narrowest part of the lake from both sides. When the rock fill was placed on the lake bed, it started to subside. The rate of settlement was monitored closely during the filling process and the geometrical placements were carried out until the subsidence of the lake bed halted. The width of the embankment crest is about 30 m and the average height is about 20 m.

Due to the circulation of salt-water in N-W to S-E directions in the lake and transportation between the Ports of Sharafkhaneh and Rahmanlu, a waterway should be kept open. Consequently, an opening must be built to facilitate the access of marine traffic for different parts of the lake. A bridge with the length of 1,260 m, comprising of 19 spans has been considered. The main span is in the form of an overhead tied arch structure in the length of 100 m and the side spans are in form of flat deck systems. The bridge abutments land on the adjacent embankment in a manner ensuring adequate continuity for road and railway traffic in the abutment areas. In construction of the bridge, more than 400 steel pipe piles having a total length of 32 km were driven. Due to the thick layers of sensitive and super soft clay sediments, the bridge foundations had to be placed on deep competent stratum. Design of the piles compiled different methods such as static analysis, dynamic testing, and correlations to in situ tests, particularly cone penetration test with pore pressure measurements.

The CPTu was the major geotechnical tool and source of useful subsoil data in this project [1]. The location of embankment and causeway route as well as the bridge longitudinal view are shown in Figure.1.

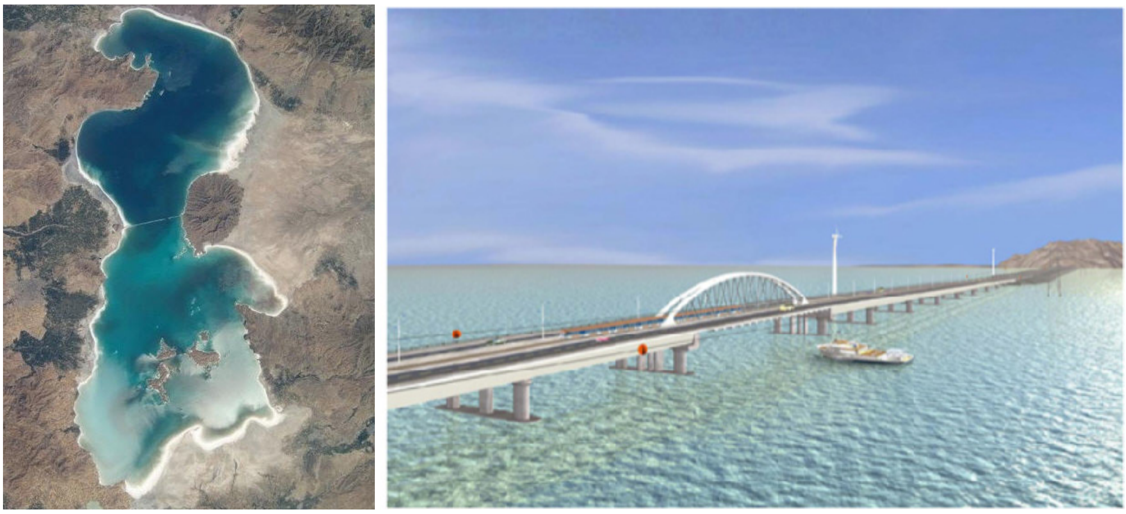


Figure 1.Urmiyeh Lake map and the causeway route and bridge longitudinal view

Geological and geotechnical investigations were performed to determine the thickness, physical and mechanical properties of the subsoil layers. Investigations carried out by drilling boreholes, sampling from the soil layers, and performance of laboratory tests, field tests and piezocone (CPTu) soundings. CPTu were performed in twelve locations along the bridge route and embankment to depths of 100 m below the lake-bed.

2-GEOTECHNICAL INVESTIGATION OF THE URMIYEH LAKE SITE

The sedimentary rocks underlying the recent lake deposits are limestone and shale of the Permian and Cretaceous periods respectively. The igneous rocks are typically granite, volcanic breccias, and trachyandesite-dacit. The region has been subjected to complex faulting, folding and fracturing with numerous rock outcrops along the shoreline and lake islands.

Particular attention was given to study more recent geological sediments of the Pliocene-Pleistocene periods. In order to determine the geological properties of soil, three boreholes in the lake bed sediments were advanced to a depth of 150 m. Samples were collected using thin-walled tube sampler from various depths. The soft clay in the upper 10 m was too soft to be sampled. The sample quality in the lower beds was generally good, although some disturbance was noted [2].

The variety and type of primary sedimentary structures found in the laminated beds during this investigation indicate that they have resulted from a traction and fall-out process from turbulent suspension. The complexity of the sediments can be rationalized by the use of following depositional mode: This model which is very common in the lake describes the effect of Brownian forces between different particles. In this process, flocculated clay particles stick on silt and fine sand grains particles, which cause them to settle rapidly. It should be mentioned that concentration of ions and cat ions in supper salt water accelerates the process. Under this condition the top layers are largely underconsolidated. The upper soft clay layers are highly flocculated compressible, and under ongoing consolidation. They have collapsible structure under dynamic loading (earthquake) condition. Figure. 2 is a photo of thin-walled tube samples from the site, showing fissures (stained) caused by seismic action and subsequently filled by fine sand. The lower part of the sediments is organic matter, the remnant of species such as Algae and Artemia salina of brine crustacean that can tolerate fluctuation in the salinity of water. Oxidation produced dark color sludge. The range and sequence of structures can be summarized as five basic units believed to have local stratigraphic significance [3].

Figure.2-Stained fissures filled by fine sand

3-SOIL INTERPRATATIONS BY CPTu RECORDS

During the past decades, the cone penetration test (CPT) has gained wide popularity and acknowledgement as a preferred in situ tool for subsurface investigation and soil characterization. The CPT is a robust, simple, fast, reliable and economical test that provides continuous sounding of subsurface sediments. During penetration, the cone penetrometer simultaneously measures the cone tip resistance, q_c, and sleeve friction, f_s. When the piezocone penetration test (CPTu) is used, the pore pressures generated during penetration can also be measured. The CPTu measurements can be effectively used in many geotechnical engineering applications, such as soil stratification and identification, and to evaluate different soil properties such as the strength and consolidation characteristics of the geomedia. This makes CPT technology valuable for a wide range of geotechnical engineering applications [4].

One important application of the CPT is its use in soil type identification and classification profiling. Begemann (1965) [5] pioneered soil profiling from the CPT, showing that, coarse-grained soils generally demonstrate larger values of cone resistance (q_c) and sleeve friction (f_s) than fine-grained soils. Begemann showed that the soil type is a function of the ratio between the sleeve friction and the cone resistance (the friction ratio, R_f).

After Begemann, other researchers presented different soil profiling charts based on mechanical CPT data i.e. Sanglerat et al. (1974) [6], Schmertmann (1978) [7]. Douglas and Olsen (1981) [8] were the first to propose a soil profiling chart based on tests with the electrical cone penetrometer. Robertson et al. (1986) [9] were the first to present a chart based on the piezocone with the cone resistance corrected for pore pressure at the shoulder.

The chart identifies numbered areas that separate the soil types in twelve zones. Later Robertson (1990) [10] proposed a refinement of the Robertson et al. (1986) [9] profiling chart. The normalization was proposed to compensate for the cone resistance dependency on the overburden stress, and therefore when analyzing deep CPTu soundings (i. e., deeper than about 30 m), a profiling chart developed for more shallow soundings does not apply well to the deeper sites. Robertson (1990) [10] proposed charts plot a normalized cone resistance, Q_t, against a normalized friction ratio, F_t, and accompanying normalized cone resistance, Q_t against pore pressure ratio, B_q, which is defined by equations (1) to (3) as follows:

$$Q_t = (q_t - \sigma_v) / (\sigma`_v) \quad (1)$$

$$F_t = (f_s) / (q_t - \sigma_v) \quad (2)$$

$$B_q = (u_2 - u_0) / (q_t - \sigma_v) \quad (3)$$

where Q_t = normalized cone resistance, q_t = cone resistance corrected for pore water pressure on shoulder, σ_v = total overburden stress, σ'_v = effective overburden stress, $(q_t - \sigma_v)$ = net cone resistance, F_t = normalized friction ratio, f_s = sleeve friction, B_q = pore pressure ratio, u_2 = pore pressure measured at cone shoulder and u_0 = hydrostatic pore pressure.

Recently, Eslami and Fellenius (2004) [11] investigated several CPT and CPTu approaches for soil behavior classification. They proposed a new approach to classify the soil based on CPTu data. Plotting an effective cone resistance defined by equation (4) against sleeve friction, f_s, was found to provide a more consistent delineation of envelopes than a plot of only the cone resistance.

$$q_E = (q_t - u_2) \quad (4)$$

where q_E = effective cone resistance.

The q_E-value was shown to be a consistent value for use in relation to soil responses such as pile shaft and pile toe resistances [4]. Notice that, as mentioned by Robertson et al., 1986 [9], the measured pore water pressure is a function of where the pore pressure gage is located. Therefore, the q_E-value is by no means a measurement of effective stress in conventional sense. In dense, coarse-grained soils, the q_E-value differs only marginally from the q_t-value. In contrast, cone tests in fine-grained soils could generate substantial values of excess pore water pressure causing the q_E-value to be much smaller than the q_t-value

4-DISCRIPTION OF SURPRISING SOIL BY CPTu

To study more detailed the subsurface deposits, twelve CPTu sounding were preformed along the bridge route to get more information about lake bed conditions [1]. Typical CPTu data including q_c (cone resistance), f_s (cone sleeve friction) and u_2 (pore pressure behind the cone point), for borehole DC-3 are illustrated in Figure. 3.

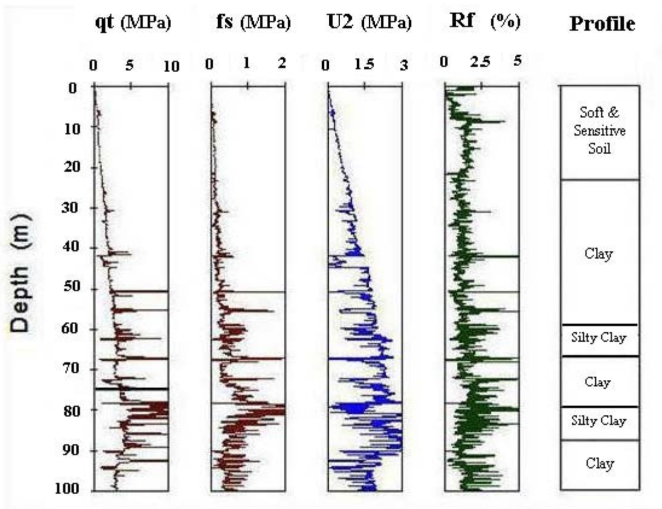


Figure. 3-CPTu logs and soil profile for borehole DC-3 by Mandro Co., 2003

Because of specific soft and sensitive deposits in sub layers for the Urmiyeh Lake which makes it unique and in order to classify these surprising soils, the Robertson (1990) [9] and Eslami-Fellenius (2004) [11] methods were applied. According to Robertson (1990) charts, normalized cone resistance, Q_t is plotted versus normalized friction ratio, F_t, and also versus pore pressure ratio, B_q. Based on Eslami and Fellenius (2004) chart, the values of effective cone resistance, q_E, is plotted versus sleeve friction, f_s. The obtained CPTu data are plotted on three charts of classification as shown in Figures 4a, b and c respectively.

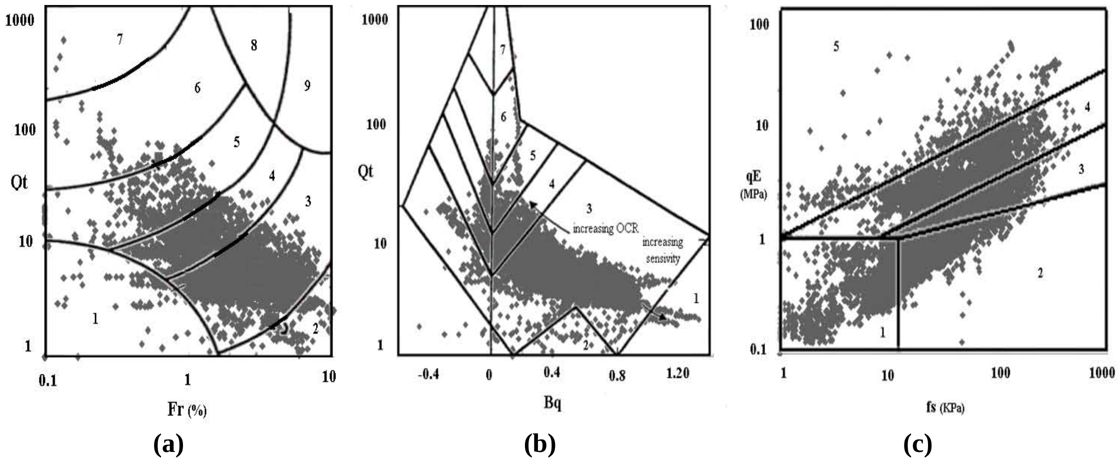


Figure. 4-Soil Profiling (a) and (b) by Robertson (1990) and (c) by Eslami-Fellenius (2004)

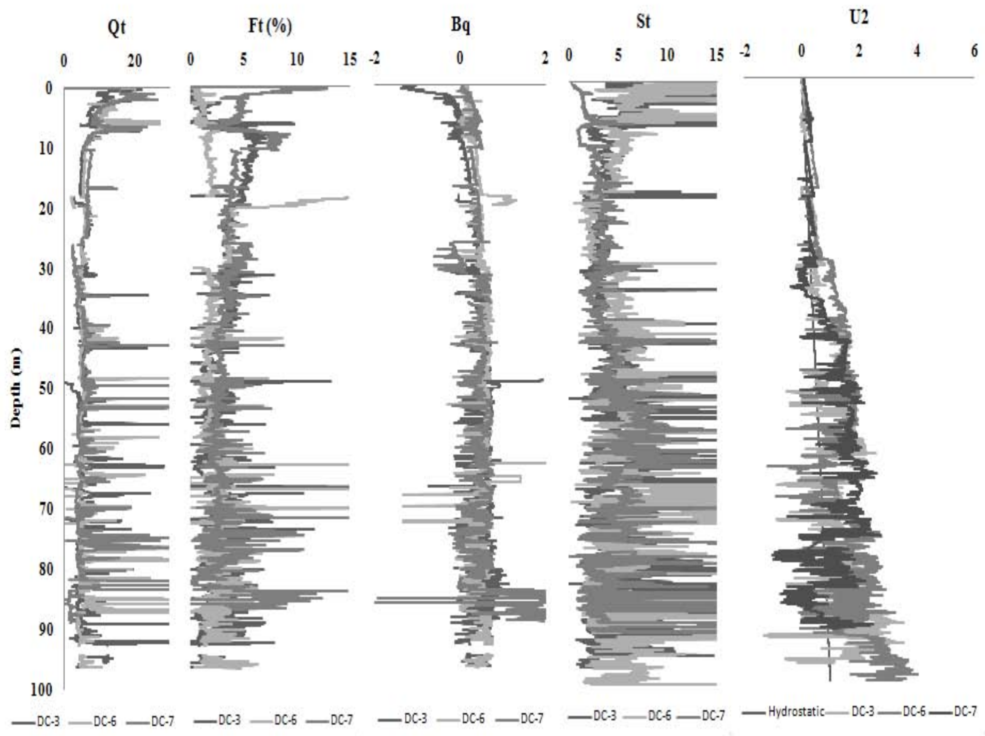
As illustrated in Figures. 4a and b Robertson et al. (1990) charts, orientation of data shows that the layers consist of clays (clay to silty clay), silt mixtures (silty clay to clayey silt), sand mixtures (sandy silt to silty sand), sand (silty sand to clean sand) and sensitive clay. Considering Eslami-Fellenius (2004) chart, Figure. 4c orientation of the data shows that the most of the layers consist of sensitive and collapsible clay, silt, clay and silt and some other type of soil like silty clay and clayey silt, sandy silt and silty sand.

In order to determine the sensivity of soil layers, based on CPTu data, sensivity of layers was evaluated using Schmertmann proposed method (1978) [7]:

$$S_t = N_s / R_f \tag{5}$$

where S_t = sensivity, N_s = empirical coefficient and R_f = friction ratio.

Based on a suggestion by Rad and Lunne (1986) [12] the N_s value ranges from 5 to 9 with average value of 7.5. The average value was considered for determination of soil layers sensivity. Based on Schmertmann (1978) method, the sensivity of sub layer soils was determined for three CPTu logs. Sensivity versus depth is shown in Fig. 5d for boreholes DC-3, 6 and 7. According to analysis, the average value of sensivity is equal to 5. Recently Research by Golpasand et al. (2006) [13] on Urmiyeh Lake soil layers based on CPTu data and laboratory testing, confirms the achieved results. The values of Q_t, F_t and B_q versus depth for boreholes DC-3, 6 and 7 are presented in Figure. 5a, b and c respectively.



(a) (b) (c) (d) (e)

Figure. 5-(a) normalized cone resistance, (b) normalized friction ratio, (c) pore pressure ratio, (d) sensitivity and (e) pore pressure values versus depth for boreholes DC-3, 6 and 7

In order to evaluate the water pore pressure condition in sub soil layers, the value of u_2 versus depth for boreholes DC-3, 6 and 7 are plotted, as presented in Figure. 5e. As it is illustrated the pore pressure is greater 2 to 3 times hydrostatic pressure. Researches by Mayne et al., (1990) [14] and Schneider et al., (2001) [15] state that piezocone response at the u_2 location will typically be hydrostatic in sands and greater than hydrostatic in soft intact clays. Positive u_2 penetration pore water pressures in such deposits may occur due to a combination of octahedral as well as shear induced pore water pressures.

5-CONCLUSIONS

A broad site investigation for construction of 1260 m long Urmiyeh Lake Causeway, including twelve CPTu soundings and three boreholes indicates that the site deposits formed from super soft sensitive clays defined as 'Tabriz Marl.' The material is visually classified as a high liquid limit silt (MH) or clay (CH).

Due to the thick layers of sensitive and super soft clay sediments, the bridge foundations must be located on deep competent stratum. Therefore, for design of the deep foundations, the CPTu was realized the major geotechnical tool and also the source of useful subsoil data in this project.

The soil profile obtained from CPTu data based on Robertson (1990) and Eslami-Fellenius (2004) CPTu classification charts showed that, the most types of sediments in the lake bed consist of continuous sensitive and very soft clay.

Evaluations based on CPTu data and correlations for sensitivity number show that, the S_t for most layers ranges from 2 to 4. Interpretations of u_2 penetration pore water pressures indicates that the u_2 for the soft and sensitive clay deposits in the lake site, ranges from almost twice to three times of the hydrostatic water pressure.

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