International Journal of Mining and Geo-Engineering

IJMGE

IJMGE 52-2 (2018)

Investigating the Effect of Sedimentary Basin on Consolidation of the Kerman Fine-Grained Soils

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Article History:

Received: 20 April 2017,

Revised: 07 March 2018,

Accepted: 16 March 2018.

ABSTRACT

In this research, the effects of a sedimentary basin, environmental conditions, and the passage of time were investigated on consolidation processes and engineering characteristics of fine-grained soils in Kerman city. For this purpose, the natural consolidation curves of soil samples extracted from different locations of Kerman city were compared with the intrinsic consolidation line (ICL) of the city. To obtain the ICL, 25 soil samples were taken from several locations and depths of the study area and were mixed with a high water content equivalent 1.0 to 1.5 times their liquid limit. Then, one-dimensional consolidation tests were performed on reconstituted soils. Using the normalizing parameter (void index) proposed by Burland and the ICL of the Kerman city deposits, the results of consolidation tests were plotted on a Iv- Log(σ́v) space. To investigate the effects of the sedimentary basin on engineering properties of fine-grained deposits in Kerman city, natural sedimentation compression curves were compared with the ICL of Kerman soils. This comparison was applied in three regions along the paths of rivers that supply the fine sediments of the Kerman plain. The results have shown that the soil structure and fabric have not been developed abundantly and the effect of the sedimentary model has caused the compression.

Keywords : *Sedimentary model, intrinsic compression, fabric, over-consolidation, Kerman city*

1. Introduction

Because of the widespread geotechnical characteristics of fine-grained soils, their examination is a challenging issue in the planning and construction of structures. The fine-grained soils are formed in a special sedimentary basin, where the depositional environment and time factors affect their engineering parameters. In this regard, it is very important to consider the role of depositional environment on geological and geotechnical characteristics of soils. Many studies have been conducted to assess the in-situ mechanical behaviors of natural sedimentary soils [1-4]. Evaluating the impacts of soil structure on mechanical behavior for natural sedimentary clays is an important issue in geotechnical engineering [5]. It has been widely recognized that natural sedimentary soils, due to the effect of soil structure, have different behavior from reconstituted soils [6-8]. Soils and other granular materials are known to be sensitive to the material fabric such as the topology of the internal structure of the material. In geomechanical studies, the fabric has been qualitatively described, and its changes have frequently been discussed through macroscale observations of the soil response [9]. Burland (1990) [1] introduced the concept of "Intrinsic Properties" to describe the strength and compressibility characteristics of reconstituted clays. He also defined the intrinsic compression line (ICL) as the one-dimensional consolidation slope in e–log (σ´v) space of a clay sample reconstituted from an initial water content equal to about 1.0–1.5 times the liquid limit (LL). By reconstituting the sample at a high initial water content, the soil ideally loses all its "memory" related to the soil structure. This concept is well understood and has important implications for interpreting geologic effects on the engineering behavior of fine-grained soils. Natural sedimentary soils generally behave differently from reconstituted soils due to the effect of the soil structure [6, 7]. The properties of these reconstituted clays were termed "intrinsic" since they were thought to be inherent to the soil and independent of the natural state and are not influenced by the soil structure (fabric and bonding). Aminizadeh et al. (2016) evaluated the effect of depositional environments and geological history of the engineering properties of the sediments of Kerman city through a large number of triaxial tests on reconstituted soil moisture greater than LL and different confining pressures, consolidated drained, and consolidated undrained conditions. Comparing the curves of stress-strain in natural and reconstituted samples indicates that in many cases, the behavior of intact and reconstituted soils was similar and the cementation and soil structure have not been much developed [10]. Tremblay et al. (2001) assessed the strength improvement by adding lime to clay soils of eastern Canada. For this purpose, he normalized the consolidation curve, drew the best fit line on the IV- log(σv́) space, and achieved the ICL due to the effect of lime adding to clay soils [11]. Barański (2008) [12] prepared the ICL for reconstituted Vistula Glaciation Tills from Płock, via a normalizing process proposed by Burland (1990). The properties of glacial Tills include structural and intrinsic parameters of compression and strength, which are used as the engineering-geological and geotechnical model to provide a consistent framework for the interpretation of site investigation data from tests on these extremely variable soils. Cerato and Lutenegger (2004) [13] obtained the ICL of fine-grained soils using the void index suggested by Burland (1990). Burland (1990) fitted a regression line through the natural sedimentation compression curves determined by Skempton (1970) [14] and identified a unique

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Sedimentation Compression Line (SCL). The SCL of the natural soils is parallel to the ICL and lies above it, because of the structure developed by natural soils during the sedimentation process. Moreover, the distance between ICL and SCL, called the "sedimentation sensitivity", is a measure of the acquired strength of the natural sediments with respect to the strength of the reconstituted clay. The Kerman city area has widespread fine-grained soils. The mineralogy, shape, particles distribution, and engineering characteristics of fine-grained soils are different in the Kerman plain. Such a difference is due to the geological properties, such as the bedrock mineralogy, sediment transporting factors (wind, water, glacial), transporting distance, the age of sediments, as well as the posture of grains, weathering, and faulting on geotechnical characteristics. Hence, the sedimentary environment factors have an important influence on the engineering parameter of fine-grained soils. Although general studies and several investigations have addressed the geotechnical and geological engineering of fine grain soils, the relationship between this characteristic with geological history and the sedimentary basin is not well investigated. Therefore, to the best of authors' knowledge, there is no scientific report in the literature about the influence of the sedimentary basin on engineering properties of fine-grained soils in the Kerman city area. In this study, we applied an overconsolidation process for interpreting the past events of the Kerman city sedimentary basin.

2. Summary of sedimentary model in the Kerman plain

Kerman city is located in the southeast of Iran in the north of the Kerman plain (Fig. 1). The physiographic shape of the Kerman plain sedimentary basin is developed due to tectonic movements of the Quaternary period. The Kerman plain is located in the depression between the Kuhbanan-Mahan mountain ranges in the east and Badamo-Davaran in the west and has a graben structure formed by circumferential reverse faults. All assessments and analyses of the present study were performed for Kerman city, which is part of the Kerman Plain.

The Kerman deposits are composed of fine-grained alluvial materials that are mainly silt and clay (CL-ML). The Kerman plain, as a closed basin, has received all the flood sediments from the heights during the Pleistocene and four major glacial periods. The transportation and deposition of flood materials have been made proportionally to the flood energy in depressions and low land areas and formed the Kerman plain. In the upper Pleistocene, due to tectonic movements, the conditions of the closed basin varied and the Kerman sedimentary basin sloped gently toward the north and northwest [15].

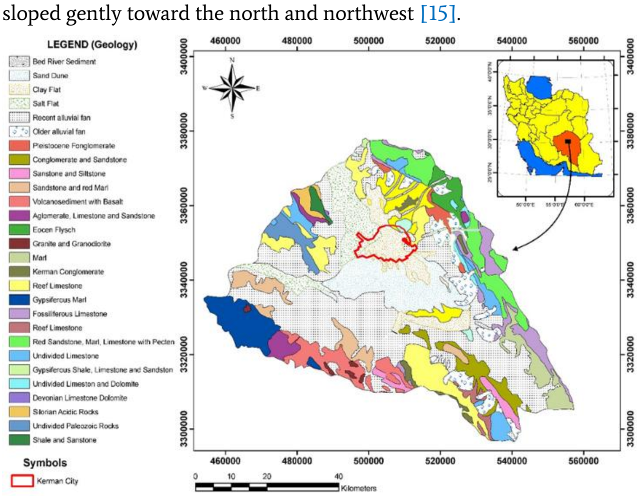

Fig. 1. Geological sedimentary basin map of the Kerman area.

3. Materials and Methods

In this research, to assess the effect of sedimentary basin model to engineering characteristics of soils in Kerman city, we compared natural sedimentation curves with the ICL of the Kerman city sediments (Kerman city-ICL). To plot the normal consolidation curves, we used the results of undisturbed consolidation test data already performed by geotechnical laboratories in Kerman province. In addition, to cover the full data, 12 standard consolidation tests performed by Geotechnical and Soil Mechanics Laboratories of Kerman province on undisturbed soils.

The consolidation curves of each test were normalized with a void index proposed by Burlnd (1990) and plotted in an Iv-Log (σ'ν) space, followed by extracting ICL of the Kerman city deposits. The results of natural consolidation tests were compared with the ICL of the Kerman city soils in three regions.

3.1. Intrinsic compression line of Kerman city sediments

To plot the ICL for the Kerman city fine-grained soils (Kerman-ICL), 25 disturbed samples were collected from 11 proper sites in the Kerman city area (Fig. 2). Afterward, each sample was mixed with a high amount of water (between 1.0 and 1.5 times of the liquid limit of the material, preferably 1.25 times). The samples were aerated and oven dried prior to the reconstituting. The prepared slurry was poured into a one-dimensional consolidation test and was consolidated by vertical static loads applied to the samples. Then, the void ratios for different levels of stress were calculated and consolidation curves of all samples were drawn together in void ratio versus vertical stress space (i.e., e-log(σ′v)) plots. Subsequently, we obtained two important quantities when dealing with the intrinsic compression curve; i.e., e*100 and e*1000, which are the mean intrinsic void ratios corresponding to the values of effective stress σ′v = 100 kPa and σ′v = 1,000 kPa, respectively. The intrinsic compression index Cc* is defined as e*100 - e*1000.

Due to the differences of the void ratio, liquid limit, and mineralogy of sediments in various depths, the ICL curves for reconstituted clay soils plotted in an e-logσ′v space are different and cover a wide range (Fig. 3).

Therefore, in order to achieve a single ICL as a basis for comparison of natural and reconstituted soils, we used the normalizing parameter proposed by Burland (1990). This normalizing parameter, which is called the void index (Iv), is calculated using Eq. 1:

$$IV = \frac{(e - e^{*}100)}{(e^{*}100 - e^{*}1000)} \tag{1}$$

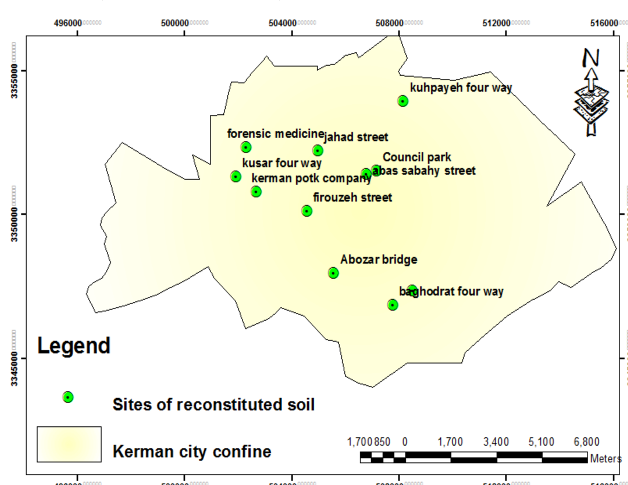

Fig. 2. Characteristics of sampling sites in Kerman city.

The normalized results were plotted in the Iv-Log (σ'ν) space and the best-fitted ICL for the Kerman city fine-grained sediment (ICL-Kerman) was obtained using Eq. 2 (Fig. 4).

$$IV = 1.998 - 0.43Ln(\sigma'v) \tag{2}$$

The equation of Kerman-ICL has a suitable overlap with the ICL proposed by Burland (1990), are slightly different in primary parts at low stresses (Fig. 5).

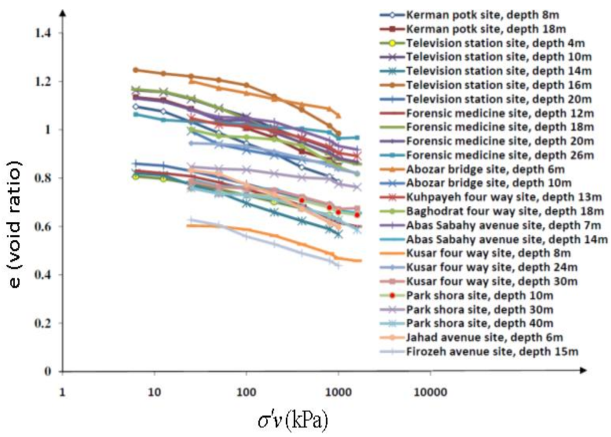

Fig. 3. Kerman-ICL in the e-Log(σ`v) space.

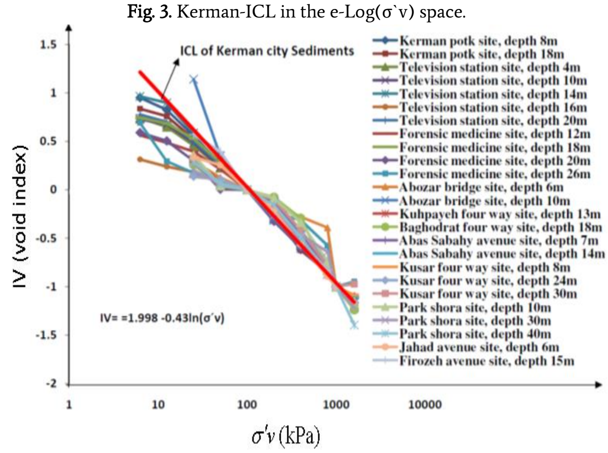

Fig. 4. Extraction of Kerman-ICL in the e-Log(σ`v) space.

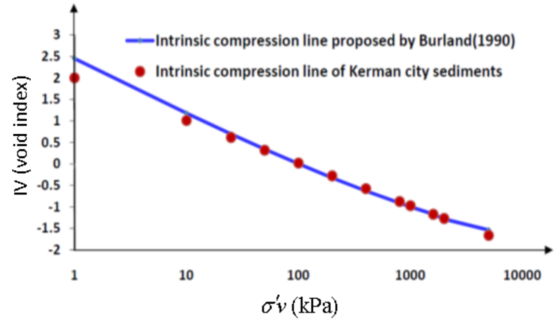

Fig. 5. Comparison of Burland (1990) ICL with Kerman-ICL.

3.2. Effect of sedimentary basin model on engineering properties of Kerman fine grained soils

To investigate the effect of sedimentary basin model on engineering properties of the Kerman city soils, we initially prepared the location map of all sites from which undisturbed samples were extracted and subjected to the consolidation tests. Then, according to the sedimentary model of Kerman city and proportional to various rivers that cause the deposition of sediments in the Kerman plain, three proper regions were chosen that cover the whole area of Kerman city. The sedimentary consolidation curves were compared with ICL of the Kerman city deposits (Kerman city-ICL) in these regions. Table 1 shows the situations of sites chosen for comparing the results of sedimentation compression curves (SCCs) with Kerman-ICL.

The results distinguish the role of depositional environment in the compression and consolidation of fine sediments in Kerman city, according to their origin and the transport distance. Fig. 6 shows the distribution map of sites at which consolidation tests were conducted on the natural undisturbed soil samples and regions for which the sedimentation compression curves (SCCs) with ICL are compared.

Table 1. Situation and abbreviation code of the sampling regions.

Region	Site Location	Longitude	Latitude	Code	Region	Site Location	Longitude	Latitude	Code
Eastern Region	Haft bagh	514009	3341486	E1	Middle Region	Pars hotel	502371	3349642	M7
	Azad University	507733	3342569	E2		Villa avenue	503739	3350841	M8
	Jupar four way	507815	3345212	E3		foresty city	502837	335018	M9
	Sound and aspect	507724	3346763	E4		Shafa four way	553302	3350222	M10
	Baghofrat four way	508517	3347346	E5		Shafa avenue	503013	3350531	M11
	22 Bahman	506743	334722	E6		Valfajr avenue	503955	3350533	M12
	Asiabad four way	505520	3347958	E7		Nader street	504655	3350582	M13
	Motahary avenue	506375	3349452	E8		Friday street	504119	3350901	M14
	Abas sabahy avenue	508600	334907	E9		1001 night avenue	503339	3350894	M15
	Shora Park	507888	3349966	E10		Forensic medicine	502330	3352321	M16
	Kuhpayeh four way	505425	3349972	E11	Western Region	Railway bridge	500987	3347682	W1
	Bazargany four way	506952	3350284	E12		Kerman airport	496150	3347721	W2
	Abozar bridge	506818	3351388	E13		Besat town	497850	3348071	W3
	Esteghlal avenue	507183	3315330	E14		Shokuh town	497612	3348312	W4
	Nader avenue	508017	3353909	E15		Elahiyeh1 town	499845	3348582	W5
Middle Region	Bazargany four way	504692	3347713	M1		Elahiyeh2 town	499499	3348615	W6
	Motahary town	503211	3347930	M2		Alghadir stadium	498686	3348732	W7
	Foresty park	502113	3348600	M3		Beheshty hospital	501365	3349462	W8
	Coal company	502212	3349023	M4		Coal residential	498195	3349691	W9
	Teacher bridge	502721	3349316	M5		Kusar bridge	499113	3350513	W10
	Oil company	503752	3349608	M6		Kusar four way	501433	33511621	W11

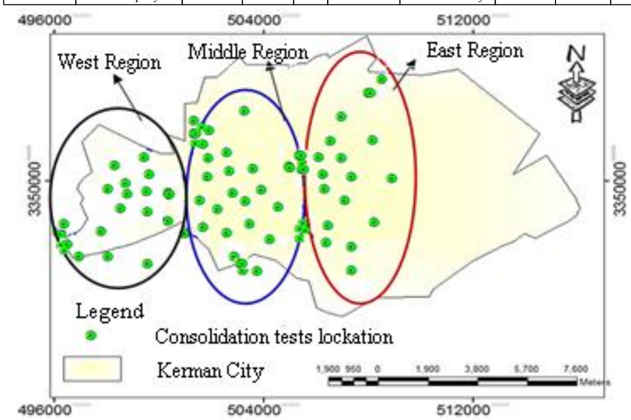

Fig. 6. The position of three Regions in the Kerman city range.

3.3. Soil consolidation in eastern region of Kerman city sediments

This area is located in the east of Kerman city (Fig. 6) along the path of the rivers originated from the Joopar Mountains in the south of Kerman city. The sediments deposited in the Kerman plain are transferred by rivers originating from the Joopar and Sekonj mountains. Therefore, they generate a higher share of deposits (Fig. 1). In this region, the results of natural consolidation tests of 15 sites were compared with the ICL results of the Kerman city soils (Kerman city-ICL). The results of this comparison are shown in Fig. 7. As can be implied, the sedimentation compression curves (SCCs) along the eastern region have been located in the left of ICL. This subject shows that in this region, the soils are over-consolidated with a high over-consolidation ratio. The degree of over-consolidation increases from the upstream to downstream river basin, which is in a good agreement with the sedimentary basin model of Kerman city. The over-consolidation process in the Kerman plain from the margin toward the center of the plain indicates an increasing trend. This is proved through comparison of the results of natural sedimentation compression curves with Kerman city-ICL in E1, E2, E6, and E11 sites.

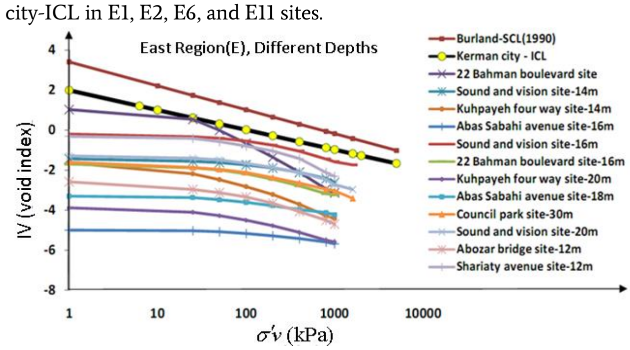

Fig. 7. Comparison of SCC curves to Kerman-ICL for the eastern region of the city at different depths.

3.4. Soil consolidation in Central Region of Kerman city sediments

This region includes the central part of Kerman city. To investigate the effects of the sedimentary basin model on the soil structure, four horizons were selected from depths 4, 8, 12, and 14 m. Then, the results of natural sedimentation compression curves (SCCs) were compared with those of experimental ICL of the Kerman city sediments (Kerman-ICL) in 16 sites. The results show that in the central part of the Kerman plain, the soils are generally compact and over-consolidated. Although the effect of the sedimentary basin, as the over-consolidation process, is not clearly understood on the cementation and soil structure and the fabric, the effect of cementation, fabric, and soil structure can be detected in the middle part of this region. . Due to the formation of cement in the soil, the sedimentation compression curves close to Kerman city-ICL and sometimes because of the formation of soil structure and bonding, they intersect each other in sites M4, M10, and M12 (Fig. 8).

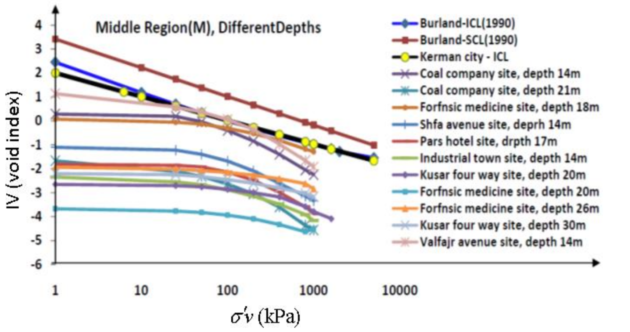

Fig. 8. Comparison of SCC curves with Kerman city-ICL for the central region of the city at different depths.

3.5. Soil consolidation in western region of Kerman city sediments

This region is located in the western part of Kerman city. Fig. 9 compares the natural sedimentation compression curves at 11 different sites with experimental Kerman-ICL. The results show that the degree of soils over-consolidation increases in the western part of Kerman city (west region). However, in some parts of the western region, like W10, the degree of consolidation of soils is less than the evolution of the structure and fabric. In sites W3 and W1, the SCCs curves are closer to the Kerman-ICL line and the soils are mostly normal consolidated. In these kind of soils, if the bonds between the soil particles are produced after the primary sedimentation without applying the surcharge, namely, the cementation occurred in-situ or after the final arrangement of the soil particles. Therefore, the distance between SCCs and ICL lines will be negligible and may intersect each other.

Generally, the results of comparison between the natural compression curves (SCCs) with Kerman city-ICL show that the same whole trend of consolidation processes in the Kerman city soils is governed in the western region of Kerman city.

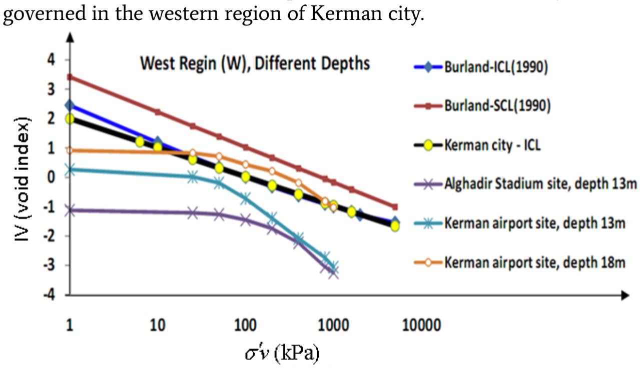

Fig 9. Comparison of consolidation curves to Kerman-ICL in the western region at different depths.

In an area that natural compression curves are closer to Kerman-ICL and the position of samples are located in the left side of Kerman-ICL, the soils are more compacted and over-consolidated. However, in some sites of the western region that are farther from the main rivers of the Kerman plain, (e.g., W2 and W4), the soils are mainly normal consolidated and contain a structure and fabric; moreover, natural consolidation curves are closer to Kerman-ICL. For site W7, the natural consolidation curve is located on the right side of the ICL.

4. Conclusion

Comparison of natural sedimentation compression curves (SCCs) with experimental Kerman-ICL shows that in three regions of the study area, the fine-grained sediments are generally compacted and over-consolidated. The existence of chemical bonds and cementation in soils has not been developed very much. In the eastern region, near to the main rivers of the Kerman plain, the over-consolidation process is dominant because of sediments turbulence, erosion processes, and water flow deviation are more active than the other phenomenon. In regions far from the main river of the basin, the phenomena such as the cementation and chemical bonds are normal and the soil structures are slightly developed. Within the western region, some sites like W2, W4, W7, W1, W3, and W10, natural sedimentation compression curves shift toward the right side of ICL; therefore, the soils in these sites are mostly normal consolidated, and in some samples, the cementation process, fabric, and soil structure are also developed. Effects of the depositional environment and the sedimentary basin model of the Kerman plain have probably caused sediments to be compacted and over-consolidated. It is due to the changes in the depositional environment of sediments in a different period of sedimentation and transporting the previous deposits that had an important role in compaction of the underlying sediments in the past. The sedimentary basin of the Kerman plain in the late Holocene leaves the closed basin state. Thus, today, the drainage system flows toward the North of the Kerman-Zarand valley. Hence, a part of the sedimentary basin deposits that had affected the consolidation of fine sediments in the Kerman plain was transported to the downstream area. Therefore, today, without the existence of a significant surcharge on the Kerman deposits, the soils are often in an over-consolidated state. The position of SCCs and experimental ICL of the Kerman soils emphasize that the fine-grained soils in Kerman city are mainly over-consolidated. In this regard, the cementation of the primary sedimentation shows an expectable, but limited, development.

Acknowledgement

The authors would like to express their gratitude to the Department of Soil Mechanics of the Kerman Province for providing the necessary data.

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