



Islamic Azad University  
Mashhad Branch

# Using the Results of CPTu to Identify the Subsurface Sediment Layers in Urmia Lake Bridge Site, NW Iran

Mohammad Reza Baghban Golpasand\*<sup>1</sup>, Mohammad Reza Nikudel<sup>1</sup>, Ebrahim Asghari-Kalajahi<sup>2</sup>

1. Department of Engineering Geology, Tarbiat Modares University, Tehran, Iran

2. Department of Earth Science, University of Tabriz, Tabriz, Iran

Received 14 May 2016; accepted 24 November 2016

## Abstract

Specifying the soil types and profiling the subsurface soil layers are the excellent examples of CPTu test potentials. In this research, the capability of CPTu test for specifying subsurface soil layers and classification of the sediments in Urmia Lake is investigated. According to previous studies, the sediments of Urmia Lake are commonly fine grained and soft deposits with organic materials. To evaluate the geotechnical parameters of these sediments in Urmia Lake Bridge site, CPTu test was performed and soils were classified applying the results of this test. The results showed that the sediments are mostly composed of clay and silt. To verify the results of CPTu tests for soil classification, the outcomes were compared with the logs of the boreholes and the results of laboratory tests. Comparisons and analysis of findings showed high consistency between the three groups of results; CPTu, boreholes logs, and laboratory tests. Thus, CPTu test can be used, with sufficient confidence and accuracy, to specify and classify the soft soil in lacustrine environments.

**Keywords:** CPTu test, Soil classification, Borehole Logging, Laboratory tests, Urmia Lake

## 1. Introduction

The soil classification systems based on CPTu test results, provide a fast and applicable procedure to identify subsurface soil layers. The conventional approach to specify the soil type using laboratory method requires geotechnical studies that include drilling, sampling, transporting of samples to the laboratory and performing relevant tests that commonly are time and cost consuming process. Therefore, the use of simpler, less expensive and faster methods for soil classification and identifying the subsurface layers are very useful and of greater interest. If a continuous, or nearly continuous, the subsurface profile is desired, CPTu test can be an acceptable approach. Soil classification using the results of the CPTu test is one of the most important utilizations of this test. A number of classification methods and recommendations are presented to specify soil type based on either CPT or/both CPTu data (Begemann 1965; Douglas and Olsen 1981; Jones and Rust 1982; Senneset and Janbu 1985; Robertson et al. 1986; Olsen and Malone 1988; Robertson and Campanella 1988; Robertson 1990; Robertson 2009; Jefferies and Davies 1991; Olsen and Koester 1995; Olsen and Mitchell 1995; Eslami and Fellenius 2004; Robertson and Wride 1997; Jung et al. 2008; Schneider et al. 2008; Cetin and Ozan 2009).

One of the first studies was done by Douglas and Olsen (1981). They presented some of the most comprehensive works on soil classification using electric CPT data. One important distinction made by Douglas and Olsen (1981) was that CPT classification charts could not be expected to provide an accurate specification of soil type based on grain size distribution but provide a guide to soil behaviour type. In the case of piezocone based classification charts, the chart proposed by Robertson (1990) provides information on soil behaviour type such as liquidity index, earth pressure coefficient, and sensitivity. The chart has been shown in Figure 1. The parameters on this chart have been described in next section. The description of soil behaviour types is presented in Table 1. In recent years, soil classification charts have been adapted and improved based on an expanded database (Robertson et al. 1986; Olsen and Farr 1986). Robertson has performed detailed and complementary researches in this object. The results of his researches, especially the chart shown in Figure 1, are the main basis of this study.

## 2. CPTu Test Procedure

CPTu test is carried out according to ASTM D5778. Figures 2 and 3 shows the main parts of the CPTu cone and the cone has been used in present study, respectively.

\*Corresponding author.

E-mail address (es): [r\\_gols@yahoo.com](mailto:r_gols@yahoo.com)

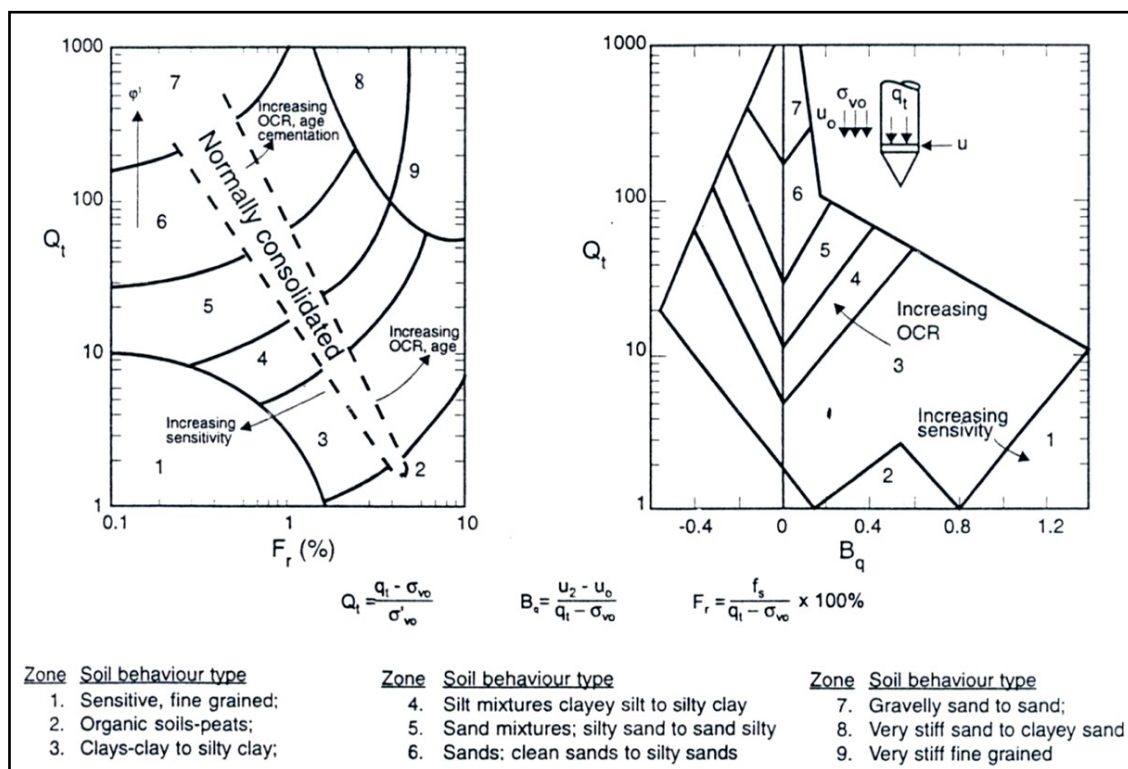


Fig 1. Soil behaviour type classification chart based on normalized CPT/CPTu data (Robertson 1990)

Table 1. Description of soil behavior type in classification chart (Robertson 1990)

Zone	Soil Behavior Type
1	Sensitive, fine grained;
2	Organic soils – peats;
3	Clays – clay to silty clay;
4	Silt mixtures, clayey silt to silty clay;
5	Sand mixtures, silty sand to sandy silt;
6	Sands: clean sands to silty sands;
7	Gravelly sand to sand;
8	Very stiff sand to clayey sand;
9	Very stiff fine grained

Four important parameters (called raw data) are obtained through performing of this test:

- 1) Cone resistance,  $q_c$ , this parameter also called “Tip resistance”.
- 2) Friction sleeve resistance,  $f_s$ ,
- 3) Friction ratio,  $R_f$  is defined as equation (1):

$$R_f = \frac{f_s}{q_c} \times 100 \quad (1)$$

- 4) Pore pressure,  $u$ ,

The results of CPTu test, are used in soil classification; determining the drained and undrained shear strength parameters, sensitivity, over-consolidation ratio (OCR), and estimating the deformation modulus for designs of geotechnical and earth structures (Cai et al. 2011).

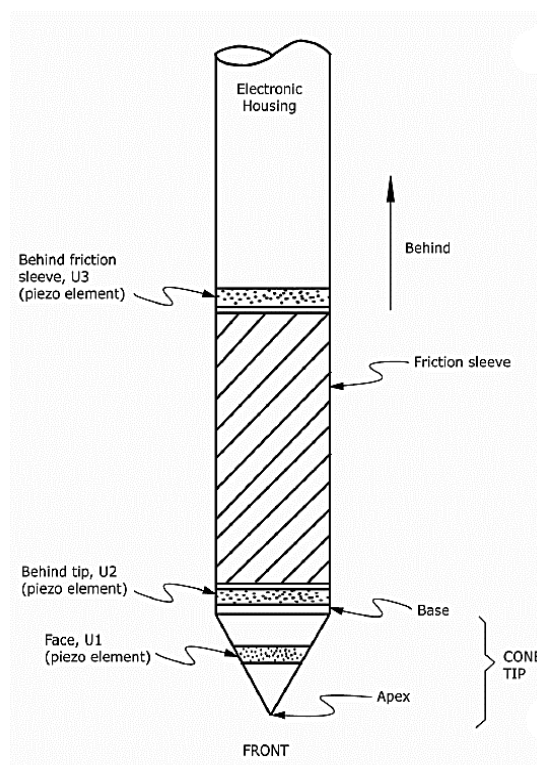


Fig 2. Main parts of the CPTu cone



Fig 3. The CPTu cone used in present study

Correlation of CPTu test results and other in-situ tests indicates the high reliability of CPTu test to evaluate soil-engineering parameters (Akca 2003; Lunne et al. 1997). Correction for pore pressure effects on cone resistance is given by the equation (2):

$$q_t = q_c + u_2(1-a) \quad (2)$$

Where

$a$ : Net Area Ratio, which is approximately equal to the ratio of the cross-sectional area of the load cell or shaft, divided by the projected area of the cone (Fig 4).

$u_2$ : pore pressure acting behind the cone, shown in Figure 2. However, correction of raw data leads to obtaining new data called the corrected data. The parameter of  $q_c$  is converted to  $q_t$ , parameter of  $f_s$  is changed into  $f_t$  and parameter of  $R_f$  is changed into  $F_r$ . These parameters can be computed through the equations (3) to (7) (Lunne et al. 1997):

$$Q_t = \frac{q_t - \sigma_{v0}}{\sigma'_{v0}} \quad (3)$$

$$\sigma_v = \sum h_i \cdot \gamma_i \quad (4)$$

$$\sigma'_{v0} = \sigma_{v0} - u_0 \quad (5)$$

$$F_r = \frac{f_s}{q_t - \sigma_{v0}} \times 100 \quad (6)$$

$$B_q = \frac{u_2 - u_0}{q_t - \sigma_v} \quad (7)$$

Where:

$\sigma_v$ : total overburden stress

$h_i$ : layer thickness

$\gamma_i$ : unit weight of soil

$\sigma'_{v0}$ : effective vertical stress

All of these parameters and the relationships between them are completely discussed in the related textbooks and references. Finally, three parameters of  $Q_t$ ,  $F_r$  and  $B_q$ , called normalized parameters, are given and soil layers can be classified using these normalized parameters. The charts proposed by Robertson (1990),

the main implement of the present study and shown in Figure 1, represent a three-dimensional classification system that incorporates all the three pieces of CPTu data. For basic CPT data where only  $q_c$  and  $f_s$  are available, the left-hand chart (Fig 1) can be used. The error in using uncorrected  $q_c$  data will only influence the data in the lower part of the chart where a normalized cone resistance is less than 10.

This part of the chart is for soft, fine-grained soils where  $q_c$  can be small and penetration pore pressures ( $u_2$ ) can be large values. Included on the normalized soil behaviour type classification chart is a zone that represents approximately normally consolidated soil behaviour. A guide is also provided to indicate the variation of normalized CPT and CPTu data for changes in over-consolidation ratio (OCR), age and sensitivity ( $S_t$ ) for fine-grained soils, where cone penetration is generally undrained, and OCR, age, cementation and friction angle ( $\phi'$ ) for cohesion less soils, where cone penetration is generally drained. According to Figure 3, soils that are situated in zones 6 and 7 represent approximately drained penetration, whereas soils in zones 1, 2, 3 and 4 represent approximately undrained penetration. Soils in zones 5, 8 and 9 may represent partially drained penetration. An advantage of pore pressure measurements during cone penetration is the ability to evaluate drainage conditions more directly. Robertson (1990) suggested that the charts in Figure 1 are still global in nature and should be used as a guide to define soil behaviour type based on CPT and CPTu data. Factors such as changes in stress history, in-situ stresses, sensitivity, stiffness, macro-fabric, mineralogy and the void ratio will also influence the classification. Occasionally, soils will fall within different zones on each chart; in these cases, judgment is required for accurately classify the soil behaviour type. Robertson's method is the most practical and efficient method for soil classification using CPTu test result. This method was revised by Robertson himself (Robertson 2009 and Robertson 2010). In the revised version of Robertson method, referring to more information gotten from many case studies by other researchers, the previous method is confirmed forcefully and no any changes were applied on the main method. This method has been validated by other researchers in several times and has been mostly accepted and suggested reliably (Powell and Lunne 2005). Considering the importance of the "soil classification using CPTu", other scholars have researched on this subject and presented methods and diagrams that are similar to Robertson method. Eslami and Fellenius (2004) reviewed all of the preceding methods and charts, that had been published since that time, for soil classification using CPT and CPTu and suggested a new method (and chart) for soil profiling using piezocone test results. They used a new parameter of  $q_E$ , they called effective cone resistance, for soil classification.

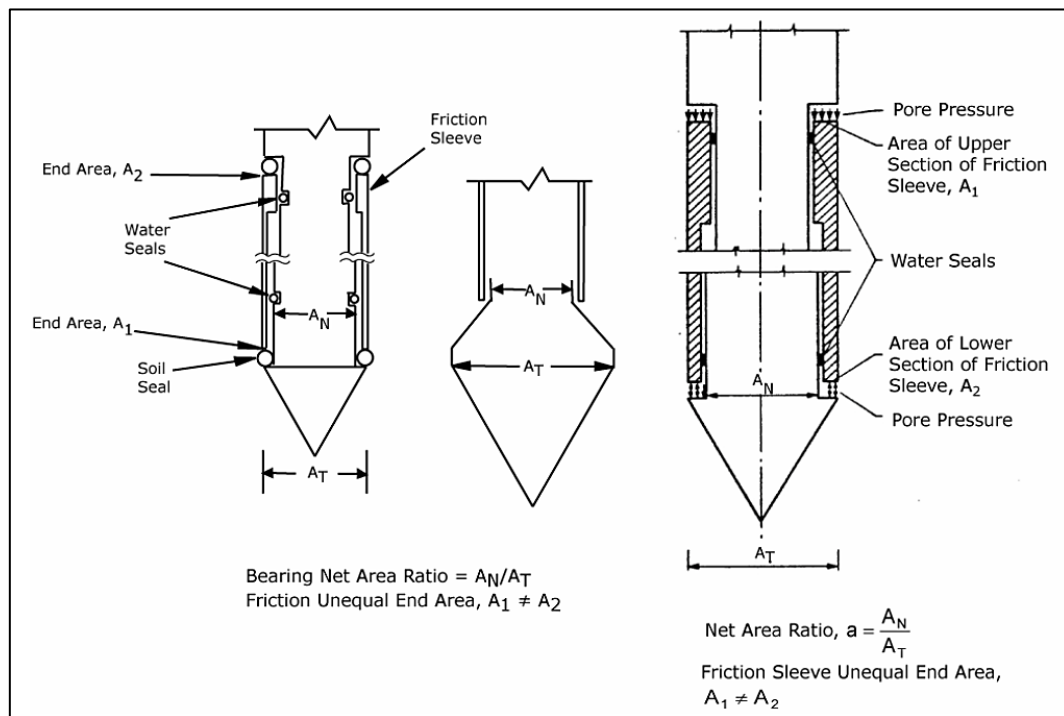


Fig 4. The concept of net area ratio and  $u_2$  (Campanella and Howie 2008)

The important aspect of their research is that they compared results with other methods and find high similarity with Robertson method. In the present study, the method and diagrams proposed by Robertson (1990) will be used to classify the sediments of Urmia Lake Bridge site. For this purpose, after a brief description of the geotechnical properties of the bridge site (located in the narrowest part of the Lake), these sediments will be classified using the data of CPTu tests and the results will be compared with the information of borehole logs and the results of laboratory tests. The comparison and validation of the results of CPTu by borehole logs and the results of laboratory tests is the novelty of this study. The results gathered from CPTu test -to Identify the subsurface sediment layers in Urmia Lake- are compared and verified by two other methods., Thus, these results would be accepted with more confidence and the capability of CPTu, to identify and classify subsurface soil layers, is confirmed with high accuracy.

### 3. Urmia Lake Bridge Site characterizations

Urmia Lake is a closed basin and the largest salty water body situated in the north-west of Iran. The geographical vicinity of the site is shown in Figure 5. The lake-water is saturated with salt and its salt content is between 250 and 300 grams per liters, which is about 8 times the salinity of free sea-waters. The mean area of this lake is 5500 km<sup>2</sup> in average and depth of water is about 8-12 m. In recent decades, the lake's surface area has generally been declined, because of several factors such as climatic variations (GEAS and UNEP 2012). In the early 1980's, Shahid Kalantary Highway was

constructed at the narrowest part of the Urmia lake to join the East and West Azerbaijan provinces shortening the distance for about 130 km between two major cities of Tabriz and Urmia. This project was started by rock-filling into the Lake from two sides of the Lake at Bridge site. Due to the geological and geotechnical condition of the lake bed in bridge site, very soft and fine grained sediments have been deposited in this part of the Lake. This phenomenon caused to the failure of the rock-fill which was constructed to shorten the distance of two sides of the Lake in the middle of it. Then, construction of the Urmia Lake Bridge was approved to connect two sides of the lake. The Urmia Lake Bridge, with the length of 1276 meters in the main part, is a road bridge in the north-west of Iran (Fig 5). This bridge crosses Lake Urmia, connecting the provinces of East Azerbaijan and West Azerbaijan. The bridge was completed in 2008.

#### 3.1. Geological and geotechnical condition of the study site

Urmia Lake has been formed tectonically among several faults, and based on the investigations carried out so far, is attributed to late Pleistocene and Holocene (Berberian and Arshadi 1975; Kelts and Shahrabi 1986). The presence of soft sediments, deposited in a tranquil environment, over the Cretaceous (semi-flysch sediments) and Miocene (Qom formation, including limestone, sandstone and marl, based on geological maps) bedrock with a rough morphology is a distinct feature of the lake's bed material (Shahrabi et al. 1985).

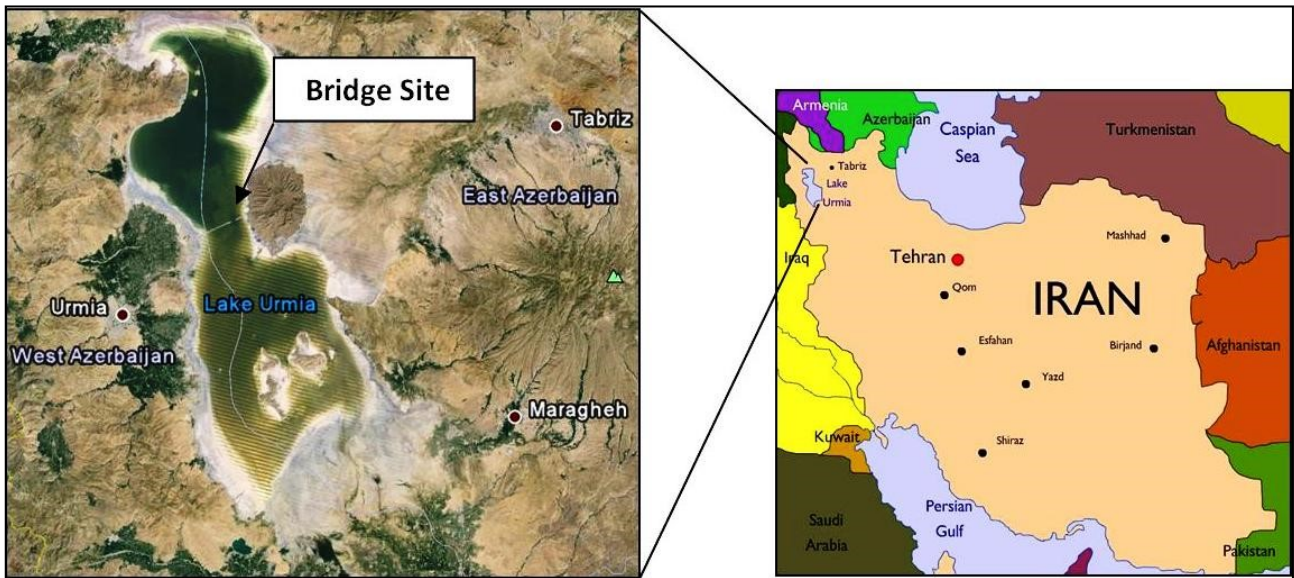


Fig 5. Geographical location of Urmia Lake Bridge in the North-West of Iran

According to published geological maps and reports, relatively complete series of geological units, from Precambrian to Quaternary, are exposed on around and islands of Urmia Lake. The units are comparable with the units of Alborz zone. Marlstones and sandstones of upper-red formation are the main agents of hyper salinity of sea water. There are several small and large islands in Urmia Lake presenting various morphological features. Some islands that have Cretaceous shale and sandstone lithology indicate terrace morphology. Some other Islands in which the Cretaceous rocks are located below the Qom formation indicate terrace (Cretaceous formation) and cliff morphology in the reef limestone of the Qom formation. The depth of the lake sediments is one major problem of this study. It is worth noting that preceding drillings for geotechnical investigations to the depth of more than 100 meters below the floor of the lake, did not reach the bed rock (Jalali et al. 2000). Based on the geophysical investigation (Fugro 2004), the sediments deposit at the bridge site is approximately 200 m thick at the middle point. Palynological evidence indicates that the sediments of Urmia Lake are attributed to late Pleistocene to early Holocene history (Jamali et al. 2008). Volcanic ashes are identified in bore holes drilled through sediments covering the basement rocks of the Lake (Kelts and Shahrabi 1986).

The Lake Urmia region is a part of an active tectonic system due to the interaction between Arabia, Anatolia, and Eurasia Plates including the North and East Anatolian Faults, the Caucasus Mountains, and the Zagros Main Recent Fault. According to this, many

faults have been identified through the basement of Urmia Lake and adjacent regions. This has caused the increase in earthquake potential around the studied area. Several recent earthquakes are documented from displacements of different faults in NW Iran; the 1930 Salmas earthquake formed a spectacular surface faulting with a NW-SE strike and involved almost equal components of normal and dextral slip (Mohajjel and Taghipour 2014).

Geotechnical investigations along the study site of the Urmia Lake Bridge, including in-situ and laboratory tests, are performed in several phases at different times (e.g. Jalali et al. 2000, and Golpasand 2004). In this study, the results of the final stage of Geotechnical operations, with considering the previous investigations, have been discussed. Jalali et al. (2000) accomplished previous investigations including borehole drilling up to a depth of 100 m in lake sediments and SPT in specified depth, to evaluate the stiffness of the soil layers. During the complementary studies in order to determine the properties of soil layers at the bridge site, geotechnical drilling with a variety of depths from 30 to 100 meters by continuous coring and performing CPTu tests was conducted (Golpasand 2004). The distances between drillings and CPTu boreholes were less than 5m. The location of drilling and CPTu testing boreholes are shown in Figure 6. The logs of two boreholes drilled in previous studies and the results of the SPT tests performed in those studies are presented in Figs 7 and 8 respectively.

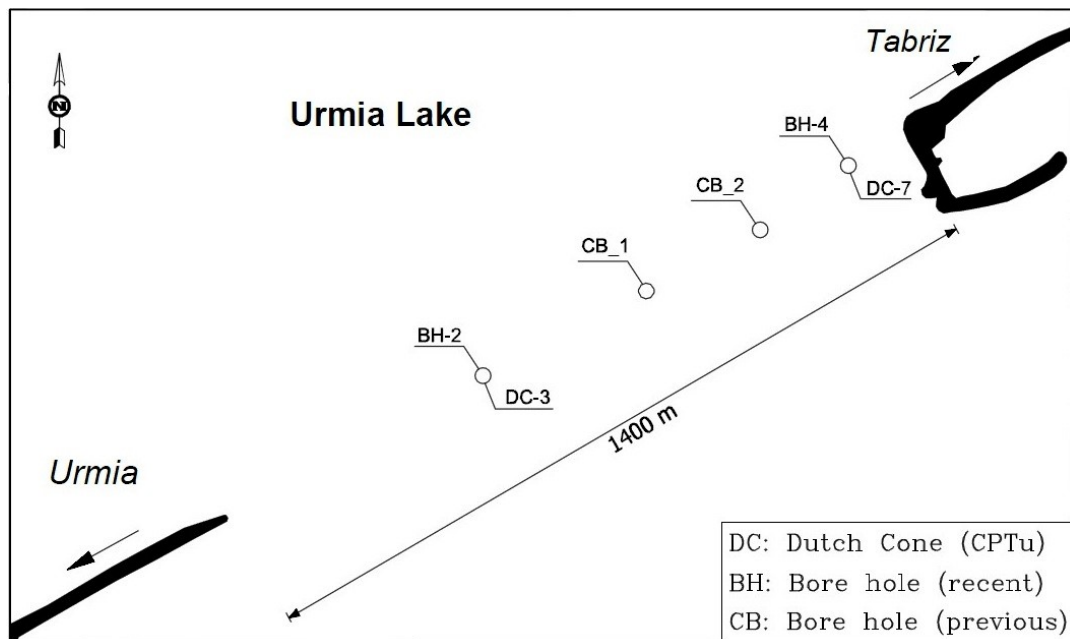


Fig 6. Location of CPTu and coring boreholes in Urmia Bridge site

As seen in these Figures, the sediments of the Urmia Lake are commonly composed of fine grained materials with local lenses and interbeds of sand and organic materials. The simplified geological cross section of Urmia Lake Bridge site is shown in Figure 9.

The logs of bore holes CB-1 and CB-2 show high similarity with the profile shown in Figure 9 especially in shallow layers. The SPT values commonly are low in these shallow layers because of the softness of the layers. It should be noted that in present studies, the borehole logs and CPTu test results will be used only to the depth of 30 meters, because of the high precision of data in shallow layers. The graphs of CPTu test in boreholes DC-3 and DC-7, in the vicinity of boreholes of BH-2 and BH-4 respectively, (Fig 6) are shown in Figures 10 and 11.

#### 4. Classification of the Urmia lake sediments by CPTu Test

In order to classify the sediments of the Urmia Lake using the CPTu test results, performed at the bridge site, normalized parameters of two CPTu boreholes, DC-3 and DC-7, are calculated and the points were plotted on Robertson's diagrams that have been illustrated in Figures 12a and 12b. As seen in these figures, most parts of the sediments are fallen in zone 3 and 4. Thus, most of the materials in the studying area, are clays-clay to silty clay and Silt mixtures, and clayey silt to silty clay. According to the CPTu graphs, especially in DC-7 (Fig 11), few points have been fallen in zones 5, 6 and 7. These zones are related to coarse grain materials such as sands and gravels (Table 1). As shown in Figure 7, the borehole of DC-7 test is located in the vicinity of

Tabriz side levee; so encountering with the coarse grain materials is rational and can be explained in this way.

#### 4.1. Analysis of data

The sediments of Urmia Lake were studied using three methods. Firstly, Geotechnical drilling and continuous coring w performed on the soft soils of the lake floor. After continuous coring and sampling, logs of boreholes were prepared. Classification and analysis processes have been done in two drilling boreholes of BH-2 and BH-4 and piezocone boreholes of DC-3 and DC-7 that are in vicinity together respectively as illustrated in Figure 7.

In the second stage, CPTu tests were performed on Urmia Lake Bridge sediments according to ASTM D5778. These soil layers are classified using charts, presented by Robertson (1990). The obtained results from two methods have been presented graphically in Figures 13 and 14. Descriptions of indexes used in the logs of boreholes, and hatches used in the CPTu classification procedure, are given in Figure 15.

According to the geotechnical logs of the boreholes, shown in the second columns from the right hand of Figures 13 and 14, and considering the information on Figure 15 (A), Urmia lake sediments are composed of fine-grained soils (silt or clay) with some organic materials. The results of CPTu for soil classification are shown as hatched boxes in the first columns, from the right hand, of charts on Figures 13 and 14. As seen in these figures and considering the information on Figure 15 (B), with the exception of some depths, most parts of sediments are within zone 3, thus, they are clays- clay to silty clay. Precise observations on the outcomes of two methods indicate high similarity between them. This fact is pronounced in Figures 13, 14 and 15.

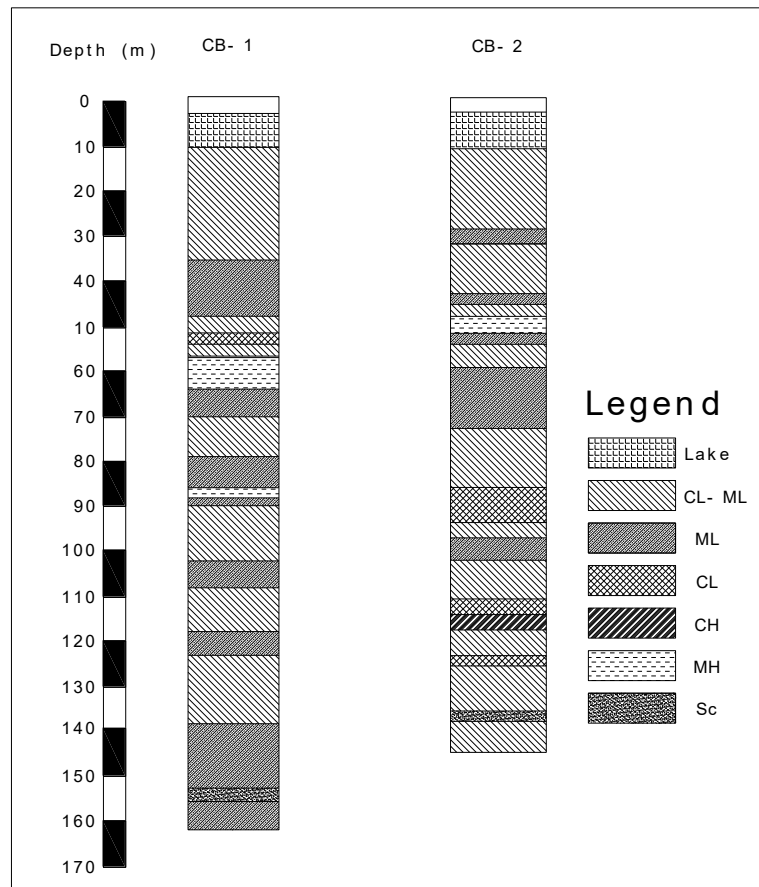


Fig 7. Geological logs of CB-1 and CB-2 boreholes drilled in bridge site (Jalali et al. 2000)

The last column from the right hand in Figures 13 and 14, shows the results of the CPTu test for soil classification. The logs of the boreholes in similar depths are shown in the behind column. Comparison of these two columns shows high consistency between them. Eslami et al. (2010) profiled Urmia Lake sediments using CPTu test results and obtained similar outcomes. Even thin layers of fine sand or chemical sediments can be recognized carefully using CPTu test. In both of the BH-2 and BH-4 boreholes (Figs 13 and 14), the thin layer of chemical sediments, containing gypsum crystals are existent in the depth of 6 to 8m. Graphs of the CPTu test results are shown in these Figures and types of soils identified using CPTu tests, are presented in last columns of them. Very clear variations are visible in the graphs and hatches, related to the depths 6 - 8m. However, in the logs of boreholes, this layer is clearly characterized in similar depths.

**4.2. Validation by laboratory tests**

Comprehensive laboratory tests were done on the soil samples, derived from the cores of the BH-2 and BH-4 boreholes depth 5 m to 30 m, to find out the geotechnical properties of Urmia Lake sediments carefully, Figure 16 shows one of the core boxes of the

borehole BH-2 (a) and the longitudinal section of the part of the core from depth 20 m of BH-4 borehole (b). The sediments of Urmia Lake are generally soft and fine grained having a lot of organic materials in considered depths. Results of the geotechnical tests are presented in Table 2.

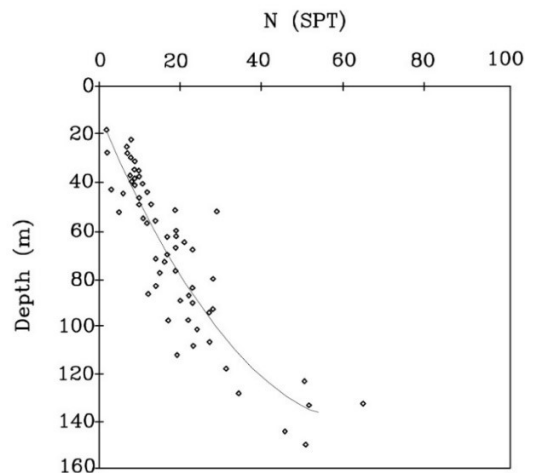


Fig 8. Results of the SPT tests performed in bridge site (Jalali et al. 2000)

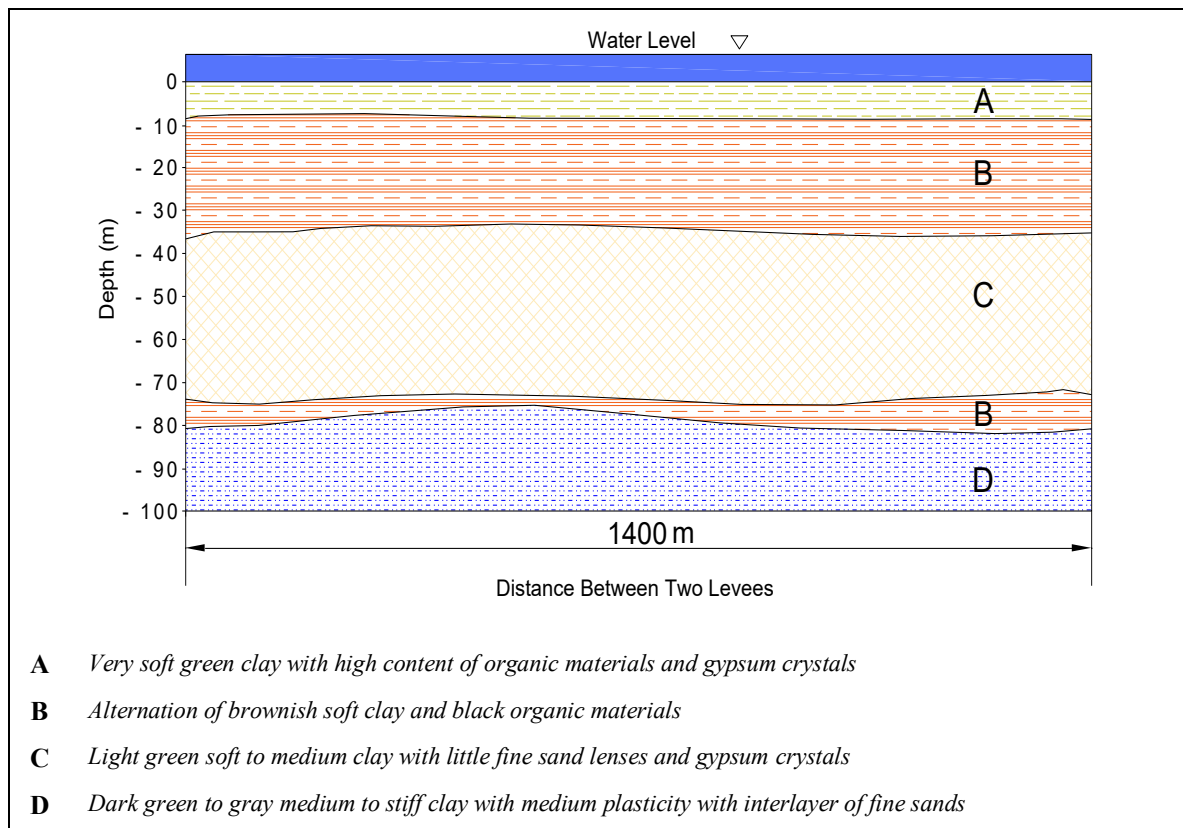


Fig 9. Simplified geological profile of Urmia lake sediments in bridge site (Golpasand 2004)

As seen in this Table, the tests were done on 12 samples have been selected along the cores of BH-2 and BH-4 boreholes from depths 5m to 30m. It should be noted that the laboratory tests have been performed according to the standard of ASTM. According to the direct shear and vane shear tests, cohesion between 9.5 and 14 kPa and internal friction angle between  $8^\circ$  and  $10^\circ$  were obtained as shear strength parameters. Compression index between 0.32 and 0.4 have resulted from consolidation test. Based on these mechanical tests, it can be concluded that the sediments of Urmia Lake are soft and compressible in studying depths. Unified classification of these sediments consist of gradation tests (including mechanical sieving and hydrometer analysis) and determination of Atterberg limits.

In order to gradation of the Samples they were initially washed on no.200 sieve and approximately all of the samples passed through the sieve. Then, hydrometer tests were executed on the samples and the gradation graphs were obtained.

Figure 17 shows the results of these tests. As seen in this Figure, more than 95 percent of the sample grains were passed from sieve no.200, so are finer than 75

Micron, thus with confidence, samples can be categorized in fine grain soils. Unified classification has resulted that the samples are mostly soft lean clay (CL or ML), including interlayers and lenses of soft fat clay (CH or MH). In some depths, the crystals or nodules of halite, gypsum and hardened chemical sediments were obvious in the samples. Based on sedimentology principals, these materials have secondary been originated due to chemical processes.

These chemical sediments have low extension in considered depths and don't affect gradation graphs. In shallow layers, chemical sediments with halite and gypsum crystal have considerable thickness have been illustrated the logs of the boreholes (Figures 13 and 14). In some depths, the samples contained black stains or layers of organic material. Presence of black organic materials in sediments is the specific aspects of Urmia Lake. As mentioned previously, Urmia Lake sediments are composed of fine-grained soils such as silt or clay with some organic materials. As shown obviously in Figure 17 Gradation tests (sieving analysis and hydrometer tests) confirm this fact (Golpasand et al. 2006).



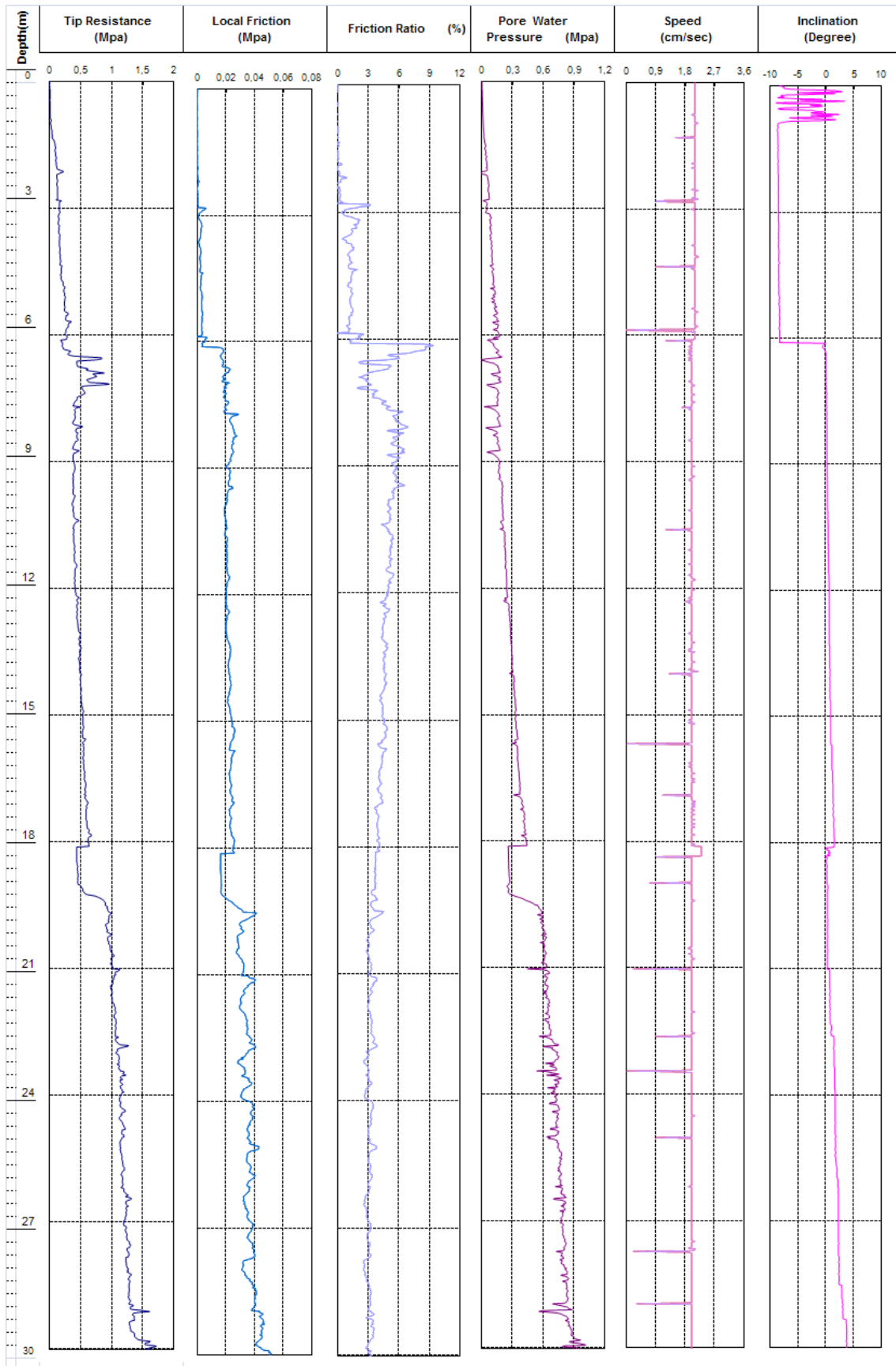


Fig 10. CPTu curves (raw data) obtained from DC-3

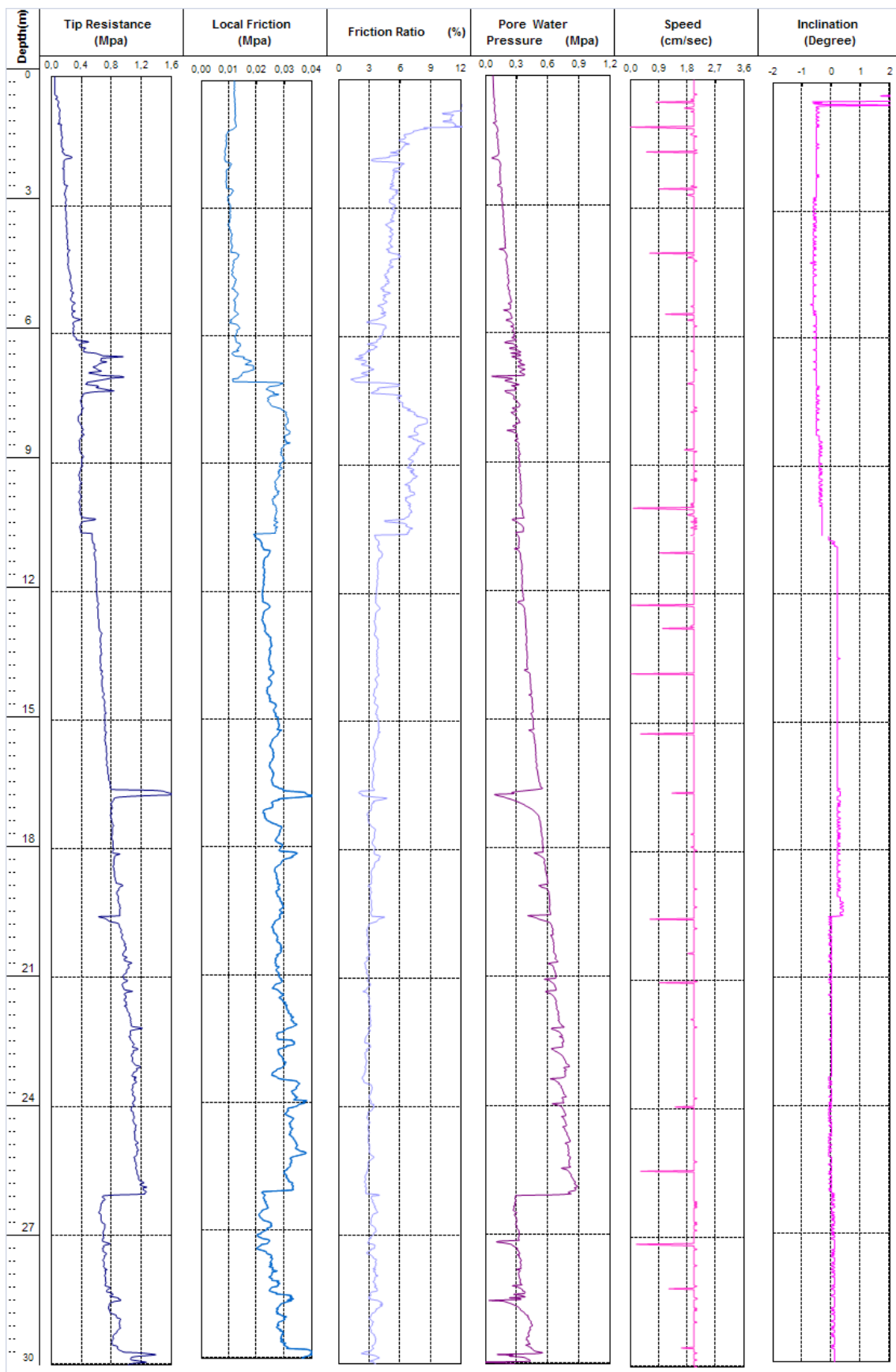


Fig 11. CPTu curves (raw data) obtained from DC-7

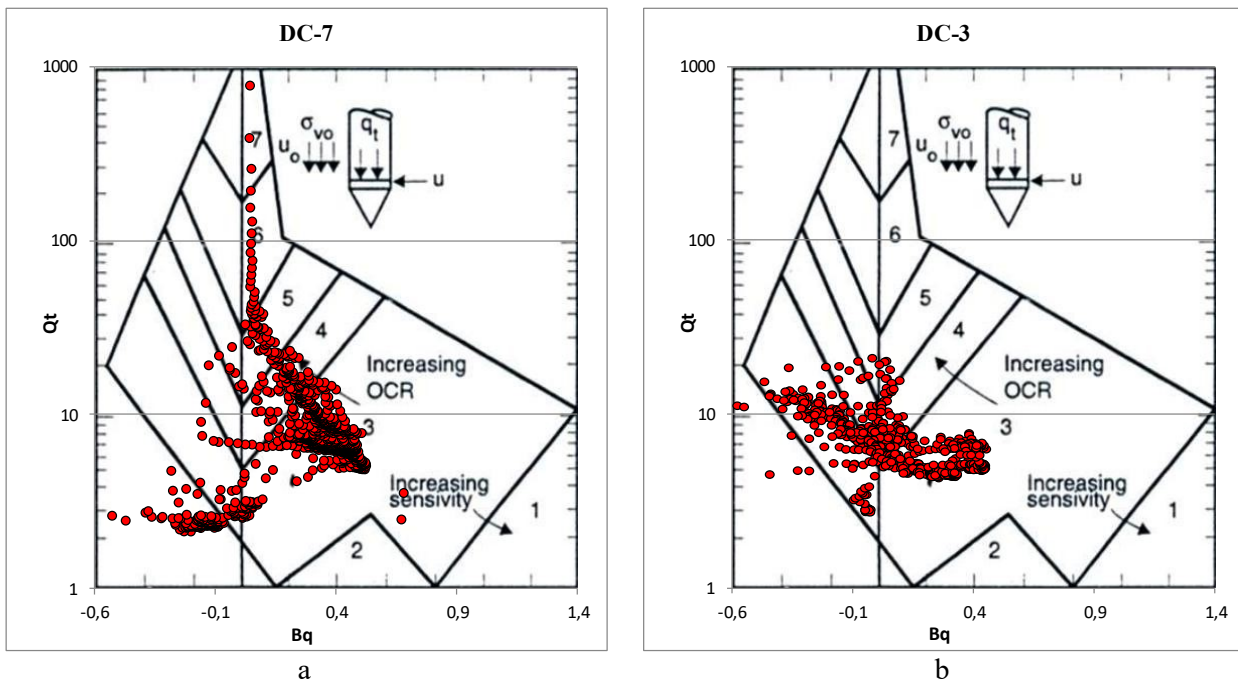


Fig 12. Soil behavior type classification using Robertson (1990) chart

## 5. Discussion

By detailed consideration in Figures 13 and 14, high compatibility is observed between the results of the CPTu test results for soil classification and the logs of the boreholes. As seen in logs of the both BH-2 and BH-4 boreholes, gypsum, halite and hardened chemical sediments are present in shallow layers (depths less than 10 m). Comparing this logs of boreholes with the last column in the right hand of Figures 13 and 14 (hatches of classification results) reveals that the soils in said depths are fall in zones 1, 2, 4, 5, even 6 of Robertson's chart. It means there are sand layers or interlayers in those depths.

Even if the CPTu measures the correct mechanical characteristics in uniformly soft or strong materials, the transition from one layer to another will not necessarily be registered as a sharp change. Cavity expansion and strain path theories, as well as laboratory studies (Schmertman 1978; Treadwell 1976), show that the Tip resistance parameter ( $q_c$ ) is influenced by the material existent in the ahead and the behind the penetration cone. Hence, the cone will start to record a change in material type before it reaches the new material and will continue to record a new material even when it has reached it. Thus, the CPTu will not always measure the correct mechanical properties in thinly inter-bedded materials.

The distance over which the cone senses interface increases with material stiffness. Hence, the cone

resistance can respond fully (i.e. reach full value within the layer) in thin soft layers better than in thin stiff layers. Soft layers thinner than 100 mm can be fully detected by the cone resistance, whereas stiff layers may need to be as thick as 750 mm or more for the cone resistance to reach its full value. The CPTu will detect thin stiff layers but the mechanical properties of stiff layers could be underestimated if the layer thickness is less than about 750 mm. It is possible to detect the presence of soft layers as thin as 75 to 100 mm using the cone resistance (Lunne et al. 1997). Therefore, care should be taken when interpreting cone resistance in thin sand layers located within a soft clay deposit (e.g. sandy thin layers or lenses within the soft and clayey sediments of Urmia Lake). It should be noted that according to geological and geotechnical characteristics of Urmia Lake sediments, especially to logs of boreholes, there is not sand layer at the mentioned depths. It seems that the gypsum, halite, and hardened chemical sediments in shallow layers act as sandy materials (from aspects of hardness and strength against cone penetration) so the points fall in zones 4, 5 and 6, and, consequently, soils would be classified into sand categories. This case is seen in both drilling and CPTu boreholes. Abnormal features in CPTu graphs in some depths such as suddenly variations in CPTu parameters, is another problem about the graphs of the CPTu in Figures 13 and 14 that affect the classification hatches.

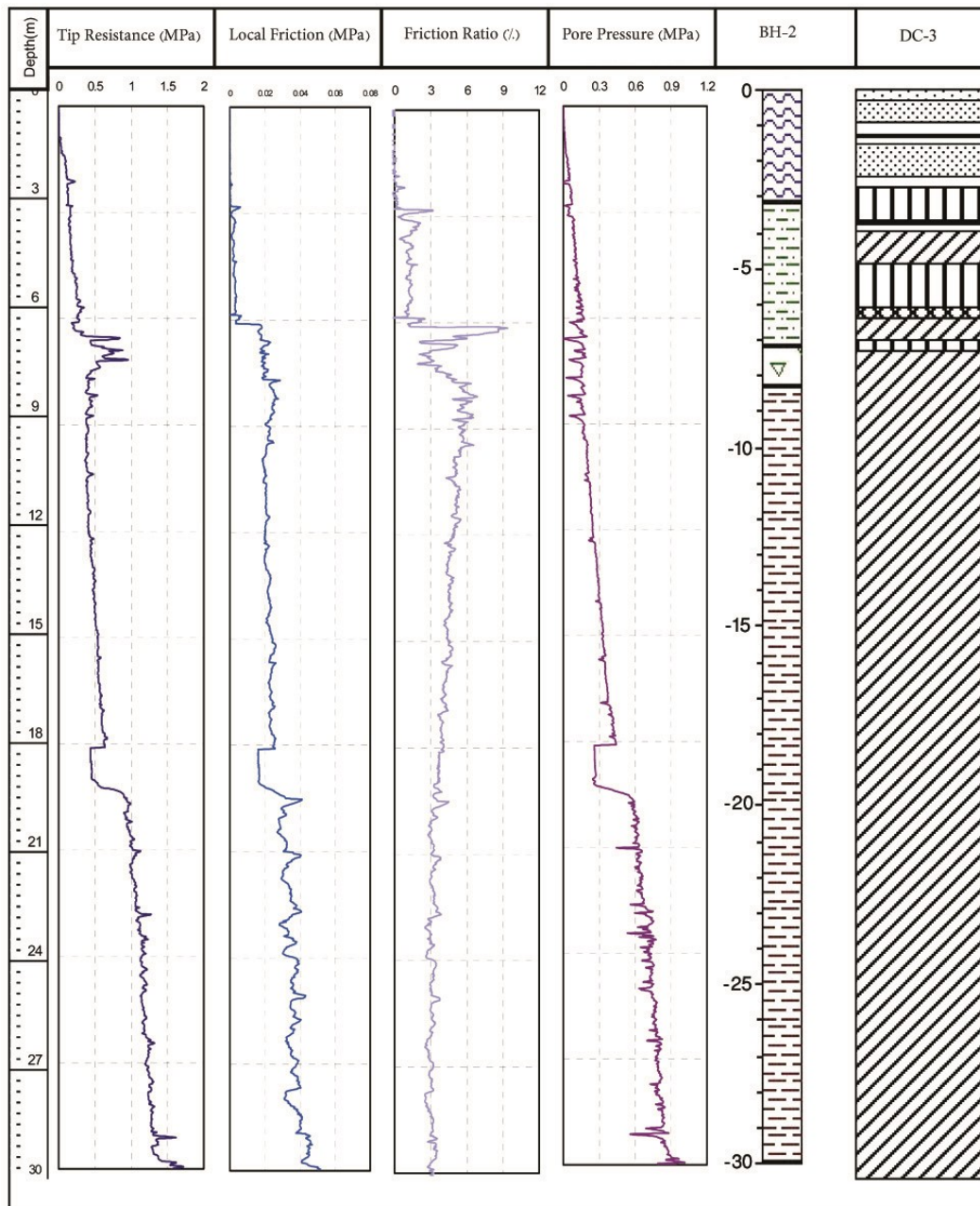


Fig 13. Results of CPTu test in borehole of DC-3, classification of soil using these results (last column) and logs of borehole of BH-2 in related depth

These features are created due to several factors that are summarized in Table 3. As seen in this Table, three significant examples of the abnormal features occur in CPTu graphs in various depths. The probable reasons of these features are also pointed in this Table. Table 3 shows that incorrect recording of the borehole logs, which sometimes occur due to operator (human) deflection, is one of the most probable error sources in

this study and any Geotechnical practices. Based on this fact and considering the independency of CPTu test from human intervention and errors, the capability and efficiency of this in-situ test for identification and profiling of subsurface soil layers is emphasis again. In other words, this test can be used confidently to determine soil type and profiling subsurface (or sub-seafloor) soil layers.

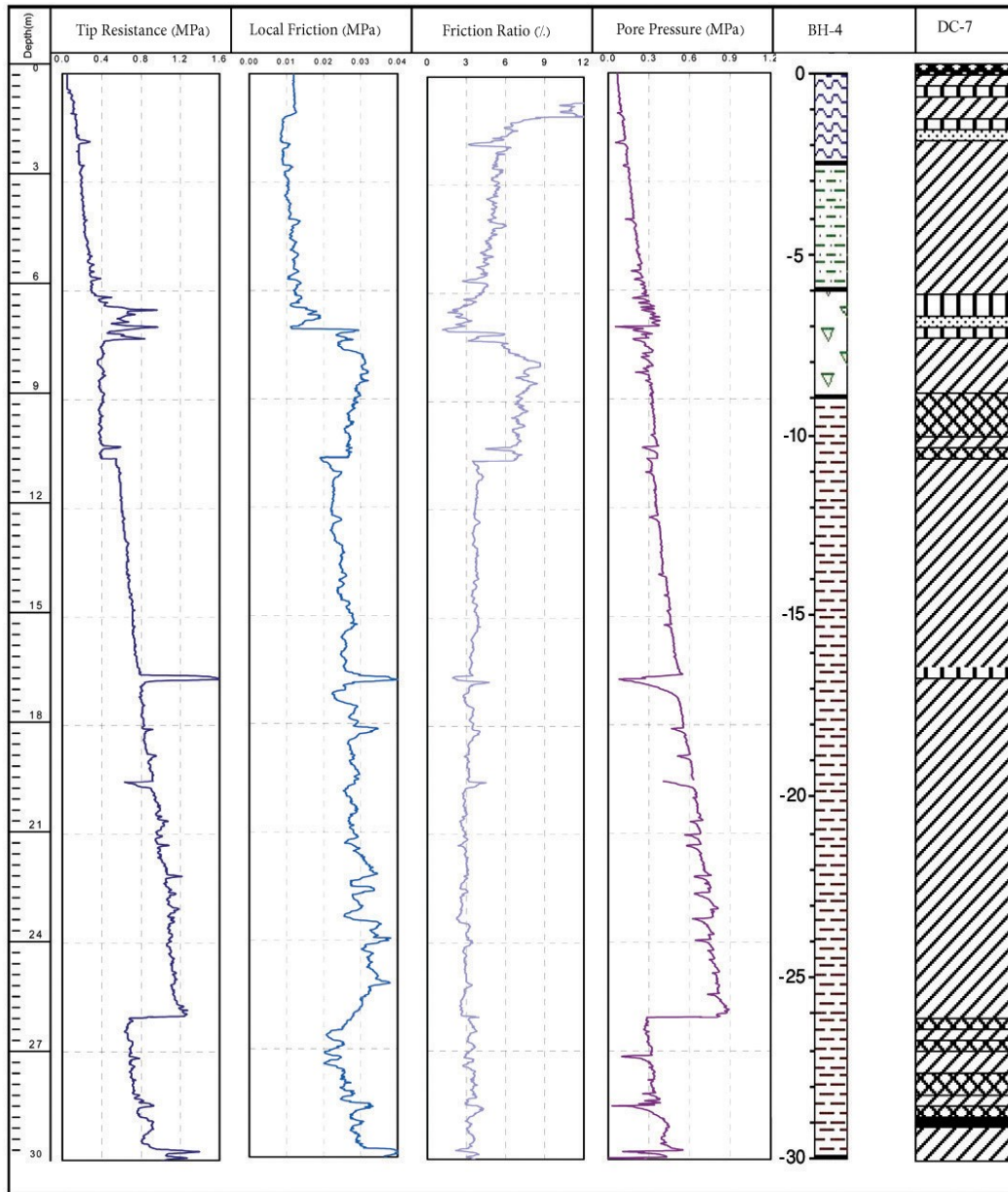


Fig 14. Results of CPTu test in borehole of DC-7, classification of soil using these results (last column) and logs of borehole of BH-4 in related depth

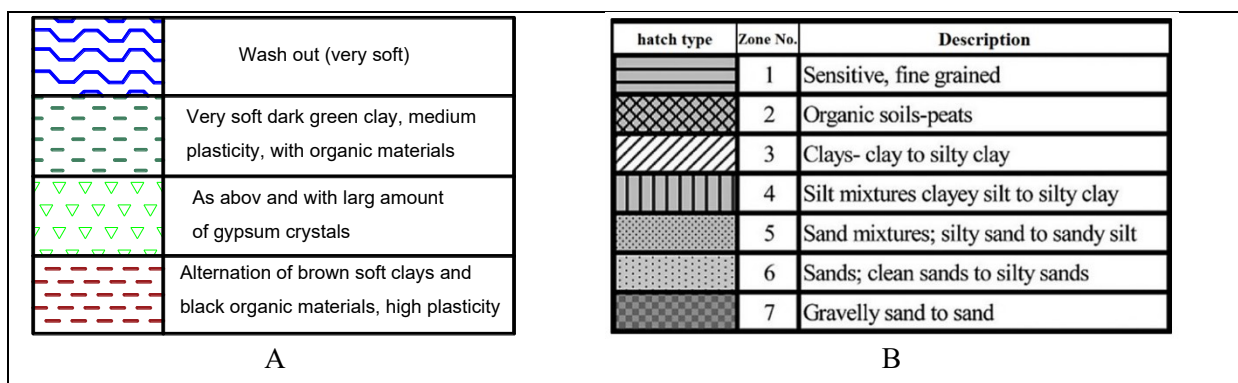


Fig 15. Description of hatches used in soil classification by CPTu (A), and indexes used in logs of boreholes (B)



Fig 16. Samples in core box (a), longitudinal cross section of core (b)

Table 2. Geotechnical properties of the samples derived from boreholes BH-2 and BH-4

Sample no.	BH	Depth (m)	Atterberg Limits		Gs	w (%)	Direct Shear		Su* (kPa)	qu** (kPa)	Cc***
			LL	PI			c (kPa)	φ (°)			
1	BH-2	5	42	23	2.64	40	-	-	-	-	-
2	BH-2	10	44	21	2.61	41	10	9.5	10	25	0.35
3	BH-2	15	47	25	2.68	44	-	-	-	-	-
4	BH-2	20	43	20	2.65	42	11	8	12	28	0.36
5	BH-2	25	52	28	2.64	45	-	-	-	-	-
6	BH-2	30	50	25	2.62	44	12	8.5	14	30	0.4
7	BH-4	5	45	22	2.67	42	-	-	-	-	-
8	BH-4	10	40	21	2.7	43	9.5	9.5	11	21	0.36
9	BH-4	15	43	25	2.63	42	-	-	-	-	-
10	BH-4	20	47	23	2.69	40	12	10	10	28	0.32
11	BH-4	25	48	26	2.65	39	-	-	-	-	-
12	BH-4	30	50	26	2.61	41	10	9	12	29	0.38

\* Vane Shear Test, \*\* Unconfined Compression (Uniaxial) Test, \*\*\* Consolidation Test

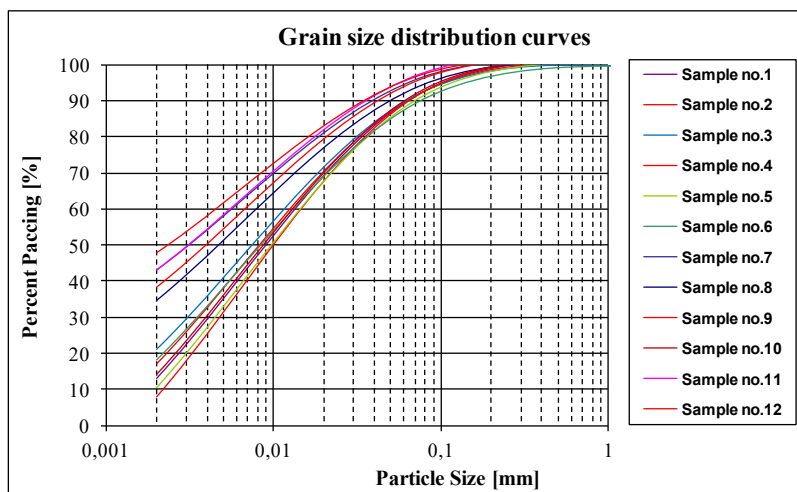


Fig 17. Soil particle distribution curves of samples

Table 3. Abnormal Features in CPTu graphs and Probable Reasons of them

CPTu Borehole	Depth (m)	Abnormal Features	Probable Reasons
DC-3	18-19	Values of $qc$ , $fs$ and $u$ suddenly decrease and return to initial order after approximately 1.5 meters.	<ul style="list-style-type: none"> <li>• Lack of proper calibration of CPTu system</li> <li>• The log of borehole BH-2 is recorded inaccuracies</li> </ul>
DC-7	6.5	Values of $qc$ and $fs$ suddenly increase but the value of $u$ suddenly decreases. Then all of the values return to initial order after approximately 0.3 meters.	<ul style="list-style-type: none"> <li>• Existing a silty thin layer in this depth</li> <li>• The log of borehole BH-4 is recorded inaccuracies</li> </ul>
DC-7	26-30	Values of $qc$ , $fs$ and $u$ suddenly decrease and it seems that probably all of the values return to initial order after approximately 4.0 meter	<ul style="list-style-type: none"> <li>• Lack of proper calibration of CPTu system</li> <li>• Error in data logger system</li> <li>• The log of borehole BH-4 is recorded inaccuracies</li> </ul>

## 6. Conclusion

CPTu test has been developed in recent decades because it is fast, repeatable, economical and free from operator (human) errors. In the present study, the capabilities of the CPTu test for classification of soft sediments of Urmia Lake Bridge site were investigated. To do this, initially, the logs of geotechnical boreholes, excavated in several phases, were studied. The logs indicated that the sediments are composed of fine grained materials (silt or clay) with a considerable amount of organic materials and halite and gypsum crystals. In next stage, the results of CPTu test were employed for classification of the sediments and profiling of the sub-seafloor soil layers. Outcomes showed that the studied soils are comprised of clays- clay to silty clay and silt mixtures, clayey silt to silty clay. The results of these studies were analyzed and compared together. Analysis of the findings showed acceptable consistency between two methods to identify the sediments of Urmia Lake. In the final stage, the findings were validated based on the results of experimental studies. To aim this purpose, current laboratory soil mechanic tests were done on the studied soils. The obtained results indicated that the sediments mostly consist of fine grain materials that are mechanically soft and compressible. Unified classification showed that the samples are mostly CL, ML, CH and MH. According to the obtained results and comparisons and analysis of them, the capability and efficiency of CPTu test to determine the soil type and its classification is emphasized. This means that CPTu test can be used with enough confidence to Identification of the underground soil layers and profiling subsurface (or sub-seafloor) soil layers.

## Acknowledgment

The contributions of Sadra Company, Mandro consulting engineers (for CPTu tests) and P. O. Rahvar consulting engineers are highly appreciated.

## References

- Akca N (2003) Correlation of SPT-CPT data from the United Arab Emirates, *Engineering Geology* 67: 219-231.
- ASTM (2000) Annual Book of ASTM Standard, American Society for Testing and Materials, Philadelphia.
- Begemann HKS (1965) The friction jacket cone as an aid in determining the soil profile. 6th International Conference on Soil Mechanics and Foundation Engineering, Montreal, Quebec, Canada, 1: 17-20.
- Berberian M, Arshadi S (1975) On the evidence of the youngest activity of the North Tabriz Fault and seismicity of Tabriz City, Geological Survey of Iran, Report 39: 397-414.
- Cai GJ, Liu SY, Puppala AJ (2011) Comparison of CPT charts for soil classification using PCPT data: Example from clay deposits in Jiangsu Province, China, *Engineering Geology* 121 (1): 89-96.
- Campanella RG, Howie JA (2008) Guidelines for the use, interpretation and application of seismic piezocone test data, Geotechnical Research Group, Department of Civil Engineering, The University of British Columbia, pp 190.
- Cetin KO, Ozan C (2009) CPT-based probabilistic soil characterization and classification, *Journal of Geotechnical and Geoenvironmental Engineering* 135(1): 84-107.
- Douglas BJ, Olsen RS (1981) Soil classification using electric cone penetrometer, cone penetration testing and experience. Symposium on Cone Penetration Testing and Experience, Geotechnical Engineering Division, ASCE. St. Louis, Missouri, 209-227.
- Eslami A, Fellenius B H (2004) CPT and CPTu data for soil profile interpretation: Review of methods and proposed new approach, *Iranian Journal of Science and Technology (IJST)* 28: 69-86.
- Eslami A, Hosseini B, Eslami M (2010) Soil profiling by CPTu in soft, sensitive soils of Orumiyeh Lake in

- Iran, Second International Symposium on Cone Penetration Testing, Huntington Beach, CA, USA.
- Fugro, (Consulting Engineers) (2004) Geophysical survey and profiling in Urmia Lake, Iran.
- GEAS (Global Environmental Alert Service) and UNEP (United Nations Environment Programme) (2012) The drying of Iran's Lake Orumieh and its environmental consequences, *Environmental Development* 2: 128–137.
- Golpasand MRB (2004) Investigation on the engineering properties of soft soils in the Urmia Lake and comparison with Cone Penetration Test (CPTu) results, M.Sc. thesis, University of Tarbiat Modares.
- Golpasand MRB, Nikudel MR, Asghari E, Yasrebi S (2006) Comparison of CPTu test and laboratory test results in determination of shear strength of Urmia Lake Bridge site soils, *Journal of Geosciences* 15 (60): 12-21 (In Persian with English Abstract).
- Jalali H, Nikudel MR, Nabavi M (2000) The characteristics of the engineering geology of Urmia Lake's soft sediments, *Journal of Geosciences* 9: (35-36), 28-43 (In Persian with English Abstract).
- Jamali M, Beaulieu JL, Shah-Hosseinei M, Anderieu-Ponel V, Ponel P, Amini A, Akhiani H, Leory SAG, Stevens L, Lahijani H (2008) A late Pleistocene long pollen record from Lake Urmia, NW Iran, *Quaternary Research* 69: 413–420.
- Jefferies M, Davies M (1991) Soil classification using the cone penetration test (discussion), *Canadian Geotechnical Journal* 28 (1): 173–176.
- Jones G, Rust E (1982) Piezometer penetration testing CPTu. 2nd European Symposium on Penetration Testing, ESOPTII, 607–613.
- Jung B, Gardoni P, Biscontin G (2008) Probabilistic soil identification based on cone penetration tests, *Geotechnique* 58 (7): 591–603.
- Kelts K, Shahrabi M (1986) Holocene sedimentology of hyper saline Lake Urmia, Northwestern Iran, *Paleogeography, Palaeoclimatology, Palaeoecology* 54: 105-130.
- Lune T, Robertson P, Powell J (1997) Cone Penetration Testing in Geotechnical Practice, First edition, Blackie & Professional, London UK. pp 352.
- Mohajjel M, Taghipour K (2014) Quaternary travertine ridges in the Lake Urmia area: active extension in NW Iran, *Turkish Journal of Earth Science* 23: 602-614.
- Olsen R, Farr J (1986) Site characterization using the cone penetration test. ASCE Specialty Conference In-Situ '86: Use of In-Situ Tests in Geotechnical Engineering, Blacksburg: 854-868.
- Olsen R, Koester J (1995) Prediction of liquefaction resistance using the CPT. International Symposium on Cone Penetration Testing, CPT 95, Linkoping, Sweden, 251–256.
- Olsen R, Malone P (1988) Soil classification and site characterization using the cone penetrometer test. 1st International Symposium on Penetration Testing ISOPT-1. A. A. Balkema, Rotterdam, Netherlands, 887–893.
- Olsen R, Mitchell J (1995) CPT stress normalization and prediction of soil classification. International Symposium on Cone Penetration Testing, CPT95, Linkoping, Sweden, 257–262.
- Powell J, Lunne T (2005) Use of CPTu data in clays/fine grained soils, *Studia Geotechnica et Mechanica* XXVII (3–4).
- Robertson P (1990) Soil classification using the cone penetration test, *Canadian Geotechnical Journal* 27 (1): 151-158.
- Robertson P (2009) Interpretation of cone penetration tests - a unified approach, *Canadian Geotechnical Journal* 46(11): 1337-1355
- Robertson P (2010) Soil behavior type from the CPT: an update. International Symposium on Cone Penetration Testing, Huntington Beach, CA, USA.
- Robertson P, Campanella R (1988) Guidelines for use, interpretation, and application of the CPT and PCPT, UBC Soil Mechanics Series No. 105 Civil Engineering Department, Vancouver, B.C., Canada.
- Robertson P, Campanella R, Gillespie D, Greige J (1986) Use of piezometer cone data. ASCE Specialty Conference In-Situ '86: Use of In-Situ Tests in Geotechnical Engineering, Geotechnical Special Publication GSP No. 6. Blacksburg, 1263-1280.
- Robertson P, Wride CE (1997) Cyclic liquefaction and its evaluation based on SPT and CPT. NCEER Workshop of Evaluation of Liquefaction Resistance of Soils, Technical Report NCEER-97-0022, the State University of New York at Buffalo, 41-87.
- Schmertman J (1978) Guidelines for cone penetration test, performance and design, US Federal Highway Administration, Washington DC, Report, FHWA TS-78-209, 145.
- Schneider J, Randolph M, Mayne P, Ramsey N (2008) Analysis of factors influencing soil classification using normalized piezocone tip resistance and pore pressure parameters, *Journal of Geotechnical and Geoenvironmental Engineering* 134 (11), 1569–1586.
- Senneset K, Janbu N (1985) Shear strength parameters obtained from static cone penetration tests, Strength Testing of Marine Sediments; Laboratory and In-Situ Measurement. ASTM Special Technical Publication, STP, 883: 41–54.
- Shahrabi M, Alavinaini M, Saidi A, Haghypour A (1985) Geological map of the Urmia in Scale 1:250000, Map No. B3. Tehran, Iran: Geological Survey of Iran.
- Treadwell D (1976) The influence of gravity, prestress, compressibility and layering on soil resistance to static penetration, Ph.D. dissertation University of California, Berkeley.