J. Basic. Appl. Sci. Res., 1(12)2979-2986, 2011
© 2011, TextRoad Publication

ISSN 2090-4304
Journal of Basic and Applied Scientific Research
www.textroad.com

Engineering Geology Criteria for Evaluation and Classification of Loess in Golestan Province

Hamed Rezaiy[1,*], Gholam Reza Lashkaripour[1], Mohammad Ghafoori[1]

[1]Department of Geology, Faculty of Sciences, Ferdowsi University of Mashhad (FUM), Mashhad, Iran

ABSTRACT

What discriminates loess from other soil types is lack of stratification, as well as uniformity of their particles, which makes them to be easily identified in field. An area of approximately 388,000 hectares of Golestan province in Iran is covered by three types of loess with sedimentology and geotechnical characteristics. A group of geological properties and transfer processes, sedimentation manner, along with physical, mechanical, and chemical characteristics of loess, which control its geotechnical properties, have been considered as engineering geology criteria. Among such criteria, those such as mechanism and distance of transfer, texture, dry density, plasticity properties, void ratio, compressibility, mineral and chemical composition, and structure of loess can be mentioned. Based upon these criteria, properties of loess in three zones have been evaluated and it was indicated that the conditions of geological origin and sedimentation considerably control the geotechnical soil behavior. Structure and skeleton of loess in the three zones were completely different in comparison with each other, which provide a suitable and easy field criterion for recognition.

KEY WORDS: Loess; Geotechnics; Engineering geology; Golestan Province; Iran

1. INTRODUCTION

Loess is aeolian deposit which is generally composed of homogeneous and angular particles. Size of particles is often similar to silt (50 – 90%) and they are accompanied by illite clay and sometimes sand. These sedimentations are recognized by lack of stratification and homogeneous sorting in field. Loess is classified into three groups, including silt, clay, and sand groups (Jinfeng at el., 2006). They are generally composed of quartz, feldspar, calcite, dolomite, mica, as well as iron and magnesium minerals and clay compounds. Due to chemical corrosion of iron minerals, loess is observed in yellow or brown color. Angularness of loess particles and alleviation manner cases high porosity (up to 50%). These particles are adhered together by smaller particles and produce a relatively firm honeycombed structure with right or even greater angles in dry conditions (Derbyshire et al., 1988).

In engineering behavior, loess soils are considered as problematic materials and the collapse phenomenon is a common risk in this type of soil (Sariosseiri et al., 2009). Numerous studies have been carried out in this regard, including the effect of soil structure on behavior of loess (Gerard et al., 2007), effect of intergranular cement on mechanical strength of loess (Sariosseiva et al., 2009), influence of climate and secondary changes (Derbyshire, 1997) and study of the effect of physical characteristics on their deformation properties (Reznik., 2007).

Loess in Golestan Province with high thickness and area of 388,000 hectares has covered more than 17% of the province area (Feiznia at el., 2005). Based on sedimentology and geotechnical characteristics, loess of the province are extended in the three zones 1, 2, and 3 (Fig. 1).

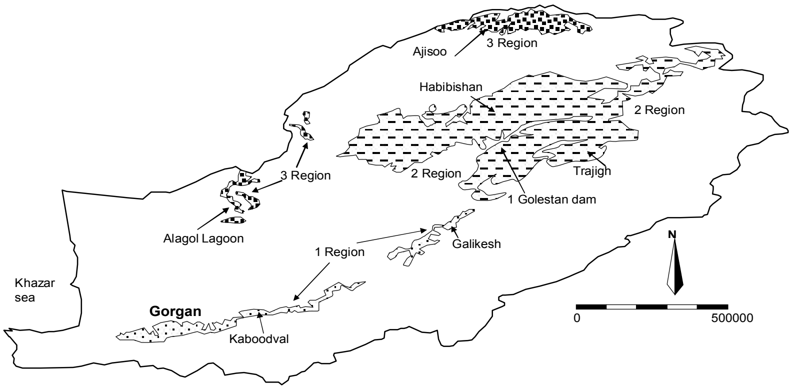

Fig.1. Extension of loess deposits in Golestan Province (Feiznia et al, 2005).

***Corresponding Author:** Hamed Rezaiy, Department of Geology, Faculty of Sciences, Ferdowsi University of Mashhad (FUM), Mashhad, Iran. Email: rezaiy.hamed@gmail.com

Being away from their origin as well as decreased wind energy has dispersed loess soils and the factors changing the soil's structure were differentiated in three areas with different climates. Along with geotechnical characteristics of soil, these factors have discriminated loess soils in these three areas. Carrying out the study and geotechnical evaluations obtained from studies of the location of civil projects in different points in the three mentioned zones, engineering geology criteria were identified and defined which are elucidated in this paper. This study is the outcome of experiments in more than 7 regions and approximately 400 meters of excavation.These criteria can function as a guide in engineering study of loess soils (Derbyshire, 2001).

2. Engineering geology criteria of loess

In order to study the geotechnical characteristics of loess soils in the three mentioned areas, we made use of the results obtained from the experiments performed on soils acquired from different depths of boreholes in seven regions, and they were compared. At each point, numerous experiments were carried out, including Particle size and engineering classification of soil according to the Unified Soil Classification System, study of soil texture, determination of unit volume weight, measurement of plastic properties (LL, PL), calculation of void ratio (e) and porosity (n), performing experimental density test by proctor method, measurement of the constituent minerals, and chemical analysis (Table 1). To compare the areas, averaging of the mean results was used. These experiments and studies were carried out to study the feasibility of implementing water structures, especially dams, and some of the obtained results of this study were used for this purpose.

The reading procedure is on book base and includes experimental results, the procedure of expanding of Province Loess soil, and ago results that concludes in results and discussion.

Table1. Several experiments performed on soils of different areas in Golestan Province.

Experimental zone		Seeding	Special weight	Paste characteristics	Density	Proctor Density	Mineralogy	Chemical decomposition
Kaboodval dam	Zone 1	15	11	18	5	8	4	2
Galikesh	Zone 1	12	17	23	4	5	2	3
Tarajigh	Zone 1	5	9	12	1	3	1	2
Golestan dam 2	Zone 2	12	21	15	2	8	2	2
Golestan dam 1	Zone 2	17	45	14	6	6	2	1
Agi-Su dam	Zone 3	15	21	9	4	5	4	1
Alagol	Zone 3	8	25	6	6	7	2	2
Sum	3	84	149	97	28	39	17	13

3. Engineering Geology Criteria of Loess

The geological characteristics, transfer and formation processes, as well as physical, mechanical, and chemical properties of loess which control their geotechnical characteristics have been considered as engineering geology criteria, which include: mechanism and distance of transfer, texture, dry density, plasticity properties, void ratio, compressibility, mineral and chemical compositions of loess, and their structure (Jefferson at el., 2004).

3.1. Transfer Mechanism

Wind is the cause of transferring loess (Jinfeng at el., 2006). The loess particles are sedimented after passing a distance when the wind energy is equal to weight of particles. These particles move from origin toward sedimentation locations in form of dust, hovering, or rolling. In time of sedimentation, the only ruling force on particles is their weight and these particles are accumulated together gently without horizontal movement. After a while, the dust particles in larger particles cause binding of the grains. The sedimentation surface has the same slope with the initial topography (Fig. 2).

Fig.2. Mechanism of loess sedimentation has the same slope with the topography of sedimentation environment (western border of Gorgan City).

3.2. Transfer Distance

Davidson and Schiller have shown that, changes in grain size distribution and characteristics of loess are related to distance from their origin (Derbyshire at el. 1997). In loess of the province, by moving in directions of N-S, NW-SE, and W-E, a gradual decrease is observed in size of particles. Loess facies changes sequentially from loess sand to sand loess and clay loess. By moving from west to east of the province, size of particles becomes smaller (Fig. 3a) and the same holds in moving from south to north, such that the percentage of passed particles through sieve 200 in grain size distribution test reduces (Fig. 3b). Origin of the province's loess is believed to be Qaraqum desert in Turkmenistan to the north because (1) the beds become thicker and coarser-grained in that direction, (2) the deposits mostly cover northward facing hills and plains (Okhravi and Amini, 2001).

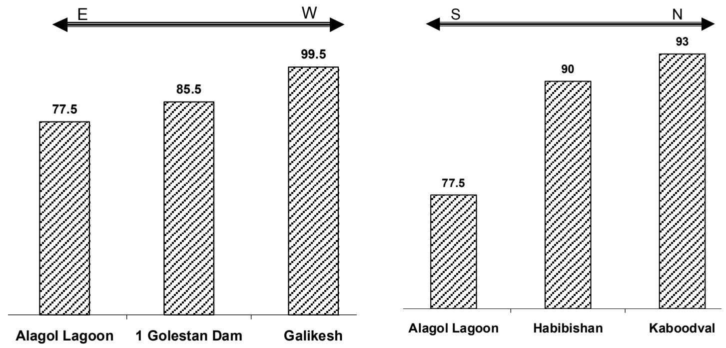

Fig.3. The percentage of passed particles through sieve 200 in directions E-W and N-S.

3.3. Texture of Loess

The grain size distribution curve indicates the soil texture. Loess sediments generally include 50-90% particles with size of silt, and more than three forth of the studied loess is in the range of silt, while one fifth of the rest is clay and the remainder is sand. Grain size distribution in the three zones greatly follows the transfer distance, such that the regions of Alagol Lake, Numal Dam, Habib-Ishan, and Golestan Dam which form the west and central part of the loess coverage region have sand particle sizes greater than those in eastern parts which are sedimented with more distance from the origin (Table 2) and the clay content relatively increases from zone 3 to zone 1. Distribution of particles indicates that, the province's loess is mostly of silt loess type (Fig. 4).

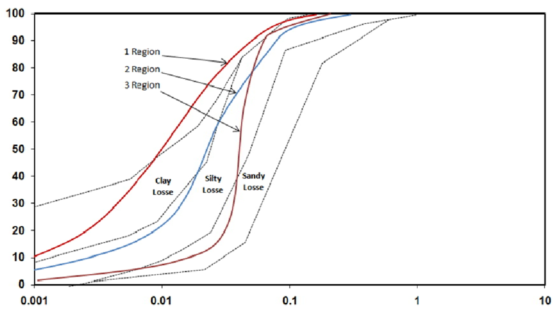

Fig.4. Grain size distribution contour of different types of loess.

Furthermore, by studying the difference between minimum and maximum percentages of grain size distribution in the three zones (Table 3), it is indicates that the difference is greater in zones 3 and 2, compared to zone 1. It can so be interpreted that by increasing the distance from origin, uniformity of particles enhance and size interference reduces.

Table2. Particle size distribution of loess soils in regions of the three areas in the province (north to south direction)

State	Sand	Silite	Clay	Province
Agisu dam	1-8	82-89	10-23	3
Golestan dam 2	5-14	63-76	10-33	2
Galikesh	3-7	60-62	31-37	1

Table3. Difference in minimum and maximum Particle size distribution of loess soils in each area

State	Sand	Silite	Clay	Province
Agisu dam	7	7	13	3
Golestan 2 dam	9	13	23	2
Galikesh	4	2	6	1

3.4. Dry Density (γ_d)

The range of dry density of the province's loess is 1.24 – 2.13 g/cm^3. Loess of zones 1 and 3 have the highest and lowest dry densities, respectively (Fig. 5), since increasing the clay content enhances the soil density and reduces the porous space in it. Nevertheless, in loess of zone 3 due to being composed of sand and silt, honeycombed are formed in them which increase porosity and decrease the density.

Lutenger and Halberg (1988) have reported the range of changes in Peorine instable loess as 1.34 – 1.55 g/cm3, and loess of zone 3 are to some extent in this range. When these materials get wet or compressed, soil structure is broken and its density increases up to 1.6 g/cm^3 (Northmore et al., 1996).

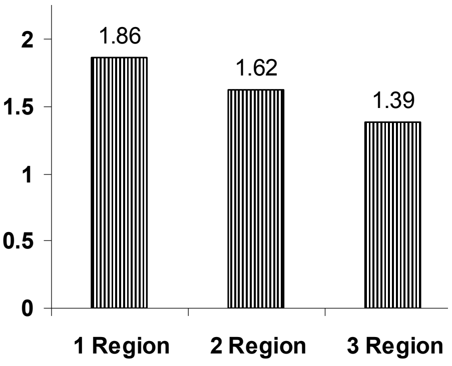

Fig.5. Values of natural dry density for the province's loess (g/cm3).

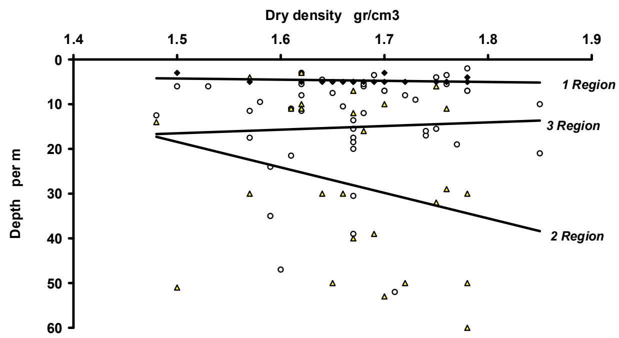

Fig.6. Changes in density versus depth in the province's loess.

Studies show that, density changes versus depth are different in the three mentioned zones, such that its changes versus depth are constant in loess of zones 1 and 3 (Fig. 6) while in zone 2 by increasing the depth, density enhances linearly. It is observed that the increase in distance from origin results in an enhancement in density.

This situation can be so interpreted that, existence of high clay content in zone 1 cause's initial cohesion and creation of the required density during sedimentation and due to continuous sedimentation, the overburden does not lead to exerting pressure on lower layers. However, in loess of zone 2, due to being composed of silt and weakness of the cement binding between grains, overburdening of lower layers makes them compressed during sedimentation. Also in loess of zone 3, because of being the grains large, compression follows immediate settlement and occurs during sedimentation. In other words, it seems that uniformity causes compression in sedimentation phase. It is believed that, sedimentation conditions mostly control the geotechnical behavior of soil.

3.5. Plasticity Characteristics

In loess, plasticity characteristic generally changes from low to medium. Gibbs and Holland (1960) have noted that the plasticity limit of loess is about 25-35% and it sometimes reaches 45%, while its plasticity index takes place in the range of 5-22%. The samples studied in the three zones of the province's loess have medium values of plasticity limit and plasticity index, as Fig. 7 demonstrates. By adding the average value of the samples in plasticity chart, all values are above line A, which indicates that the province's loess are of inorganic soils with plasticity index of low to medium and shows that the soil is very sensitive against moisture changes (Fig. 8).

By increasing the clay percentage in loess, plasticity limit and natural density enhance linearly. In this case, the soil's moisture in saturation condition becomes lower than soil's moisture in plasticity limit and

therefore the soil remains stable even in saturation condition (Miller at el., 2007). This claim can also be proved using the following relation. In saturated condition, the following relation holds among the parameters:
$e = \omega G_s \Rightarrow G_s = e / \omega$

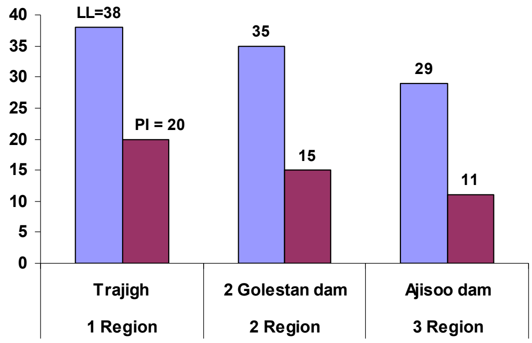

Fig.7. Medium values of plasticity limit and plasticity index in the province's loess.

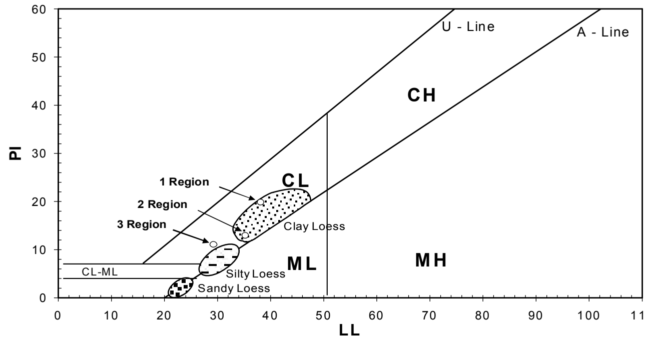

Fig.8. Position of the province's loess in plasticity chart.

Since the e / ω ratio is always constant, so if the soil's moisture in plasticity limit becomes higher than the natural moisture in saturation, value of e in plasticity condition should increase so that this ratio will remain constant. On the other hand, e is constant in saturation condition, so loess remains stable in this condition.

3.6. Void Ratio (e)

Some Chinese loess have void ratio in the range of 0.81 < e < 0.89 and porosity in the range of 45% < n < 47%; also Libyan loess have void ratio in the range of 0.84 < e < 0.91, which show similarity between values of the two regions (Jinfeng et al., 2006). However, the range of changes in void ratio in the province's loess is broader compared to the two mentioned regions, and also it has lower mean value (Fig. 9).

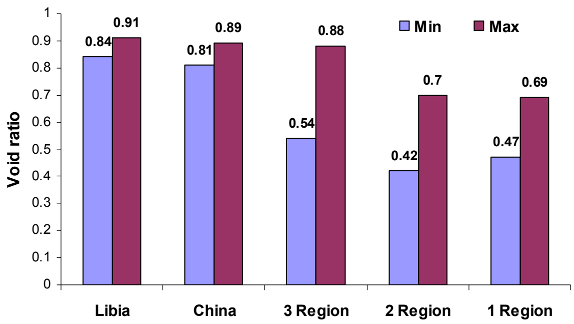

Fig.9. Comparison of void ratio between the province's loess and those in China and Libya.

3.7. Compaction

Compaction of fine-grain soils is related to their chemical and plastic characteristics, besides the compaction effort. Loess of the three mentioned zones have different densities, as a function of their clay content, such that density of loess in zone 1 is more than that in zone 3 (Fig. 10). Furthermore, the maximum dry density obtained in proctor test has direct relationship with value of natural density, which indicates that it is related to its mineralogical and geological characteristics (Fig. 11).

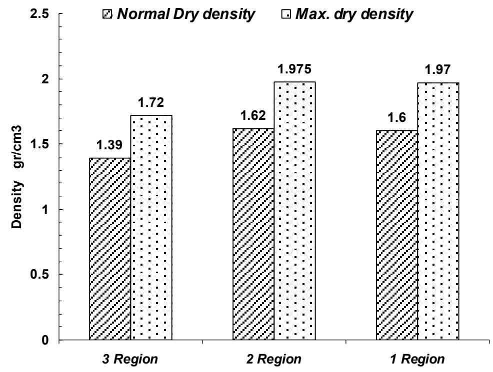

Fig.10. Comparison of natural dry density and maximum dry density of loess in the three zones of the province.

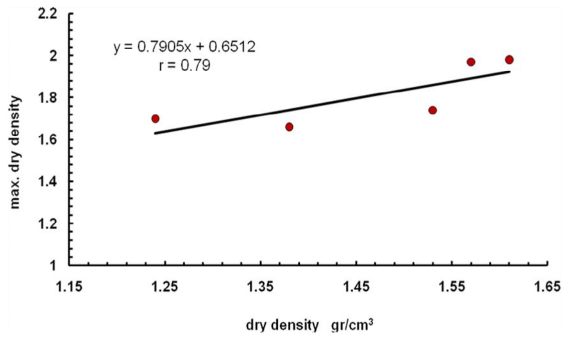

Fig.11. The relationship between maximum dry density and natural density of the province's loess.

Although content of clay minerals in loess of zone 3 is lower, the optimum moisture is higher than that in the two other zones (Fig. 1). It can be concluded that moisture absorption is not related to mineralogy of loess in zone 3, rather it is related to soil viscosity and effect of moisture in moistening the surfaces; in loess soil of zone 3, higher moisture is required for reaching the maximum dry density. Since the soil is of silt type, it has recessive behavior during exerting energy and needs higher moisture between its layers. Change of density versus moisture in zone 3 is less compared to other zones while it is similar in zones 1 and 2 (Fig. 12b).

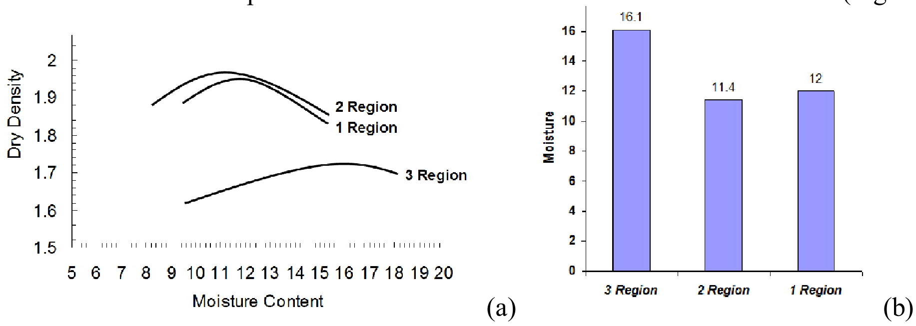

Fig.12. Changes in loess moisture in the three zones (a) and compaction curve (b).

3.8. Mineralogical and Chemical Composition

In fine-grained materials, mineralogical and chemical composition is an effective factor on engineering behavior (Northmore et el., 1996). Through studying the contents of the minerals constituting the province's loess (Table 4), it is indicated that the amounts of feldspar and clay minerals are different in the three zones. The feldspar content decreases from zone 3 to zone 1, which may be attributed to higher chemical degradation in zones 1 and 2 due to more rainfall. In addition, the content of mica and clay minerals in zone 1 has a significant difference with that in the two other zones. In many regions in the world, mineralogical composition of loess is identical to a high extent (Feda, 1988).

Table4. Percentage of the minerals constituting the loess soils of the province.

State	Feldspar	Calcite	Dolomite	Mica and Clay Minerals	Quartz
1	8	25	0	3.4	**61**
2	9.7	29.6	0	2	**58.7**
3	**13**	**20.9**	**1.6**	**1.1**	**64.5**

Furthermore, the two factors of underground water (Ghergherechi et al., 2008) and climate (Feiznia et al., 2005) can influence the amount and type of clay minerals of loess soils.

Comparing the abundance of clay minerals in zones 1 and 2, it is observed that there are significant differences in content of different clay minerals, such that les in zone 2 lacks the clay mineral smectite; the content of minerals illite and kaolinite is also different in the two zones; however, chlorite content is not much different between the two zones.

Using the soil chemistry tests, the oxides related to loess of the three zones under study were measured (Table 5). The content of SiO2 is different in the three zones, such that it decreases from zone 3 to zone 1. It can be concluded that SiO2 content is a function of grain size and decreases by increasing the distance from origin. Also, MgO content in zone 1 shows higher value in comparison with the two other zones. The other oxides do not exhibit much change in the three mentioned zones (Fig. 13).

Table5. Chemical analysis of oxides of loess soils of Golestan Province.

State	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	L.O.I
1	45.22	11.49	13.42	4.44	4.40	**16.90**
2	48.62	11.21	13.36	4.50	1.43	**15.97**
3	**54.84**	**9.54**	**11.12**	**3.43**	**2.22**	**13.59**

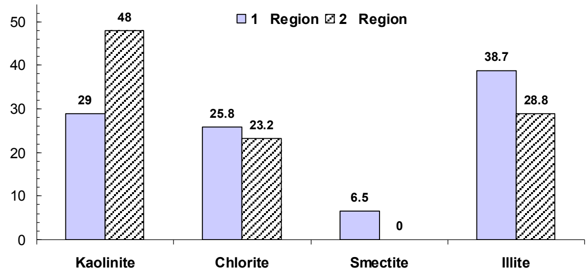

Fig.13. Abundance of clay minerals in loess of zones 1 and 2 in Golestan Province.

3.9. Structure of Loess

Study of soil structure for determination of soil characteristics has been increasingly carried out in recent years, as a factor determining the soil behavior (Leach, 1974). Herein, structure means the appearance and skeleton of loess mass in field. In field study, it was observed that loess in zone 1 with higher clay content compared to the two other zones have a brittle structure and have cracks similar to igneous rocks. This status is easily observed in new trenches (Fig. 14). With increase in depth, the density and continuity of these cracks is reduced. The mentioned cracks caused high permeability of soil in Lufrance test. It should be noted that, these cracks are different from upstream tensional cracks and have relatively high resistance against erosion. Their walls remain stable for a long time in vertical status. Also, its color is dark brown or dark red.

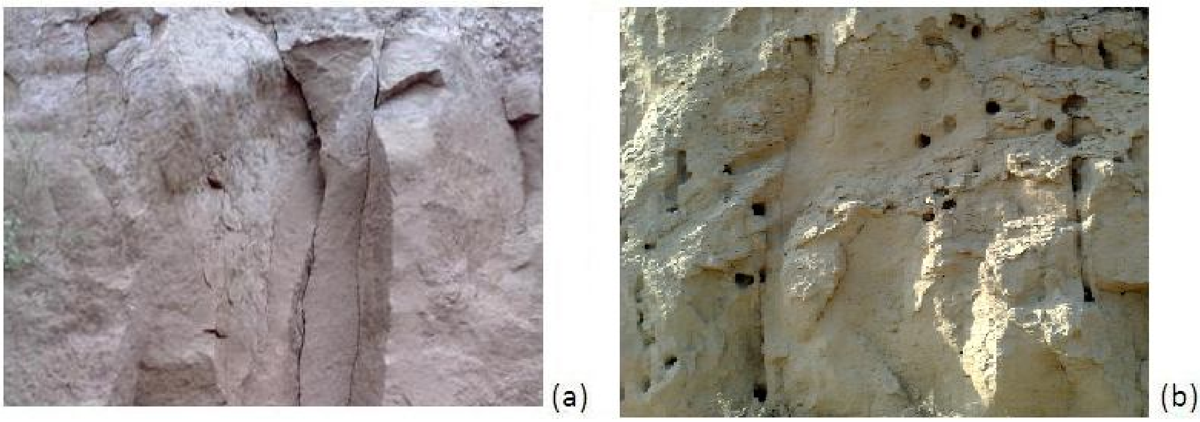

Fig.14. Structure of loess in zones 1 and 3 in Golestan Province.

Loess in zone 2 have a soft and hollow skeleton and its morphology forms hills with small and medium size and gently becomes weatherworn due to erosion factors. Mostly, erosion creates broad valleys. The color of such loess is generally buff. Loess in zone 3 is highly hollow with high porosity and is easily dissociated with small forces. Many of the formed trenches are places for birds' nest. They erode fast due to surface flow and pit erosion takes place in them (Fig. 14b).

4. Conclusion

1. More than 17% of the area of Golestan Province in north Iran is covered by loess, which is divided into three zones 1, 2, and 3, based upon sedimentation and geotechnical characteristics.
2. During sedimentation, the loess constituent grains are only under the influence of their weight and they were sedimented with the same slope with the sedimentation environment.
3. In the province's loess, a gradual decrease is observed in size of grains from west to east and from north to south. This means that with increase in distance of particles from their origin, their uniformity and density enhance and the soil density increases.
4. Loess in zone 1 has higher clay content and the size of most loess particles in the province is like silt.
5. Sedimentation conditions control the geotechnical behavior of soil to a high extent.
6. With increase in clay percentage in loess, plasticity limit and natural density increase linearly and in this case the soil moisture in saturation is less than soil moisture in plasticity limit. Therefore, structure of loess remains stable in saturation conditions.
7. Maximum amount of loess soil density is a function of natural density and a direct relationship holds between them.
8. Loess is composed of feldspar, calcite, and quartz, and its clay minerals include kaolinite, illite, and chlorite, and only in loess of zone 1 there is the mineral smectite.
9. Structure of loess in the three studied zones is completely different, which provides a filed criterion for identification.

REFERENCES

Derbyshire, E., 2001, Geological hazards in loess terrains with particular reference to the regions of China: Earth – Science, Reviews, v. 54, p. 31-60

Derbyshire, E., Kemp, A.R., and Meng, X., 1997, Climate change, loess and paleosols: proxy measures and resolution in North China: Journal of the Geological Society, v. 154, p. 793-805

Derbyshire, E., and Mellors, T.W., 1988, Geological and geotechnical characteristics of some engineering loess and loessic soils from China and Britain: a comparison: Engineering Geology, v. 25, p. 135-175.

Feda, J., 1988, Collapse of loess upon wetting: Engineering Geology, v. 25, p. 263-269

Feiznia, S., Ghauomian, J., and Khajeh, M., 2005, The study of the effect of physical, chemical and climate factors on surface erosion sediment yield of loess soils (Case study in Golestan Province), http://www.sid.ir/fa/VEWSSID/J_pdf/560138466m03.pdf

Gerard A., Kruse, M., Dijkstra, A. T., and Schokking, F., 2007, Effects of soil structure on soil behavior: Illustrated with loess, glacially loaded clay and simulated flaser bedding examples: Engineering Geology, v. 91, p. 34–45.

Ghergherechi, Sh., and Khormali, F., 2008, Distribution and origin of clay minerals influenced by ground-water table and land use in south-west Golestan Province: Agric. Sci. Natur. Resour., v. 15, no. (3), www.jasnr.info, www.sid.ir.

Jefferson, I. F., Mavlyanova, N., O'Hara-Dhand, K., and Smalley, I.J., 2004, The engineering geology of loess ground tasks for investigators—the Mavlyanov program of loess research: Engineering Geology, v. 74, p. 33-37.

Jinfeng, L., Zhengtang, G., Yansong, Q., Qingzheng, H., and Baoyin, Y., 2006, Eolian origin of the Miocene loess-soil sequence at Qin'an, China: Evidence of quartz morphology and quartz grain-size: Chinese Science Bulletin, v. 50, p. 2806–2809

Leach, J. A., 1974, Soil structures preserved in carbonate concretions in loess: Quarterly Journal of Engineering Geology & Hydrogeology, v. 7, p. 311-314.

Miller, H., Djerbib, Y., Jefferson, I.F.m and Smally I.J., 2007, Modelling the collapse of metastable loess soils: Nottingham Trent University, England

Northmore, K. J., Bell, F.G., and Culshaw, M. G., 1996, The engineering properties and behaviour of the brick earth of south Essex: Quarterly Journal of Engineering Geology & Hydrogeology, v. 29, p. 147-161.

Okhravi, R., and Amini, A., 2001, Characteristics and provenance of the loess deposits of the Gharatikan watershed in Northeast Iran: Global and Planetary Change, v. 28, p. 11-22 .

Sariosseiri, F., and Muhunthan, B., 2009, Effect of cement treatment on geotechnical properties of some Washington State soils: Engineering Geology, v. 104, p. 119–125

Reznik, Y. M., 2007, Influence of physical properties on deformation characteristics of collapsible soils: Engineering Geology, v. 92, p. 27–37