Australian Journal of Basic and Applied Sciences, 6(8): 83-92, 2012
ISSN 1991-8178

Measuring The Properties Of The Microstructure Loess In Golestan Province

Hamed Rezaee, G. Lashkaripour, M. Ghafoori, N. hafezimoghaddas

Department of Geology, Ferdowsi University of Mashhad (FUM), Iran

Abstract: Engineering properties of soils is controlled mainly by microstructures. In past studies on the relationship between microstructure and engineering properties of soil have been carried out. But in Loess it has been less or the microstructure components have been studied incompletely. Generally, the microstructure of Loess consists of three components grains, cement and pours. The frequency, type and distribution procedure of each of them control the geological – engineering of this soil against the static and dynamic loads. Using technology and new technology, measuring and calculating the parameters of the microstructure can be done easily. In recent years, fractal geometry has also been used to examine microstructure parameters and a numerical analysis is based on studies of the Loess. For general microstructure features, there are four statistical methods, geometric methods, modeling techniques and signal processing techniques. In this study, the two geometric and modeling methods are used. In this two methods by using mercury penetration inside the porosimetry and Scanning Electron Microscope-SEM, the microstructures of Loess are verified

Key words: Microstructures, Loess, Scanning Electron Microscope (SEM), Golestan Province

INTRODUCTION

Loess is a deposit, homogeneous eolian with well sorting, porous in the size of the silt (1 to 50 microns) with yellow pea light which has covered more than 10 percent of earth's surface (Smalley *et al*., 2010).The soils in geotechnical engineering are among the problematic soils of collapse. The collapse soil is one of the most important problems of natural agents in dried zones (Hormdee,2008).Due to heavy loads in saturated conditions, the structure of Loess faces with collapse and the microstructure converts from an open fabric into to a closed configuration (Jehring,2006). Because of the open and porous structure of this more than 95 percent consolidation is done in less than 10 minutes (Price, 2009). Sorting of the process is concentrated with the aggregate particles and cement. Cement is mainly consisted of calcium carbonate and clay and it plays a significant role in the collapse growth. So knowing the components of Loess soil microstructure is of particular importance.

Engineering properties of soils is controlled mainly by microstructures (Hu *et al*., 2001).In past studies on the relationship between microstructure and engineering properties of soil have been carried out (Hu *et al*., 2001). But in Loess it has been less or the microstructure components have been studied incompletely. Generally, the microstructure of Loess consists of three components grains, cement and pores.

The frequency, type and distribution procedure of each of them control the geological – engineering of this soil against the static and dynamic loads. The grains are mostly made of quartz, feldspar and mica which are based on the type and amount of cement between the grains of the four types of Loess band figure (Jehring,2006). Besides clay and limestone cement it is possible that different salts to be put on the surface of the particles as solid and semisolid (Karstunen & Leoni, 2009, Nouaouria *et al*., 2008). According to the amount of clay, silt and sands, the Loess is divided into to three types of clayey loess, silty loess and sandy loess (Hunt,2005;Sweeney & Smalley,1988; Angelova, 2007). The clayey Loess is usually a type of CL-ML (Hunt,2005). Microstructure characteristics of the soils are quite different. The mechanical behavior of Loess is dependent to the structure and quality of its grains bands (Bell, 2007) which form the structure fabric of Loess and they consist of grains and microstructures.Also the internal friction angle of Loess is dependent to the signs of plasticity index, connectivity of grains and their density (Bell, 2007) .Due to the exclusive structure, they are easily detected in the desert and it has a friability structure (Iriondo & Krohling, 2007).The friability is directly associated with the attachment between grains. Also these soils cannot be classified the same as other soils and paying attention to the parameters and the microstructure measurements can be so helpful in assessing such soils. In classification of these soils, the physical, mechanical and genre measurements must be under attention (Jefferson *et al*.,2004).

Although recorded in 1820 by Karl Von Leon hard studying on Loess was started (Smalley *et al*.,2001), but the microstructure studies of electron microscopy (SEM) is related to the past decade (Romero & Simms,2008).Using technology and new technology, measuring and calculating the parameters of the microstructure can be done easily. In recent years, fractal geometry has also been used to examine microstructure parameters (Lu *et al*.,2003) and a numerical analysis is based on studies of the Loess.

There are different reports regarding the man inability against the dangers of Loess in protection and

Corresponding Author: Hamed Rezaee, Department of Geology, Ferdowsi University of Mashhad (FUM), Iran
Tel: 0098-9113710347; E-mail: *Rezaiy.hamed@gmail.com*

preservation of structures in such soils.

Phenomena such as Collapsibility, Liquefaction, Dispersivity, Piping, Erosion, Unconcurrent Settlement, Karstification phenomena and like this are the risks that somehow depending on environmental conditions and geological features can occur in Loess. All of these hazardous phenomena are somehow associated with the Loess microstructure parameters (Olsezewska ,1975).

In Golestan province there are three different types of Loess with engineering-geological features (Rezaiy *et al*., 2011). Nearly 17 percent of the province's land area is covered by loess soil. (Khajeh *et al*.,2004) and they have devoted about 322000 hectares of the soils of this province to themselves and by different methods, the industrial, agricultural and engineering activities are done associated with that; In Golestan province, in order to do the water project, there are some problems and risks related to Loess. The province is composed of four major catchment which are poured to the Caspian Sea by several rivers runoff and the Loess of the province are the most sensitive soils which several problems can happen in contact with them. On the other hand, the dense distribution of villages, the lands appropriate for agriculture and development of industry and mechanization has least to the development of man interference in the natural structures and there are new risks and dangers which are so serious in each area of the catchment.

The main mineral resources of the brick factories which work with Loess due to the high seismicity, and having suitable topography, arable land and gardens will be provided with the product. In engineering of many of the water structures (transferring, storing and deviation canals) in a way that it is associated with Loess and it is used for both loan sources or as a base in connection with structures and engineering activities. Also different reports have been provided in the field of damageable effects of Loess on the engineering structures of the province, Iran and other places and it indicates that in contact with Loess and their usage, some special issues and conditions must be considered so that the provision to be made in due course.

MATERIALS AND METHODS

For general microstructure features, there are four statistical methods, geometric methods, modeling techniques and signal processing techniques (Shadroo *et al*.,2007). In this study, the two geometric and modeling methods are used. In this two methods by using mercury penetration inside the porosimetry and Scanning Electron Microscope-SEM, the microstructures of Loess are verified (Romero & Simms,2008).With a sampling done on 7 places of Golestan province (figure 1), the Loess deposits which have been provided by the Mashhad University of scanning electron microscopy images of microscopic (SEM) and according to these images, the microstructure properties have been measured.

The working process is in a way that the maximum sizes of 5 mm of the intact specimens are prepared and then the preparation is done under the microscope photography. The software Image Tool is used and the Microstructure Image Processing System was developed (Figure 2). The image is taken from the sample under the microscope, is the two-dimensional view of the sample and it is a typical gray image. Image processing is the conversion of a digital image into a normal image. The digital image is a measured image which consists of some small squares (pixels). Each digital image has two rows and columns.

This research is a part of Ph.D. thesis topics as geology engineering: “An investigation on effect dynamic compaction and static loads on shear strength of loess's soils in Golestan Province”, And it is being done.

Discussions:

T Geometric regularity of soil grains together is called the structure of soil. Ped is consisted of the Social Cluster and that is made of several Domains. Domain is the smallest part of a soil and is observable by electron microscopy. The formation of clusters and procedure of formation of the second structure of soil determines Loess and it is the density of porous of space between peds.

Generally, Larionov(1965) has introduced three types of structures including Granular, an Aggregate and Granular-Aggregate in Loess (Bell *et al*.,1986).

By eye consideration in microscopic images of Loess which were studied, there is mainly a grain and cement between the grains causes the formation of a honeycomb, but in some of the cases that there is a high level of clay, Aggregate is observed individually as well. In the formation of aggregate, domain is in Loess and clay minerals and by the pasting of limestone and clay and cement, cluster will be formed. The situation of ped formation in silti and sand Loess is usually the same and the cluster and ped are a function of grains density and the peds are generally a type of grains, but in the clayey Loess in addition to grains, the quarters of microstructures of clayey mineral form the cluster together and from the accumulation of them some peds with high void retio are formed and they create the corner cube aggregate formation.

The aggregates are grades according to the easiness of seeing the structure of soil in peds, the level of soil making of main materials and the joining power between grains and they are separated into the instable, average and strong structures. In the instable structure of grains, they are damaged and they are detectable in the firm structure of pedons.

Connective between the grains in Loess is a decisive factor in building pedon and in Loess they are formed with higher cement of pedon which are more complete and in the Loess which don't have cement, the cluster accumulation is not seen and pedon does not exist obviously. Factors such as shrinkage soils, swelling, ice and melting and animals activities will change the soil structure.

Loess soils are mainly of non-cohesive soil types and have a honeycomb structure. Loess soil that contains abundant clay is the type of adhesive that which has a dispersed structure. The movement and sediment of micro-particles of grains in the size of clay in a dilute solution has a brown movement and during this accidentally movement, some gravity forces are created between defensive or absorbing forces.

The gravity force is the result of vandervals existing between the grains in a solution and depending on which force is dominant, the aggregate in the scattered or flocculated forms are deposited. In the Loess soils that the mechanisms of sedimentation is done in the hanging space of air is different from the diluted solution. Therefore, due to low humidity, surface gravity lacks the gravity forces and aggregate is deposits in a scattered form and it causes that the structure to be the same as honeycomb and porous.

The porous space (pores) in the Loess is seen in two forms of inside aggregate and outside aggregate. The inside aggregates are usually small and they create the distance between two adjacent grains and they are closed. But the mechanical processes of grain dust (crack) and may be connected. The pores inside the grains are generally small (micro pore) and outside of aggregate are large (macro pore).

The structure of loess consists of two components of skeleton grains and cement is formed between grains. The grains are made of two quartz, feldspar and mica and cement which are usually made of clay and lime. The amount and type of cement controls the mechanical behavior and physical properties of Loess.

Secondary processes and the activities of animals change the structure of Loess and they create a new structure such Fissure, Channel, Dense Excremental Infilling Pseudo-sand structure (Guo *et al*.,1996).Composition and mineralogy of the type of cement between the grains is done by energy dispersive X-ray analysis (EDX).In the images of studied samples, four main components of grains, fabric, porosity and connectivity between the grains (connective) have been studied and for each of the factors some quantity parameters have been determined (table 1).

Table 1:

Factor	Parameter	Symbol	Meaning
Shape of grain	Maximum Grain diameter	D_g	The biggest length of grains
	Sphericity	S_r	Represents a level close to the grain is a sphere.
	Circularity	R	The level of sharp or flat edges of grains
	Fractal dimension of grains	DF_g	The ratio of lager grains from Dg to Dg
Arrangement of grains	Grain oreintation	O_g	The direction of thick side of grains in the long line
	Density of grain arrangement	P_d	The grain density in a hypothetical
	Geometry fractal dimension	DF_f	Fractal geometry of grain arrangement density
Porosity	Pore geometry	D_p,L_p,SP_r	The biggest length and width and the pore area
	Density of pore arrangement	P_p	The pore density in a hypothetical length
	Porosity Fractal geometry	DF_p	Fractal geometry, density, pore arrangement
Connectivity	Linkage of grains	D_c	The frequency and distribution of cement between the grains
	Density of cement arrangement	C_c	Density of the cement in a hypothetical length
	Cement Fractal geometry	DF_c	Fractal geometry of cement distribution arrangement

Table 2: The quantity parameters of microstructure features of Golestan Loess

Parameters			S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9
Shape	Maximum Grain diameter (D_g)		0.023	0.035	0.032	0.042	0.018	0.045	0.041	0.056	0.061
	Sphericity (S_r)		0.752	0.707	0.780	0.685	0.755	0.798	0.660	0.750	0.722
	Circularity (R)		0.589	0.679	0.849	0.369	0.745	0.464	0.730	0.902	0.736
	Fractal dimension of grains (DF_g)		0.491	0.632	0.763	0.488	0.593	0.603	0.735	0.804	0.872
Arrangement	Grain oreintation (O_g)		24.2	8.3	9.3	16.5	0.09	1.06	18.5	16.5	30.3
	Density of grain arrangement (P_d)	V	0.185	0.618	0.346	0.682	0.465	0.510	0.482	0.258	0.531
		H	0.174	0.803	0.503	0.689	0.503	0.537	0.411	0.324	0.579
	Geometry fractal dimension (DF_f)		1.427	1.958	1.585	1.999	1.782	1.696	1.672	1.644	1.734
Porosity	Pores Density (D_p) per 1/μm		0.037	0.020	0.023	0.021	-	-	0.046	-	0.016
	pore surface ratio (SP_r)		0.291	0.278	0.358	0.261	0.229	0.376	0.264	0.317	0.272
	Density of pore arrangement (P_p)	V	0.352	0.306	0.221	0.302	0.223	0.368	0.311	0.390	0.359
		H	0.248	0.342	0.094	0.307	0.093	0.370	0.224	0.384	0.378
	Porosity Fractal geometry (DF_p)		1.772	1.671	1.683	1.935	1.970	1.452	1.878	1.473	1.639
Connectivity	Linkage of grains (D_c)		0.139	0.170	0.587	0.393	0.626	0.608	0.462	0.393	0.606
	Density of cement arrangement	V	0.456	0.149	0.268	0.009	0.273	0.095	0.032	0.286	0.062
		H	0.579	0.156	0.561	0.01	0.442	0.122	0.120	0.358	0.091
	Cement Fractal geometry (DF_c)		-	-	-	-	-	1.473	1.537	-	1.735

1- Shape of grain:

The geometrical dimensions and the situation of its surfaces introduce the form of grains. In this research, the four parameters of maximum diameter of grain, sphericity, circularity and fractal dimension of grains have been used for introduction and explanation. The definition and procedure of measurement of each of the parameters is as follows.

1-1- The maximum diameter of grain (Dg):

The maximum diameter of grain is pointed out to the longest dimension. In SEM images of the environment circle diameter, a grain was calculated (Figure 3). In a picture, about 25 grains were selected and the average grain diameter was determined. The grain diameter can influence the arrangement, texture, porosity between grains and to control them.

1-2- Sphericity (Sr):

The amount of closeness of a grain to a sphere represents the Sphericity of that but in the two-dimensional space and level of closeness to the circle is called Sphericity. The Sphericity of a sphere grain is equal to one. In SEM images, the Sphericity is counted from the square root of the spherical environment of a grain diameter (Dc) to the inscribed circle diameter (Di) (Riley sphericity method) (Figure 4).

Equation (1) $$S_r = \sqrt{\frac{D_i}{D_c}}$$

1-3 Roundness (R):

The roundness indicates the level of sharpness or flatness of grain edges; In the SEM images, the roundness of the ratio of the sharpest radius of grain (r) towards the circle inscribed in the grain (Di) (Figure 5). Roundness of the clastic grains depends on the degree of grain abrasion during transport, grain size and the carried distance.

Equation (2) $$R = \frac{r}{D_i}$$

1-4- Fractal Dimensions of grains (DFg):

Fractal is a method to describe the soil grains and in relation with the parameters of curve and its texture. Fractal dimension is provided from the ratio of number (N) of bigger grains from a size to the diameter of the same grain (Dg). Based on a statistical work, by selecting more than 25 samples, the amount DFg was calculated in Image Tools Software and then it was calculated for the size of all the grains.

Equation (3) $$DF_g = -\lim_{D_g \to 0} \frac{\ln N_{(Dg)}}{\ln D_g}$$

2 - Grain fabric:

Fabric describes how the grains are put towards each other. In order to review the Fabric of microstructure, the two parameters of the grains and arrangement of density of grains was used.

1-2- Grain Orientation (Og):

Along the axis of the bigger diameter of grains ratio to a level, it indicates the direction of grains. The basic level can be a horizon, perpendicular to the axis of loading or any surface for the purpose of evaluation (Figure 6). The grain orientation before and after applying a static load and dynamic load will be different. For the purpose of control and the separation of bigger diameter axis of grains which is calculated according to degree, it has been stated in the left and right side as positive and negative. The negative sign means the direction towards left.

2-2 Density of grain arrangement (Pd):

Density of grain arrangement is calculated from the total ratio of grains length to the total line length of grains which are measured on that; the grains in different direction have varied density. In this study, the SEM images have been obtained from three horizontal ways and three vertical ways (figure 7) and according to its results, the soil grains are analyzed.

2-3 Fractal geometry arrangement of density fabric (DFf):

Fractal geometry arrangement of density fabric was obtained by counting the number of boxes (figure 8). So by this method that has been done by plating a network from the determined number of square sizes and by counting the number of the squares (N (ε)) which were covered by the grains, the fractal geometry of grains can

be calculated by the following equation in which ε is the network scale and N (ε) is equal to the total number of squares which the grains are put in them.

Equatio n (4) $$DF_f = -\lim_{\varepsilon \to 0} \frac{\ln N_{(\varepsilon)}}{\ln \varepsilon}$$

3 - Porosity:

It is used to evaluate the properties of the pore diameter, porosity, pore density and arrangement of its fractal dimension.

3-1 pore geometry:

The width of maximum pores (Dp) is counted by measuring the diameter of circle. In an image by measuring at least 35 pores, the average of that will be calculated. In order to display it better and measure it easier the Adjust Threshold was used in Image Tools Software and the pores were separated from the rest components of SEM image (Figure 9). Also the length of maximum pore (Lp) was counted by measuring the longest direction in the pore canal.

Dp-Pores Density of the total pore area of the maximum pore size image (Si) is calculated and analyzed for parameters associated with pores or macro pore.

Equation (5) $$D_p = \frac{\sum_{i=1}^{n} L_p}{S_i}$$

The pore surface ratio (SPr) of the total pore surface area (Sp) (red color in Figure 9) is obtained from the image entire surface (Si). This is a good indicator of the soil hollowness and porosity and it is associated with the mechanical parameters as well. This ratio is measurable by method of box counting (DBC).

Equation (6) $$SP_r = \frac{\sum S_p}{S_i}$$

3-2 Density Arrangement of Pores (Pp):

It shows the level of closeness and density of pores in a line. In order to review the density arrangement of pores, up to three horizontal and three vertical lines of pores are measured. Density arrangement of pores is obtained from the ratio of total pores length to line total length which the measurement has been done on that.

This parameter is associated with Dp and SPr. It is also linked to the percentage of porosity and hollowness, which is obtained through physical examination.

3-3 Fractal Geometry Of Density Pore Arrangement (DFp):

The same as grains density arrangement, by counting the number of fractal geometry boxes the Fractal geometry, density pore arrangement is obtained by the following equation in which ε is the network scale and N (ε) is equal to the total number of squares which the pores are put in that.

Equation(7) $$DF_p = -\lim \frac{\ln N_{(\varepsilon)}}{\ln \varepsilon}$$

4 - Connective:

Connective introduces the level and type of cement between grains in the microstructure components. The indices of links between the grains, arrangement of cement distribution density and fractal geometry arrangement of cement distribution in this research has been verified.

4-1 Link between the grains (Dc):

The link between grains is the connective agent and the connectivity between them. This parameter is defined as follows.

Equation (8) $$D_c = \frac{\sum W_g - \sum W_p}{\sum W_g}$$

That in that Wg = the width between two adjacent grains and Wp the pore width between two adjacent grains. At least one grain from four grains is surrounded and there is three conditions between them or the grains

are close to each other and they are connected to each other at one or several points (Wg=0), or totally they have been filled with cement (Wp=0) or there is cement or pores between them (Wp> 0 and Wg> 0).

Type of cement will be so helpful in analyzing the stability of the microstructure. Three agents of calcium carbonate, silt and cement clay are formed between the loess grains (Figure 10). The effect of clay cement because of the abundance and more distribution is more significant on the stability of skeletons of loess. Also the clay as a narrow layer covers the bigger particles and it accelerates the linkage between the grains. The clayey cement is generally in three forms of clayey bridge, clayey pillar and clayey chain which connect the grains.

4-2 Arrangement Of Density Distribution Of Cement (Cc):

Arrangement of density distribution of cement exhibits the procedure of cement distribution between the grains in a line. In order to review the arrangement of pores density in three horizontal and three vertical lines better, the cement level between the grains has been measured. Arrangement of cement distribution density is provided from the ratio of the total cement length to total length of line that measurement has been done on that.

4-3 Fractal Geometry Of Cement Distribution Arrangement (DFc):

The same as grains density arrangement, by using the method of counting the number of fractal geometry boxes, the distribution of cement is also calculated by the following equation in which ε is the network scale and N(ε) is equal to the total number of squares which the pores are inside them.

Equation (9)
$$DF_c = -\lim \frac{\ln N_{(\varepsilon)}}{\ln \varepsilon}$$

Results of measurements of parameters of microstructure which were described are shown in Table 2 in numeric form.

4. Conclusions And Recommendations:

1. The simple tools of image scans and reviewing the relations between components of loess in two-dimensional space can provide much information regarding the microstructure situation of that.
2. Image Tool and Excel software can provide easy methods to measure the parameters of the microstructure of loess.
3. Parameters 15 of microstructures in four sections of figure of grains, fabric, porosity and connective in an assessment of Golestan Loess were introduced.
4. Because of the homogenous texture and Grain size distribution of loess, fractal geometry is a good method to measure microstructure parameters.
5. The pores exist in two forms of inside aggregate and outside aggregate in the loess of Golestan. The inside aggregate is linked to the density between grains and cement between them, but the outside aggregate is the result of creating small cracks, the activity of animals and the breakage of soil structure.
6. Clayey cement in Golestan loess connects the grains to each other by three forms of clayey bridge, clayey pillar and clayey chain.
7. In the loess of area one, aggregation of calcium carbonate in the form of cement or network, affects the non-woven fibers of microstructure of loess.

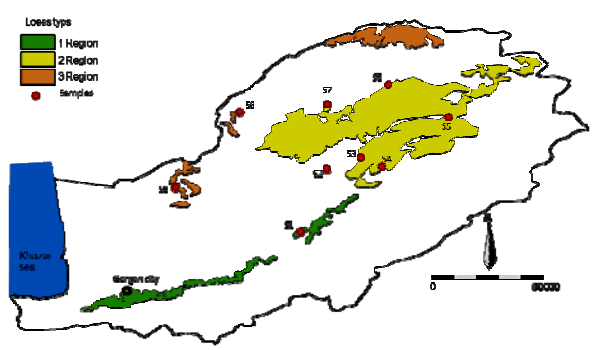

Fig. 1: Distribution of Loess in Golestan Province in IRAN

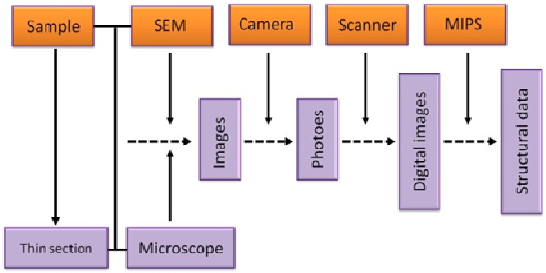

Fig. 2: Steps in quantifying micro structural parameters using MIPS Hu *et al*.,2001

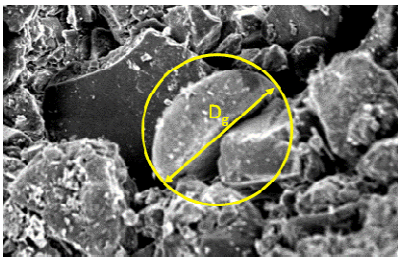

Fig. 3: Represents the maximum grain diameter (D_g)

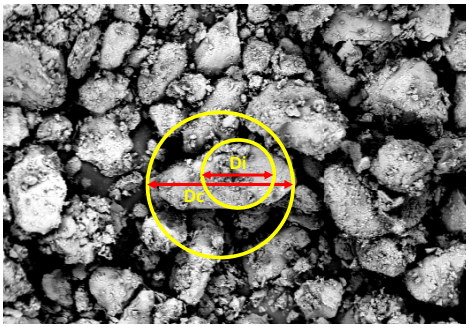

Fig. 4: Measurement of spherical grains

Fig. 5: Displays the components of the grain roundness

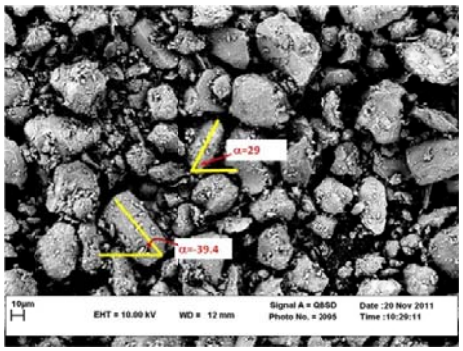

Fig. 6: Measures the orientation of grains

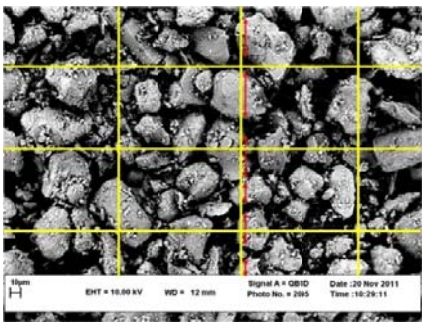

Fig. 7: Measures the density of grains along the vertical and horizontal arrangement

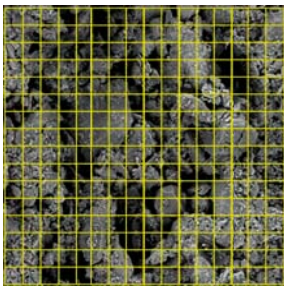

Fig. 8: Differential Box Counting (DBC) method for the density arrangement of grains, pores and loess soil Cement

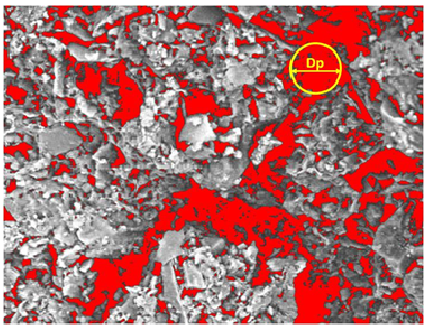

Fig. 9: Separation of pores in the Image Tools

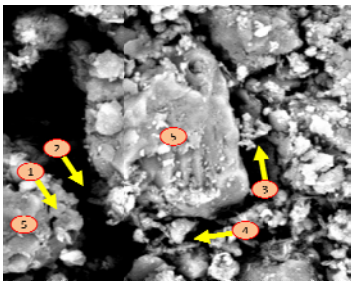

Fig. 10: connectives between the grains.
Description: 1. Cement 2. Pore 3. Clayey bridge 4. Silt bridge 5, grain

REFERENCES

Angelova, R.N., 2007. Loess-cement long-term strength - a facilitating factor for loess improvement applications. geologica balcanica, 36(3-4): 21-24.

Bell, F.G., 2007. Engineering Geology. Second Edition, ISBN-13: 978-0-7506-8077-6,P.213, Elsevier Ltd., All rights reserved. http://books.elsevier.com

Bell, F.G., J.C. Cripps and M.G. Culshaw, 1996. A review of the engineering behaviour of soils and rocks with respect to groundwater. Geological Society, London, Engineering Geology Special Publications, 3: 1-23, doi: 10.1144/GSL.ENG.1986.003.01.01

Guo, Z., N. Fedoroff, D. Liu, 1996. micromorphology of the loess-paleosol sequence of the last 130 ka in china and paleoclimatic events .Science in china (series D),Vil.39,No.5

Hormdee, D., 2008. Investigation on Collapse Potential of Loess Soil. Proceedings of the Eighteenth International Offshore and Polar Engineering Conference,Vancouver, BC, Canada, July 6-11, 2008, The International Society of Offshore and Polar Engineers (ISOPE), ISBN 978-1-880653-70-8 (Set); ISBN 1-880653-68-0 (Set)

Hu, R.L., M.R. Yeung, C.F. Lee, S.J. Wang, 2001. Mechanical behavior and microstructural variation of loess under dynamic compaction, Engineering Geology 59 P.203-217 , www.elsevier.nl/locate/enggeo

Hunt, R., 2005. Characteristics of geologic materials and formations (a field guide for geotechnical engineers), Taylor & Francis Group, ISBN 1-4200-4276-9, http://www.taylorandfrancis.com

Iriondo, M.H., D.M. Krohling, 2007. Non-classical types of loess , Sedimentary Geology, 202: 352-368, www.elsevier.com/locate/sedgeoJehring S., Engineering Geology problems in loess deposits. http://www.geo.tu-freiberg.de/oberseminar/os06_07/Susann_Jehring.pdf

Jefferson, I.F., N. Mavlyanova, K. O'Hara-Dhanda, I.J. Smalley, 2004. The engineering geology of loess ground: 15 tasks for investigators—the Mavlyanov programme of loess research, Engineering Geology, 74: 33-37, www.elsevier.com/locate/enggeo

Karstunen, M., M. Leoni, 2009. Geotechnics of Soft Soils (Focus on Ground Improvement). ISBN: 978-0-203-88333-4 (ebook), http://www.taylorandfrancis.com, Taylor & Francis Group, London, UKKarstunen M. & Leoni

Geotechnics, M. of Soft Soils,Focus on Ground Improvement , Taylor & Francis Group, London, UK, ISBN: 978-0-203-88333-4, Taylor & Francis Group, London, UK

Khajeh, M., J. Ghauomian, S. Faiznia, 2004. The study of lateral variation of grain size and mineralogy in order to determine prevailing winds dirction in the formation of loess sediments of golstan provuce,Desert V.9,N.2, http://journals.ut.ac.ir/page/download-7BrX4i059EI.artdl

Lu, P., I.F. Jefferson, M.S. Rosenbaum, I.J. Smalley, 2003. Fractal characteristics of loess formation:evidence from laboratory experiments, Engineering Geology 69 287–293, www.elsevier.com/locate/enggeo

Nouaouria, M.S., M. Guenfoud, B. Lafifi, 2008. Engineering properties of loess in Algeria. Engineering Geology 99, P.85–90, www.elsevier.com/locate/enggeo

Olsezewska, 1975. sem analysis of microstructures of loess deposits .bulletin of the international association of engineering geology, 11: 45-48.

Price, D.G., 2009. Engineering Geology-Principles and Practice ISBN: 978-3-540-29249-4 , Springer-Verlag Berlin Heidelberg

Romero, E., P.H. Simms, 2008. Microstructure Investigation in Unsaturated Soils: A Review with Special Attention to Contribution of Mercury Intrusion Porosimetry and Environmental Scanning Electron Microscopy, Geotech Geol Eng,DOI 10.1007/s10706-008-9204-5, Springer Science+Business Media B.V.

Rezaee, H., 2010. Feasibility of construction of small water utilities Enquiry about the geotechnical characteristics of soils in Golestan province, Gorgan University of Agricaltural Sciences and Natural Resources

Sweeney, S.J., I.J. Smalley, 1988. Occurrence and Geotechnical properties of loess in Canada. Engineering geology ,V.25,P.123-134,Elsevier science publishers B.V.

Smalley Ian, Markovic Slobodan B., Svir_cev Zorica, 2010. Loess is [almost totally formed by] the accumulation of dust.Quaternary International, doi:10.1016/j.quaint.2010.07.011

Smalley, I.J., I.F. Jefferso, T.A. Dijkstra, E. Derbyshire, 2001. Some major events in the development of the scientific study of loess, Earth-Science Reviews, 54: 5-18. www.elsevier.comrlocaterearscirev

Shadroo, Sh., R. Maarefdost, M. Yaghobi, H. Pourreza, 2007. Scan images using multi-fractal estimation, entropy and fuzzy clustering, First Joint Congress on Fuzzy and Intelligent Systems, Ferdowsi University of Mashhad, Iran 29-31.