Geopersia ***5** (1), 2015, PP. 45-54*

Assessment of structural sensitivity of Kerman City deposits

Mohammad Reza Aminizadeh Bazanjani, Iman Aghamolaie*, Golamreza Lashkaripour, Mohammad Ghafoori
Department of Geology and Engineering Geology, Ferdowsi University of Mashhad, Mashhad, Iran
**Corresponding author, e-mail: imaneng189@gmail.com*
(*received: 04/03/2014 ; accepted: 26/01/2015*)

Abstract

This research was performed to determine the efficiency effect of sedimentary environment of Kerman City area on soil structure by comparing natural and reconstituted consolidation curves. In this regard, four different criteria such as sensitivity strength, stress sensitivity, Schmertman criteria and the result of the uniaxial compression test were used. The base of these criteria is to compare the results of natural and undisturbed soil consolidation tests. The position of undrained shear strength of Kerman City soils in Iv-Su space was located on the left side of the intrinsic strength line and this confirms that the stress sensitivity of soils is less than the unit. Therefore, the soils in the city subzone are mostly over consolidated, and cementation and chemical bonds have not developed. The swelling sensitivity of fine grained soils based on Schmertman criteria are often less than 2 or slightly larger than 2.5 indicating that the soils of Kerman City subzones have underdeveloped swelling sensitivity due to poor cementation.

Keywords: *Intrinsic Compression line, Sedimentary Environment, Strength Sensitivity, Stress Sensitivity.*

Introduction

The depositional environment is a part of the Earth's surface and has physical, chemical and biological specific property and is distinct from adjacent areas. Therefore, the sediments deposited in the environment have common physical and mechanical properties and varies with its surrounding areas (Selley, 1996). Structure and fabrics are the most effective factors on soil strength and are related to conditions of the sedimentary environment. Natural soils generally are affected by environmental factors, and their structure is formed over a longtime. This structure impacts on the geotechnical parameters of the soil and increases its shear strength (Asghari, 2002). Gens and Nova (1993) defined structured soils as unknown materials; thus determination of their engineering properties is difficult. Boruvka *et al*. (2002) in his study on the vulnerability of structures from moisture, concluded that the stability of soil structure represents an indicator for the quality of soils. Bujang *et al*. (2005) in his study, focused on the effect of chemical admixture materials such as cement and lime on engineering properties (such as uniaxial compression strength) of organic soils in tropical zones and found that cement and lime increase soil strength but reduce the liquid limit. The effects of environment on fabric and structure could be measured by stress sensitivity criteria. Pfleiderer (2005) also outlined the history of sedimentation and digenesis in the estimation and interpretation of the geotechnical property of the Vienna sedimentary basin, Austria. Barański (2008) examined the effect of soil structure on compressibility and resistance of Plvka glacial tills by comparison of natural and reconstituted clay behavior. Amir (1994, 1995) analyzed the effect of silt deposition on the deformation behavior of semi-saturated and unsaturated soils and concluded that the type of deposition, has important roles on the mechanical behavior of materials. The soil sensitivity is an indicator that could be determined by the development of fabric and structure. In addition, stress susceptibility and compressibility of soils indicate the potential degradation rate of natural structured soil.

Sedimentary environment of Kerman City

The physiographic shape of Kerman plain sedimentary environment is formed due to tectonic movements of the Quaternary period. Kerman plain is located in the depression between Kuhbanan-Mahan mountain ranges in the east and Badamo-Davaran in the west and has a Graben structure formed by circumferential reverse faults (Fig. 1). Kerman City is a part of Kerman plain and in the present research all the assessments and analysis were done in the Kerman City area. The Kerman City deposits are formed from fine grained alluvial materials that are mainly silt and clay (CL-ML).

Kerman plain- as a closed environment- received all the flood sediments during the Pleistocene and four major glacial periods were issued from the high areas. Transportation and deposition of flood materials were done proportional to flood energy in depressions and low land areas and formed Kerman plain. In Upper Pleistocene, due to tectonic movements, the conditions of the closed basin varied and the Kerman sedimentary basin sloped gently to the north and north-west direction (Qajar *et al*., 1996). These changes had an impact on the characteristics of soil engineering. In this research, the effect of the changes that occurred in the sedimentation environment was studied on consolidation properties of clayey soil in the Kerman City area.

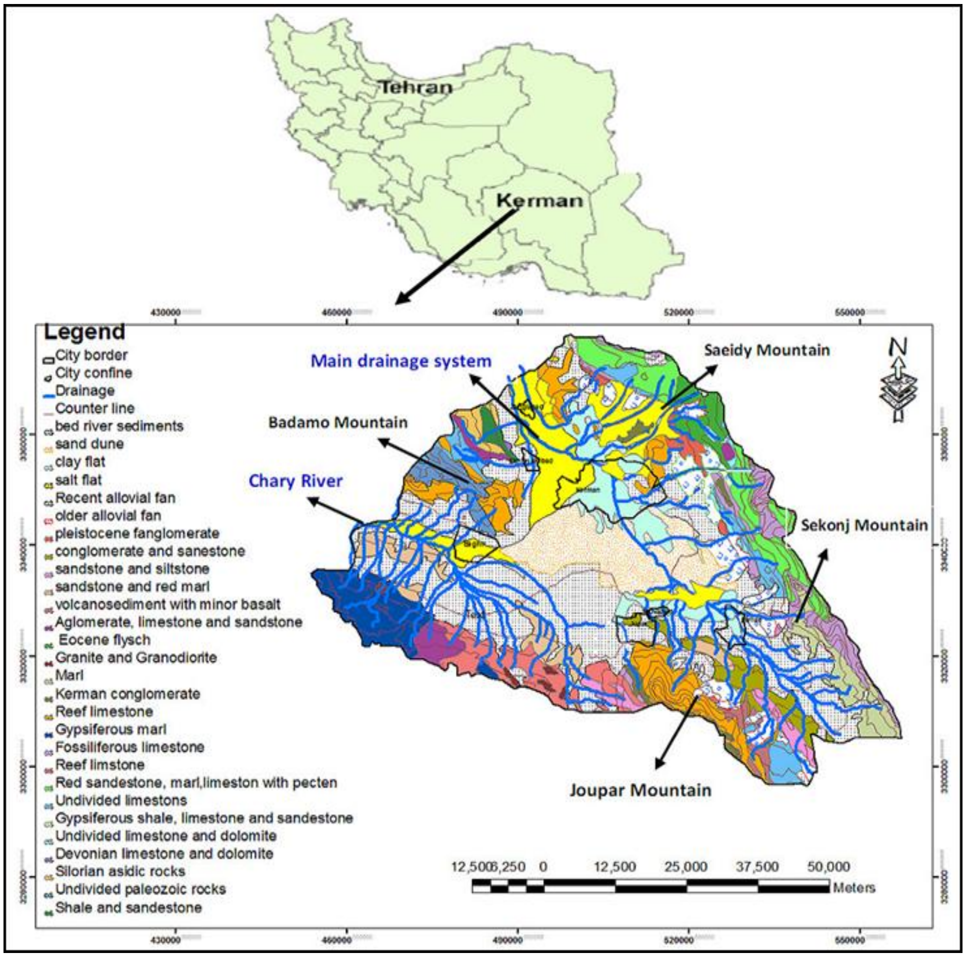

Figure 1. Kerman sedimentary environment reproduced from 1:500000 geological map (Geological organization, 1369)

Materials and Methods

In this research, the necessary scrutiny to assess the stress sensitivity of Kerman City soils was done in different depth and locations (Fig. 2). Therefore, four different criteria were used such as strength sensitivity, stress sensitivity, Schmertman (1969) criteria and results of the uniaxial compression test. Based on the earlier mentioned methods, the results of natural and reconstituted soil consolidation tests were compared to each other. For reconstitution of soils, the undisturbed soil samples were mixed with high moisture content between 1.25 and 1.5 times their liquid limit. Then, one-dimensional consolidation tests were conducted on reconstituted samples and the results plotted in the e-Log (σ`v) space, called intrinsic compression curves. The natural and intrinsic compression curves were based on the different methods used for calculation of soils sensitivity in the sediments.

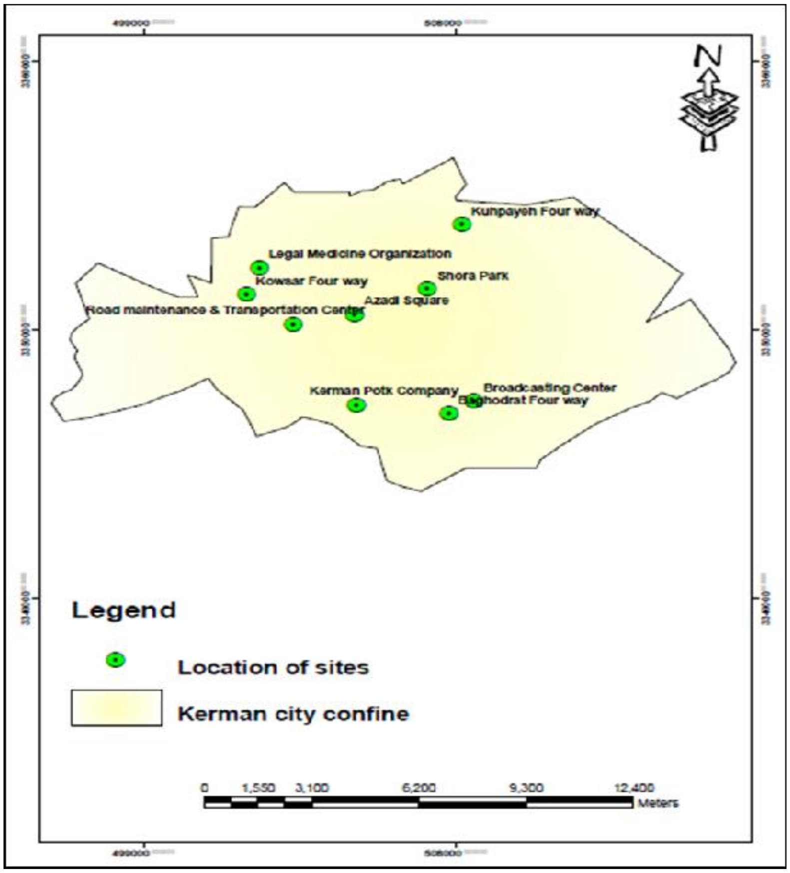

Figure 2. Location map of sampling

Strength sensitivity criteria

Sensitivity resistance of fine-grained and clay soils is a criteria that was proposed by Chandler (2000). To scrutiny of the intrinsic strength sensitivity of fine soils, in the first step, the intrinsic strength sensitivity line was plotted in the Iv-Su space (Fig. 3). Afterwards, the structural sensitivity of soil samples was determined, based on the position of undrained shear strength of any soil samples related to the intrinsic strength line. The intrinsic strength line was achieved by drawing undrained intrinsic strength of reconstituted samples against a void index of natural soil samples in Iv–su space (Heidari, 2001).

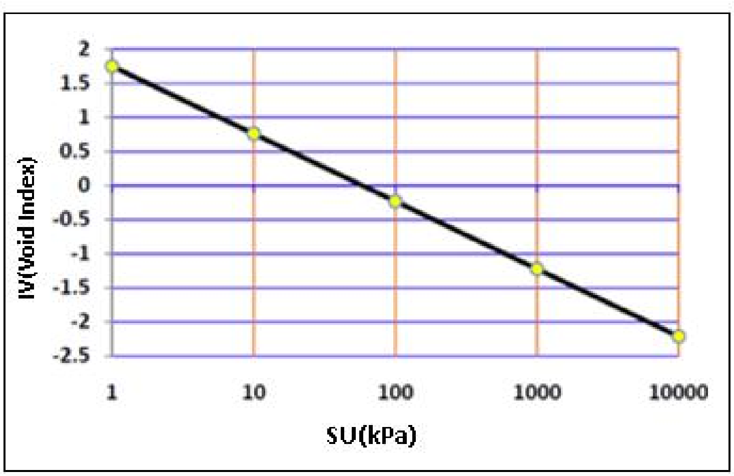

Figure 3. Intrinsic strength line of Chandler (Quoting Heydari, 2006)

The curve of Figure 3 was plotted based on the result of tests performed on reconstituted soils. In reconstituted soils, the roles of fabric and structures were omitted. Therefore, the intrinsic strength line that was presented by Chandler (2000) can be used for all clay soils as a reference line in different sites. As a result, Chandler (2000) intrinsic strength line for studying the stress sensitivity in Kerman City soils was used. For determining the strength sensitivity of Kerman City subzone soils, a number of uniaxial compression tests were performed on the natural soils and then undrained intrinsic strength that is equal to half of the uniaxial compression strength of soils were obtained. One-dimensional consolidation test was also performed on the same samples, and the natural void ratios as presented by Burland (1990), were normalized by means of the void index (Iv) and the *in-situ* void index of soil samples were calculated. Having the values of *in-situ* void index and undrained strength, the position of soil samples was located on the Iv-Su space. The position of a soil sample relative to strength sensitivity line shows the strength sensitivity of soils in the sites. Sensitive strength is determined by use of Equation 1 given as:

E1: St= Su/Su* (1)

where Su and Su* are undrained shear strength of natural and reconstituted soils, respectively. Undrained shear strength of reconstituted soil (Su*) was obtained by transferring natural undrained shear strength to the intrinsic strength line in the same void index (Fig. 4). The study of strength sensitivity of soils was performed in the Azadi Square, office of way and Urbanization and Broadcasting Organization sites in Kerman City (Fig. 4). For each site, the undrained strength and *in-situ* void index were calculated and the results plotted on the Iv-Su space. The position of undrained strength of all the samples was placed in the left of the Chandler intrinsic strength line. Thus, Su*may be larger than Su and therefore the sensitivity strength of Kerman City soils is less than unity (Fig. 4).

The position of soils having undeveloped structures placed in the left of the intrinsic strength line confirms over-consolidation of the soils. The over-consolidation degree variation related to the distance of soil samples is related to the intrinsic strength line in Iv-Su space.

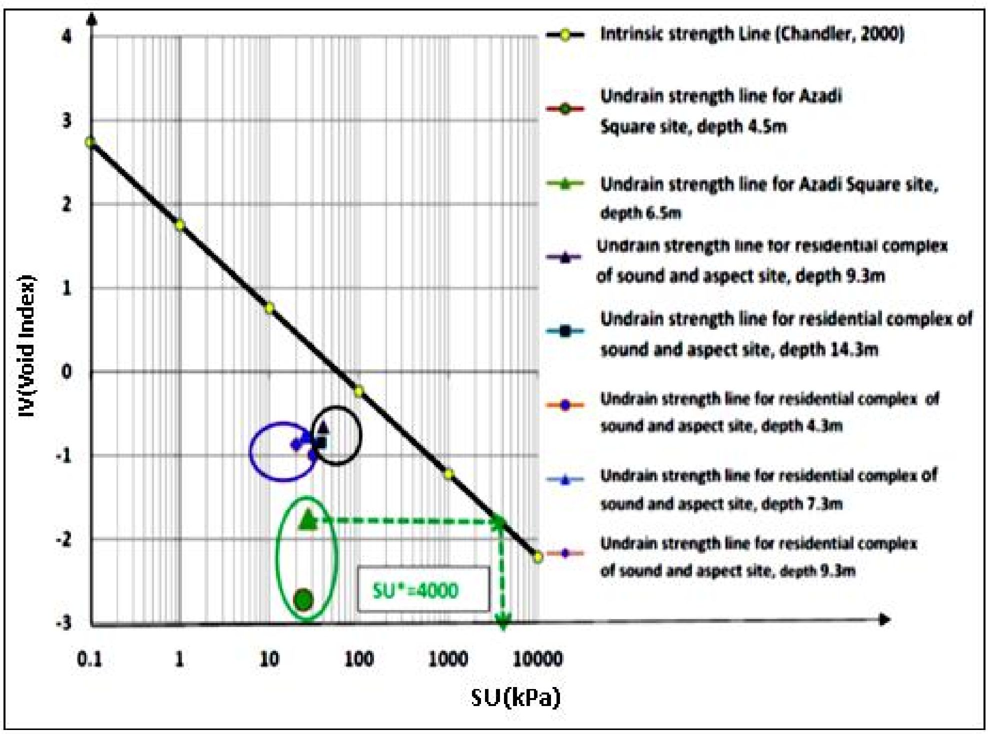

Figure 4. Assessment of soil structure based on strength sensitivity criteria in Kerman city area

According to Figure 4, the soils in Azadi Square as compared to other sites are more compacted and over consolidated. Generally, the initial void ratio and undrained shear strength of the soil are important to determine the degree of sensitivity.

Stress sensitivity

In assessment of the soil structure in Kerman City, the stress sensitivity model as suggested by Skempton (1970) was used. This model was developed by Chandler (2000) and reproduced by Viton and Cotcchia (2010). The mentioned model was used as a framework for expressing the behavior of fine soils based on stress sensitivity. For this purpose, the soil samples were reconstituted at 25 sites in the study area and consolidation tests were performed. Then, using the normalized parameters as suggested by Burland (1990), the intrinsic line of Kerman deposits (Kerman City sediment-ICL) were plotted in the Iv-Log (σ'v) space. Using a stress sensitivity model (Viton and Cotcchia, 2010), and comparison of natural consolidated curves with intrinsic compression line of Kerman City sediments, the parameters of model were extracted. Then, required indicators such as stress sensitivity (Sσ), yield stress ratio (YSR), and *in situ* stress ratio (IsSR) were calculated (Fig. 5).

Figure 6 shows the example of calculation carried out and Table 1 presents the overall

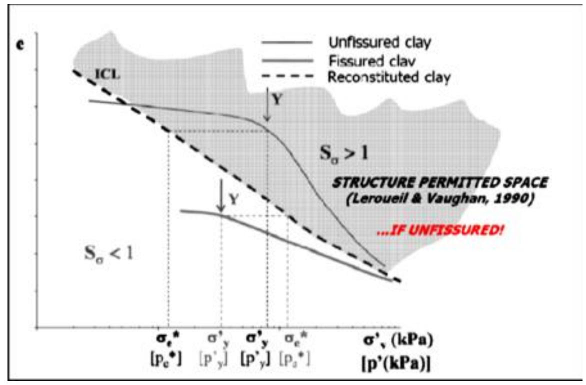

Figure 5. Stress sensitivity zoning considering ICL line (Whiton & Cotecchia, 2010)

computation. Stress sensitivity on Iv-Logσ'v space, is the distance between natural yield stress and vertical stress on the intrinsic compression line (ICL) at the same void ratio as shown in Equation2 (Cotecchia and Chandler, 2000, 1997):

$$S\sigma = \sigma'vy / \sigma'e^* \quad (2)$$

In the stress sensitivity model, the *in-situ* stress ratio (IsSR) and yield stress ratio (YSR) are determined using Equations 3 and 4 (Gaspar, 2005):

$$YSR = \sigma'vy / \sigma'v0 \quad (3)$$

$$IsSR = \sigma'v0 / \sigma'e^* \quad (4)$$

According to the results obtained by this model,

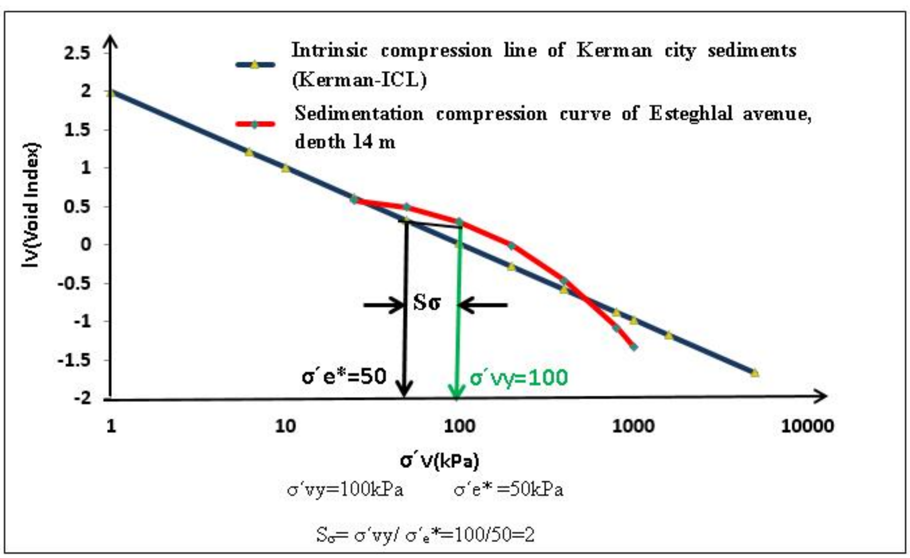

Figure 6. Stress sensitivity analysis in Esteghlal Avenue site, depth 14 m

Equation 5 is established between these parameters:

$$S\sigma = YSR \times IsSR \qquad (5)$$

The natural consolidation curves for studied soils were located mainly on the left of the intrinsic compression line. Hence, on the basis of the proposed model, the stress sensitivity for most samples was less than the unit.

Comparison between stress and strength sensitivity results

Results of strength and stress sensitivity are compared to each other. The result revealed that the value of stress and strength sensitivity for all studied sites was less than the unit, indicating that there is a good consistency between the results of both criteria. The position of *in-situ* stresses was located on the left of the intrinsic compression line, and the undrained shear strength position placed on the left of the intrinsic strength line. Consequently, the soil structure and cementation in Kerman City deposits has not been well developed and soil strength is related to over consolidation process and high compaction. The results of both methods are in accordance with each other. Illustrations of comparison of the results of strength sensitivity with stress sensitivity for soils of Kerman City range are shown in Figure 7 and numerical values in Table 1.

Table 1 Comparison of strength and stress sensitivity in Kerman city soils

No	Depth (m)	Site Location	e_0	Iv_0	σ´v0 (kPa)	σ´vy (kPa)	σ´e* (kPa)	Sσ	SU (kPa)	SU* (kPa)	qu (kPa)	St
1	4-4.45	Azadi Square	0.605	-2.72	75	100	110000	0.001	24	29000	49	0.00083
2	6-6.45	Azadi Square	0.695	-1.746	100	170	10000	0.017	27	4000	53	0.0067
3	9-9.45	Road maintenance & Transportation Center	0.786	-0.755	150	150	2000	0.075	36	260	73	0.1384
4	14-14.45	Road maintenance & Transportation Center	0.778	-0.844	205	220	1000	0.22	35	400	71	0.0875
5	4-4.30	Broadcasting Center	0.764	-0.99	80	140	4000	0.035	31	500	62	0.062
6	7-7.30	Broadcasting Center	0.776	-0.863	115	120	3000	0.04	25	250	50	0.5
7	9-9.30	Broadcasting Center	0.775	-0.87	160	190	2000	0.095	22	300	44	0.073

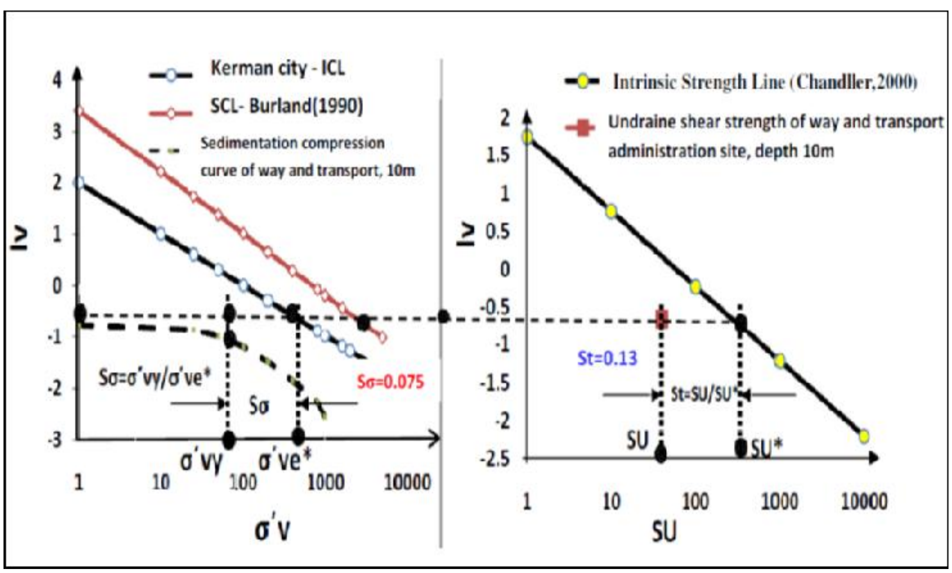

Figure 7. Comparison of stress and strength sensitivity in Kerman Broadcasting site, depth 10m

The results of strength sensitivity analysis showed the undrained strength generally placed in the left of the intrinsic strength line (Chandler, 2000). This revealed that the structures of the studied soils have not been developed and the soils are highly compressive and over-consolidated.

Stress sensitivity criteria of Schmertman (1969)

It should be noted that, the compression index (Cc) represents the slope of the curve of void ratio versus the logarithm of effective pressure beyond the maximum past effective stress. Also, the swell index (Cs) represents the slope of the rebound curve of void ratio versus the logarithm of effective pressure. Compression and swell index are conventionally determined by laboratory oedometer tests, used for the calculation of consolidation settlement of over consolidated fine grained soils. Furthermore, the swelling sensitivity is the swelling index ratio of natural and reconstituted clay soils (Cs*/Cs) in low stress level (after yield point) (Schmertman, 1969). The soil structure can be realized based on difference in soil swelling of natural and reconstituted samples. Hence, the swelling index is used to estimate the consolidation settlement for over consolidated fine grained soils (Nihan, 2009).

If the swelling index ratio of natural and reconstituted clay soils is less than 2, the cementation and sensitivity of soils are low. However, the soil sensitivity and cementation is high if the swelling index is greater than 2.5 and this shows that soil sensitivity and cementation is high (Heidari, 2001). For calculating the soil sensitivity of Kerman City deposits with (Schmertman, 1969) criteria, the natural consolidation curves were plotted. Then, the soil samples were reconstituted with high water content about 1.25 to 1.5 times the liquid limit. Afterward, one-dimensional consolidation tests were performed, and intrinsic consolidation curves plotted in e-Log ($\sigma'v$) space. Consequently, swelling index was calculated for natural and reconstituted soil samples. From the division of intrinsic swelling index to natural swelling index (Cs*/Cs), the swelling sensitivity criteria was calculated. Examples of the calculation method are illustrated in Figures 8 and 9 and all of the results are listed in Table 2.

Table 2. Swelling Sensitivity of Kerman city fine-grained soils

No	Site location	Depth (m)	Intrinsic swelling index	Natural swelling index	Swelling sensitivity criteria
1	Legal Medicine Organization	12	0.03851	0.01410	2.731
2	Legal Medicine Organization	18	0.03202	0.02341	1.367
3	Legal Medicine Organization	20	0.02224	0.00984	2.2559
4	Legal Medicine Organization	26	0.02305	0.02139	1.077
5	Broadcasting Center	4	0.03258	0.0282	1.155
6	Broadcasting Center	14	0.02898	0.02077	1.395
7	Broadcasting Center	20	0.01367	0.00566	2.415
8	Kerman Potk Company	8	0.02665	0.02059	1.294
9	Kerman Potk Company	18	0.04328	0.01961	2.206
10	KuhpayehFour way	13	0.02091	0.00740	2.823
11	ShoraPark	10	0.01842	0.00948	1.942
12	Shora Park	30	0.02477	0.00935	2.648
13	ShoraPark	40	0.03633	0.01307	2.779
14	KowsarFour way	8	0.02639	0.01473	1.791
15	KowsarFour way	24	0.00643	0.00619	1.038
16	KowsarFour way	30	0.02352	0.01752	1.342
17	BaghodratFour way	18	0.05058	0.02426	2.084

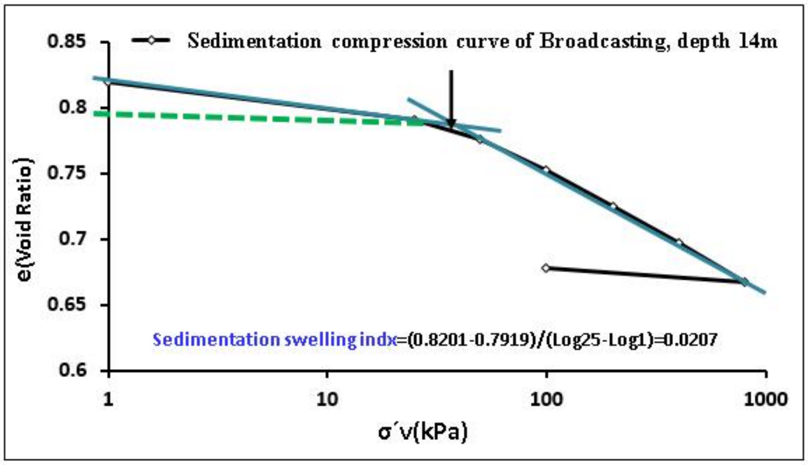

Figure 8. Sedimentation Swelling Index of Broadcasting site, depth 14 m

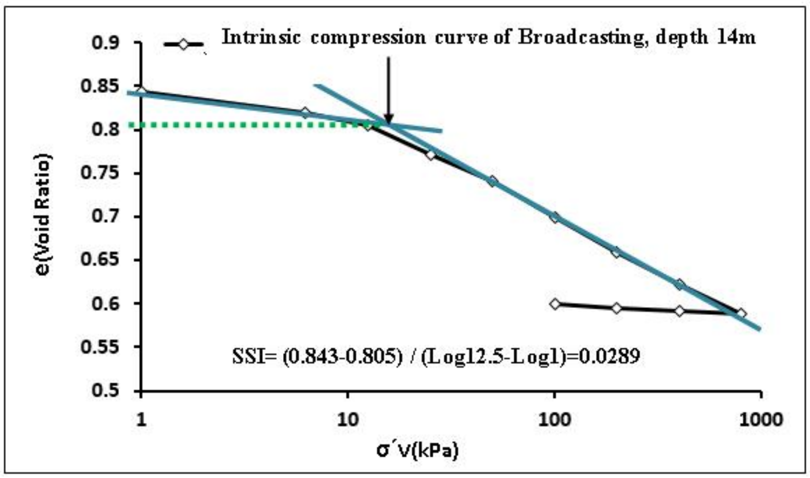

Figure 9. Intrinsic Swelling Index of Broadcasting site, depth 14 m

In these criteria, the limit between stable and unstable soil structure is 2. Based on Table 2, the swelling sensitivity for Kerman City subzones soils is less than 2 or slightly larger than 2.5. Therefore, the sensitivity swelling of soils is low and have poor cementation and non-development structure.

Uniaxial compression result

For sensitivity analysis of soil structure in Kerman City deposits using the uniaxial compression tests, the uniaxial compression strength of natural and reconstituted samples are compared to each other. Hence, two natural samples to Azadi Square site were prepared in depths of 6 and 10 m, and uniaxial compression strength tests performed on them. They were then reconstituted with moisture content higher than liquid limit and intrinsic uniaxial compression strength of the samples determined (Fig. 10 and 11). After that, the average uniaxial compressive strength in both natural and reconstructed soils was calculated and overall sensitivity obtained. The experimental results showed that the soils can be considered with low sensitivity as listed in Table 3. The average of undrained shear strength of soil sensitivity in natural and reconstructed samples can be calculated by means of some equations.

The sensitivity tests showed that the studied soil can be considered as a component soil with low sensitivity, because of the clay minerals. In addition, the decrease of the resistance of some samples at various depths can be ascribed to microscopic cracks and joints found in the Kerman City soils.

Table 3. Result of uniaxial compressive test in undisturbed and reconstituted soil samples

No	Location	Depth(m)	Uniaxial compressive strength of natural sample qu(kg/cm^2)	Uniaxial compressive strength of Reconstituted sample qu*(kg/cm^2)	Sensitivity value St=qu/qu*
1	Azadi Square	6-6.45	0.5656	0.1194	4.737
2	Azadi Square	10-10.45	0.4113	0.330	1.244

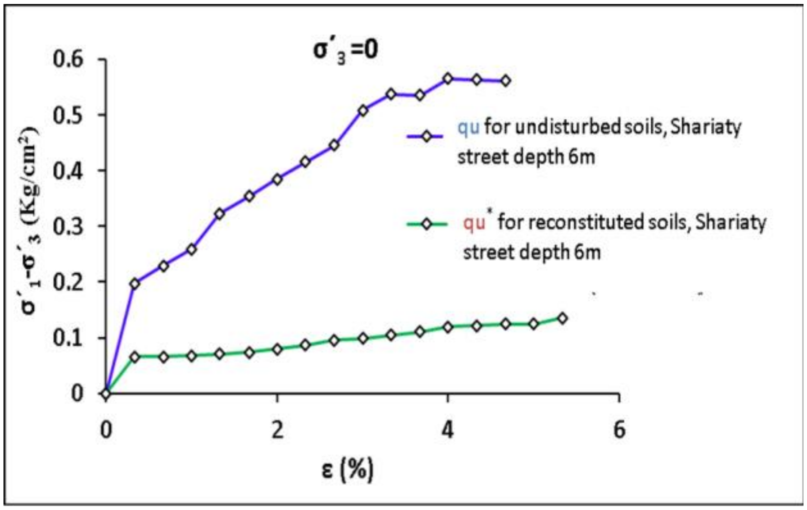

Figure 10. Natural and reconstituted uniaxial stress- strain curves (Shariaystreet, depth 6m)

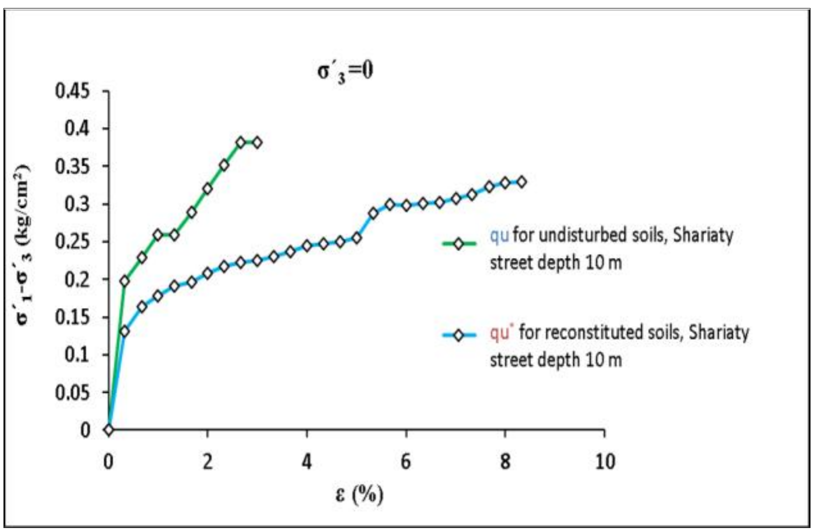

Figure 11. Natural and reconstituted uniaxial stress - strain curves (Shariaystreet, depth 10 m)

Conclusions

1. The study of Kerman city soils showed that the position of undrained shear strength of soil samples in the Iv-Su space is located on the left of the intrinsic strength line. The degree of over consolidation is related to the distance of the soil sample's position from intrinsic strength line in the Iv-Su space. According to the results obtained, the Azadi Square site samples are more compacted and over consolidated compared with other sites.

2. Assessment of structural sensitivity of soils by stress sensitivity model showed that the natural sedimentary consolidated curves on Iv-Log (σ'v) space are mainly located on the left of the intrinsic

compression line. Therefore, the stress sensitivity for most cases is less than the unit, which is a confirmation for over consolidation and compaction of soils in Kerman City sediments.

3. Assessment of structural sensitivity of soil using Schmertman's (1969) criteria, indicated that the sensitivity swelling of soils varied, and is often less than 2 or slightly greater than 2.5. According to this criterion, number 2 is the border limit for sensitive and stable structure soils. Hence, the Kerman City subzone deposits have poor cementation and low swelling sensitivity.

4. The mean stress sensitivity values of uniaxial compressive strength in both natural and reconstituted state, showed that the soils have relatively low sensitivity and the structures did not develop significantly.

References

Amirsoleymani, T., 1994. Deposition and behavior of partially saturated silt.Proc. of 1st International Symposium on Engineering Characteristics of Arid Soils, London, pp. 207-214.

Amirsoleymani, T., 1995. Influence of deposition on deformation of Unsaturated Soils. .Proc. of the first International Conference on unsaturated soils, 2: 687-694.

Asghari, A., 2002. Effects of cementation on the shear strength and deformability Tehran coarse grain soils. PhD thesis, Department of Geology, Faculty of Sciences, Tarbiat Modarres University, 252pp.

Barański, M., 2008. Engineering-geological properties of normally consolidated tills from Płock area. Geologija Vilnius. 50: 40-48.

Boruvka, L., Valla, M., Donatova, H., Nemecek, K., 2002. Vulnerability of soil aggregates in relation to soil properties, Rostlinna Vyroba, 48: 328-329.

Bujang, B.K., Huat, S.M., Thamer, A.M., 2005. Effect of chemical admixtures on the engineering properties of tropical peat soils. American Journal of Applied Sciences, 2: 1113-1120.

Burland, J. B., 1990. On the compressibility and shear strength of natural clays Geotechnique, 40: 329-378.

Chandler, R.J., 2000. Clay sediments in depositional basins: the Geotechnical cycle, Quaterly Journal of Engineering Geology and Hydrology, 33: 7-39.

Cotecchia, F., Chandler, R.J. 1997. The influence of structure on the prefailure behaviour of a natural clay Géotechnique, 47: 523-544.

Cotecchia, F., Chandler, R.J., 2000. A general framework for the mechanical behaviour of clay Géotechnique, 50: 431-447.

Gens, A., Nova, R., 1993. Conceptual bases for a constitutive model for bonded soils and weak rocks, Proc. Int. Symp. on Geotech. Engere. of Hard Soils-Soft Rock, the Netherlands, and Balkema, Rotterdam.1: 485-494.

Heidari, M., 2001. The relationship between mechanical properties and structure offine-grained soils of southern Tehran, PhD thesis, Engineering Geology, Faculty of Sciences, Tarbiat Modarres University, 310pp.

Nihan, S.I., 2009.Estimation of swell index of fine grained soils using regression equations and artificial neural networks**,** Scientific Research and Essay. 4: 1047-1056.

Pfleiderer, S., Hofmann, T., Auer, J., 2005. Geological interpretation of geotechnical properties of sediments in Vienna basin, Geophysical Reserch Abstracts.

Qajar, M.H., Nazemzadeh, M., Azizan, H., Rowshanravan, J., 1996. The history of Kerman Basin during the Neogene and Quaternary, GSI, Regional Center for S.E. Iran (Kerman), 74 pp.

Schmertmann, J.H., 1969. Swell sensitivity, Geotechnique. 19: 530-533.

Selley, R. C., 1996. Ancient sedimentary environments and their sub-surface diagnosis, 4th ed.

Skempton, A.W., 1970. The consolidation of clays by gravitational compaction. Q. J. Geological Soc. 125: 373-411.

Viton, C., Cotecchia, F., 2010. On the geotechnical characterization of a stiff medium fissured clay from Italy, 21st Alert Geomaterials Workshop, Aussois, 4-6 October, Technical University of Bari, Italy.