Journal of Geotechnical Geology

Journal homepage: geotech.iauzah.ac.ir

Zahedan Branch,
Islamic Azad University

Investigation of the swelling aspect from Marageh city's clayey soil based on mineralogy effects and physicochemical properties

Dariush Ahadi-Ravoshti*[1], Maryam Golnezhad[2]

[1]*Department of Agriculture, University of Mohaghegh Ardabili, Ardabil, Iran*
[2]*Department of Agriculture, University of Tabriz, Tabriz, Iran*

ARTICLE INFORMATION

Received 11 January 2020
Revised 10 April 2020
Accepted 23 April 2020

KEYWORDS
Swelling potential; Clayey soil; Mineralogy; Regression analysis; Marageh city.

ABSTRACT

The swelling potential is the most important factor on engineering and agricultural design of foundations on fine-grained soils which it can be cause expansion problems for these structures. So, providing the suitable views of swelling condition can help to solid designs. The presented paper, tried to understand the clayey soil's swelling potential related to Marageh city in East Azerbaijan Province, NW of Iran; by using comprehensive laboratory tests (concluded 25 samples from 10 different sampling location) which included physicochemical properties, USDA class of soil and clay mineralogical aspects. The experiment results was used by regression analysis for formulate the swelling based on laboratory indexes (i.e., water absorption, porosity, density, Gs, SO_4^-, Cl^-, pH, Casagrande limits, UCS, XRD and clay content). According to the analysis results, the studied soil's (where classified as clay, clay loam and silty clay) swelling status is varied and located in moderate to high potential.

1. Introduction

Swelling soils are found in large parts of the world, especially in arid and semi-arid regions. These soils belong to the group of clay soils and are usually a mixture of clay and non-clay minerals. The geotechnical characteristics of these soils are controlled by their clay section. This group of soils contains a significant amount of montmorionite mineral, which swells with dewatering and shrinks due to water loss. These soils are a serious problem for engineering structures due to their ability to swell and shrink in the face of seasonal fluctuations in humidity (Das, 2008). In the United States, the annual damage caused by the destructive behavior of swollen soils to highways, passages, airports, tunnel cover, irrigation canals, and other structures is estimated at $ 9,000 million which has been greater than the damage caused by natural disasters such as floods, hurricanes and earthquakes. If the moisture content of a swollen soil remains unchanged, swelling and shrinkage will not occur. Therefore, an important parameter in the study of swelling and shrinkage phenomena is the effect of changing the moisture content of swollen soils, generally in areas where, depending on environmental conditions, the soil is more exposed and drying successively (Chen, 1988).

The swelling phenomenon is the results of the volume change and uptake in fine-grained soils (clay content soils) in front of water (or moisture) which lead to expansion in soil. Mainly, the swelling is the three-dimensional event

* **Corresponding author.**
E-mail address: dariushahadi@gmail.com
M.Sc., Research Assistant.

https://doi.org/10.30495/GEOTECH.2020.679339
Available online 17 May 2020
1735-8566/

were dilated soils to its surroundings which brought widespread damages and lost costs (Driscoll and Crilly, 2000). In fact, these soils present significant structural challenges and sudden behavior were contact with water were reflected on soil volume variations (Farrokhpay et al., 2016). According to the experimental research, the clay content and type of clay minerals can be influential on soils swellability. For example Kaolinite with the chemical composition $Al_2Si_2O_5(OH)_4$ is lowest swelling potential and Montmorillonite with the chemical composition $(Na,Ca)_{0.33}(Al,Mg)_2(Si_4O_{10})(OH)_2{\cdot}nH_2O$ is reported as highest swelling potential clay mineral (Ahadi-Ravoshti and Hashemimajd, 2017). As a result, the swelling behavior of such soils is closely related to Montmorillonite (or Smectite group) of clay minerals. Generally, the clay minerals formed as tetrahedral or octahedral hydroxide silicates sheets and layers which are provide unique ability to preserve the water in their structures (Azarafza et al., 2018). Swellability is measured for clayey soils by using laboratory or in-situ experiments which can be identified as direct or indirect procedures. The direct methods is conducted by using experiments like odeometer, direct swell test and air table to estimate the swelling potential rate. Indirect methods use the soil mechanics tests results such as plasticity and soil activity indices to evaluate the swelling potential rate (Yilmaz, 2006).

In Iran, due to the existence of different geological formations and facies and the existence of different climatic conditions on the one hand and its location in the arid and semi-arid zone of the tropics and the existence of arid deserts and large semi-arid regions in the country has created suitable conditions throughout the country in terms of creating and expanding different areas of problematic soils, especially soils with inflation potential. Events such as soil inflation in cities such as Yazd, Isfahan, Qom, Mashhad, Semnan, etc., are important evidence that the resulting damage has always been recorded in the heart of history (Aghanabati, 2007). The only way to deal with the problems caused by the problems of problematic soils is to classify, zoning and considering in the design of structures, which in itself requires raising the level of engineering and technical knowledge in this field (Murray, 2013).

In fact, swelling and shrinkage are not intrinsic properties for clay particles, but rather the result of the function between moisture uptake and suction and the inherent mineralogical and hydrophilic properties of clay particles in the soil (Charlie et al., 1984). The phenomenon of swelling or shrinkage and the extent of their effect is a function of the mineralogical conditions and type of clay minerals involved in the soil (for example, chlorite, illite, smectite or montmorionite). Quantity, shape, grain size, site topography, climatic and climatic conditions are the most important controlling factors in soil inflation potential (Coduto, 2001). A direct and observable result in the behavior of swollen soils is related to Montmorionite mineralization (Day, 2001).

In rainy and wet seasons, when the clayey soil becomes wet and absorbs moisture, it shows a significant increase in volume. This increase in volume causes the propulsive force to enter upwards and into the infrastructure. This action creates a series of horizontal and vertical cracks in the body of the structure. Schematic of soil swelling pattern of moisture absorption time is shown in Fig. 1 (Grunwald, 2006).

Engineers did not know the nature of the damage caused by swollen soils until the late 1930s. In 1938, the first land reclamation office was established in the United States. Researchers at the agency pioneered the study of swollen soils (Chen, 1988). Apart from the increasing number of studies on problematic soils, especially swollen ones, the design of surface foundations of light structures more than heavy structures built on soils with inflatable potential, is considered by engineers and experts. Geotechnics (Meehan and Karp, 1994). Undoubtedly, the need for new designs in the construction on swollen soils is a serious matter. The failure of traditional criteria in designing and estimating the bearing capacity of surface foundations on these soils has doubled the importance of this issue (Jones and Holtz, 1973). Having a correct understanding of the damage caused by swollen soils on structures and structures built on these soils, requires an interactive study between the buildings as a structure related to the soil under the foundation. For this purpose, the existence of a dotted framework of soil-structure interaction seems necessary. Figure 2 shows a logical flowchart for soil-structure interaction analysis. As can be seen in this Fig., identifying swollen soils and identifying their chemical composition and components is a critical first step in the study. Since swollen clays are part of the soil evolution cycle, it is important to determine changes in their constituents (Lucian et al., 2006).

The presented study use the laboratory methods for investigate the swellability of studied clayey soil.

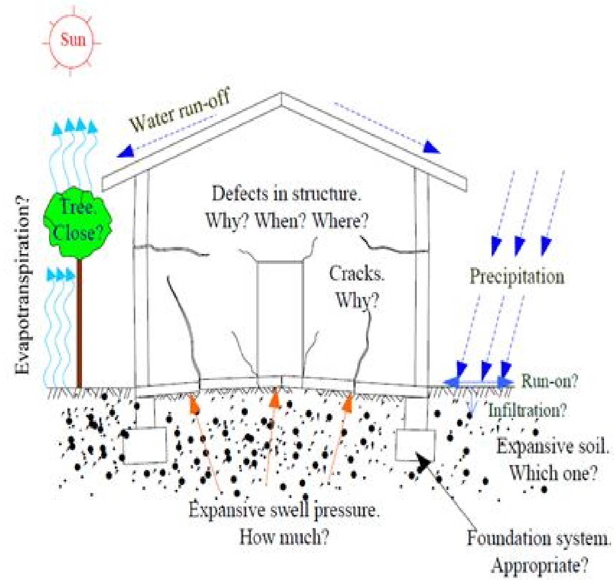

Figure 1. An overview of ideally inflatable soil problems (Murray, 2013)

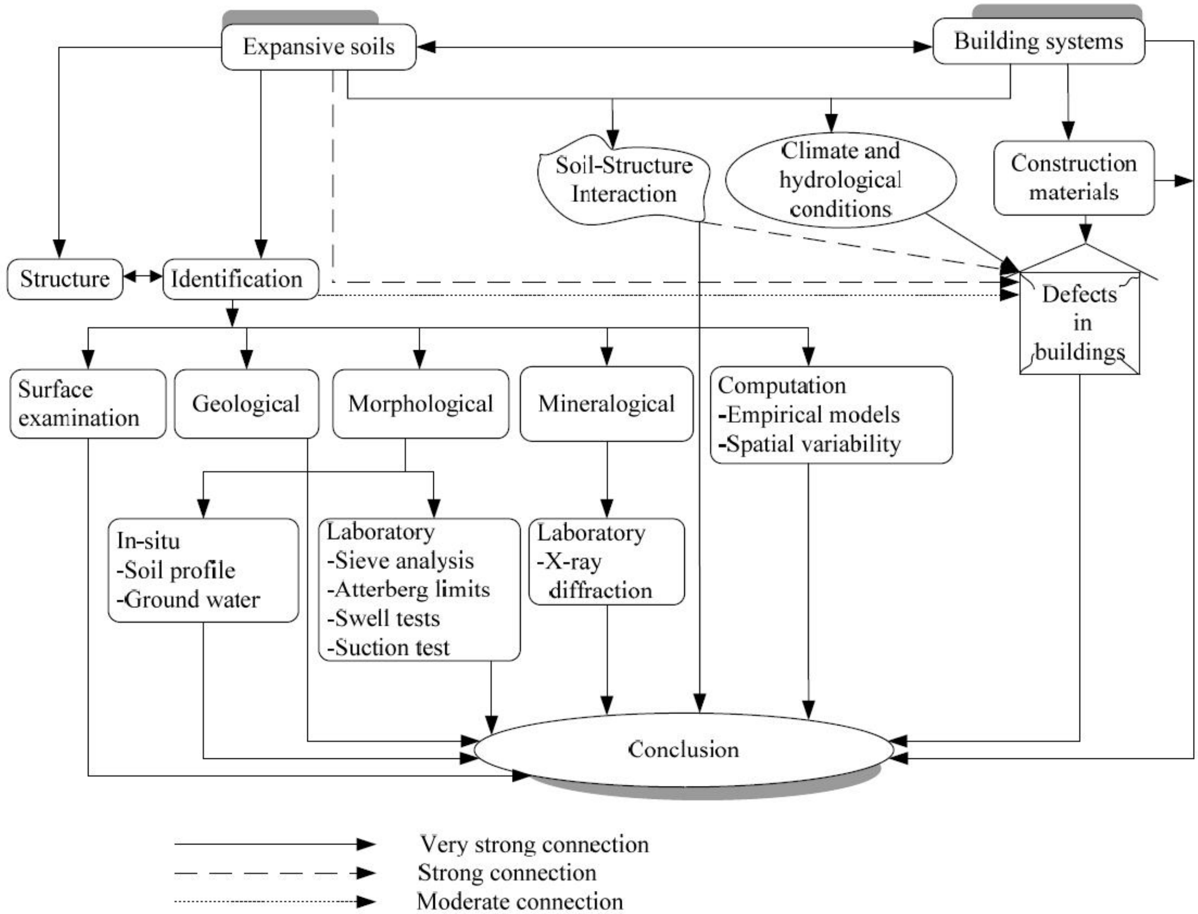

Figure 2. Flowchart of the process of studying swellabe soils (Lucian et al., 2006)

2. Material and Methods

2.1. Studied Case

Maragheh city is ancient city and capital of Maragheh County, East Azerbaijan Province, located in northwest of Iran. Maragheh is on the bank of the river Sufi Chay. It is 130 km from Tabriz and seconded largest city after Tabriz in northwestern Iran. The city is situated in a narrow valley running nearly north and south at the eastern extremity of a well-cultivated plain opening towards Lake Urmia, the world's sixth-largest saltwater lake, which lies 30 km to the west. The town is encompassed by a high wall ruined in many places, and has four gates. Maragheh is surrounded by extensive vineyards and orchards, all well watered by canals led from the river, and producing great quantities of fruit. Geological map of the Maragheh region with the scale of 1:100,000 is provide by Geological Survey and Mineral Exploration of Iran (GSI) were presented in Fig. 3. According to this figure, this Maragheh city is located on young alluvial formations, lake sediments of evaporate deposits related to Neocene formations from Urmia lake to volcanic and igneous masses of rocky outcrops of Sahand Mountain activity. The Maragheh region, due to certain geological conditions and being on the Sahand alluvial fan, is considered as drainage path for Maragheh-Bonab plain and Urmia Lake basin. Drainages with erosion-sedimentation cycles in lapse of time have caused changes in the morphology of region (Ghazifard et al. 2016). Thus, it is will be quite obvious that the city bed is generally sedimentary and contains varying amounts of clay. For this purpose, the issue of swelling of clay soils in the city of Maragheh has been raised with considerable seriousness and requires full evaluations in this field.

2.2. Laboratory assessments

In order to evaluate the swelling potential of Maragheh city's clayey soils, the comprehensive laboratory tests concluded 25 samples from 10 different sampling locations in Maragheh are conducted. The applied tests are classified in physical, chemical and soil (mechanical) experiments to provide the suitable understanding about physicochemical properties of clay minerals and fine-grained soils. In the other hand, the studied soil is classified based on United States department of agriculture (USDA) classification system to estimate the clay types in soil.

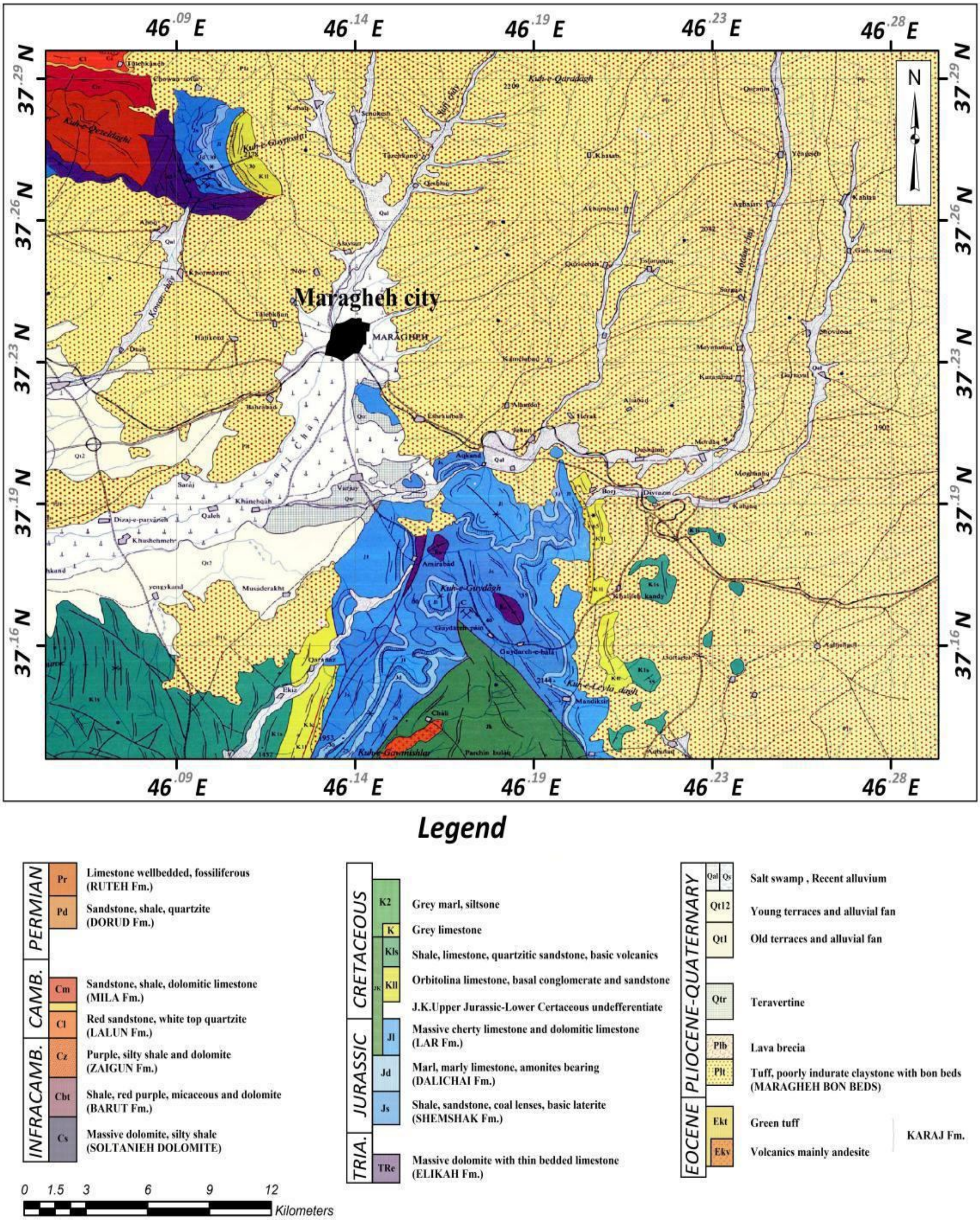

Figure 3. Geological map of the Maragheh region (GSI, 2009)

The tests were conducted in accordance with the ASTM. The water absorption, porosity, dry density, saturated density, specific-gravity, clay particles tests were performed to determine the physical characteristics, the X-ray diffraction analysis (XRD), sulfate-chloride (SO_4^-/Cl^-) and pH tests were performed to determine the chemical characteristics and the sieve analysis, plastic limits, clay particles, uniaxial compressive strength (UCS) tests performed to determine the soil (mechanical) characteristics.

3. Results and Discussions

According to the results of the physical tests were conducted on the samples the Maragheh clay has wide which is related to the climatic and geological conditions of the Maragheh region. The Urmia Lake and Sahand volcanic mountain is the main geological structures were controlled these elements. Results of these tests are presented in the Table 1. The chemical analysis is classified in XRD, sulfate-chloride and pH tests were performing by ASTM standards. The XRD is a determination technique used for structural study of materials crystals which is commonly used to the detection of the clay minerals (Drits and Tchoubar, 2012). For the XRD analysis, the samples are passed form the #200 sieve (standard US sieve analysis) and stirred with distilled water which is done for the collection of the clay materials base on Stoke's law, then the prepared samples is used to XRD detection of the minerals. The results of the XRD detection of the Maragheh clay are illustrated in Table 2. As seen in this Table, the most minerals are detected form clay groups are smectite and Iilite. The sulfate-chloride and pH tests are conducted on some selected samples. The results of the sulfate-chloride and pH tests for Maragheh clay are shown in Table 3. The mechanical properties of soils are performed for classification and swelling potential assessment of Maragheh clay. The main mechanical tests is classified in sieve analysis, hydrometer, plastic limits, clay particles, swelling tests were conducted on the samples based on the ASTM standard. In this regard, the sieve analysis was used for particle size distribution and hydrometer was used to fine-grained particles (silt and clay) calculation. In the plastic limits is contains liquid limit (LL), plastic limit (PL), plastic index (PI) were obtained from the Casagrande standard test. The results of soil (mechanical) tests of the Maragheh clay are presented in Table 4.

Table 1. Physical characteristics of the Maragheh clayey soil

Parameters	Unit	Max	Min	Mean
Water absorption	%	16.4	7.7	12.05
Porosity	%	75.1	40.9	58.00
Dry density	kN/m^3	22.9	18.0	20.45
Saturated density	kN/m^3	25.3	21.1	23.20
Specific gravity	-	2.71	2.50	2.60

Table 2. XRD results of the Maragheh clayey soil

Sample No.	Identified Clay (%)		
	Montmorionite	Illite	Kaolinite
XRD1	55	31	14
XRD2	37	25	38
XRD3	44	50	6
XRD4	51	33	16
XRD5	54	37	9
XRD6	50	29	21
XRD7	50	31	19
XRD8	45	20	35
XRD9	43	25	32
XRD10	61	18	21
XRD11	49	25	26
XRD12	45	27	28
XRD13	43	33	24
XRD14	40	30	30
XRD15	49	30	21
XRD16	34	29	37
XRD17	32	50	18
XRD18	37	27	36
XRD19	50	22	28
XRD20	50	19	31
XRD21	43	33	24
XRD22	41	28	31
XRD23	39	40	21
XRD24	31	25	44
XRD25	50	19	31

Table 3. Chemical characteristics of the Maragheh clayey soil

Sample No.	SO_4^-	Cl^-	pH
Ch-1	0.08	0.07	7.7
Ch-2	0.05	0.04	7.7
Ch-3	0.06	0.05	7.7
Ch-4	0.06	0.04	7.7
Ch-5	0.09	0.01	7.6
Ch-6	0.18	0.01	7.6
Ch-7	0.11	0.08	7.6
Ch-8	0.10	0.10	7.7
Ch-9	0.08	0.10	7.3
Ch-10	0.04	0.01	7.7
Ch-11	0.07	0.01	7.6
Ch-12	0.08	0.08	7.4
Ch-13	0.06	0.03	7.7
Ch-14	0.10	0.04	7.7
Ch-15	0.13	0.04	7.6
Ch-16	0.11	0.06	7.6
Ch-17	0.08	0.08	7.3
Ch-18	0.18	0.05	7.7
Ch-19	0.15	0.05	7.7
Ch-20	0.11	0.01	7.5
Ch-21	0.08	0.07	7.5
Ch-22	0.06	0.08	7.6
Ch-23	0.18	0.01	7.7

Table 4. The clayey soil mechanical evaluation for Maragheh

Sample No.	USDA class	Fine-grained particles (%)			Casagrande limits (%)			UCS (kPa)
		Passing #200	Silt	Clay	LL	PL	PI	
SM-1	Silty clay	55	25	30	65	25	40	120
SM-2	Clay	72	21	51	50	25	25	180
SM-3	Clay	65	20	45	57	20	37	210
SM-4	Silty clay	60	27	33	43	33	10	230
SM-5	Clay	60	27	33	49	29	20	120
SM-6	Clay	64	10	54	58	35	23	100
SM-7	Clay loam	71	32	39	65	21	44	120
SM-8	Clay	58	30	28	60	33	27	150
SM-9	Clay	51	14	37	60	30	30	180
SM-10	Clay	55	20	35	67	25	42	180
SM-11	Clay	59	34	25	51	25	26	120
SM-12	Clay loam	63	30	33	58	28	30	150
SM-13	Clay	63	30	33	44	33	11	150
SM-14	Clay	60	20	40	51	32	19	200
SM-15	Clay	60	17	43	60	33	27	210
SM-16	Clay	71	21	50	68	25	43	210
SM-17	Clay	65	27	38	65	25	40	180
SM-18	Clay	63	36	27	55	29	26	150
SM-19	Clay	49	24	25	51	27	24	120
SM-20	Silty clay	43	25	18	43	31	12	120
SM-21	Silty clay	57	28	29	49	20	29	100
SM-22	Clay	59	26	33	47	23	24	180
SM-23	Clay	60	21	39	50	28	22	200
SM-24	Clay	62	22	40	60	25	35	200
SM-25	Clay	71	20	51	60	33	27	180

In order to estimation of clayey soil's swellability, the direct and indirect procedures were proposed by several scholars. Direct methods are utilized based on laboratory tests such as the uniaxial consolidation and the inflatability tests, which usually involve additional costs.

Indirect methods are usually ancillary methods that can be estimated based on soil mechanics tests results such as plasticity and soil activity indices. Yilmaz (2006) present the soil activity chart for simple application to obtain swelling potential by indirect procedures.

Fig. 4 is shows the indirect swelling potential for studied soils. As seen in this figure, the most of samples classified as low to moderate swellability which some samples shows high potential of swelling. In this regard, it can be said that fine-grained soils in the study area have extensive and special conditions in terms of swelling. Thus, this area needs special attention in terms of inflation.

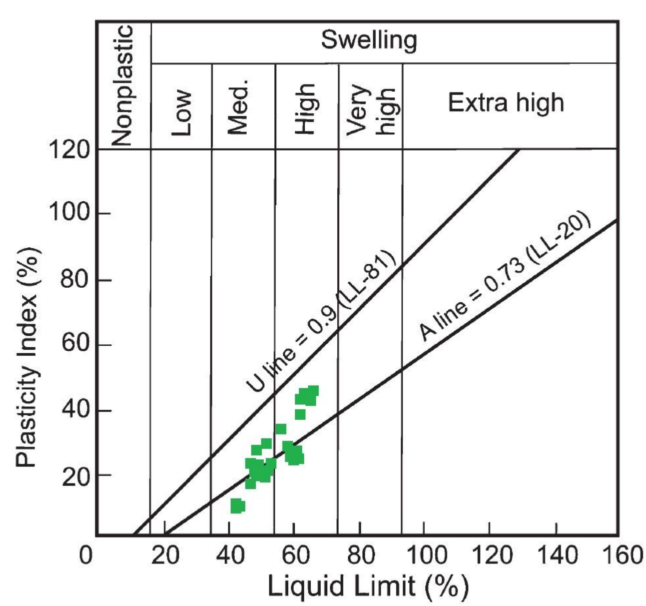

Figure 4. The swelling activity chart for Maragheh

4. Conclusion

This study focused on the Maragheh city's clayey soil characteristics to evaluate the swelling potential of fine-grained soils which it can be cause expansion problems for these structures. The Maragheh located in west of on the outwash plain of Urmia Lake in East-Azerbaijan province, NW of Iran. Geologically, Maragheh city is located on young alluvial formations, lake sediments of evaporate deposits related to Neocene formations from Urmia lake to volcanic and igneous masses of rocky outcrops of Sahand Mountain activity. The Maragheh region, due to certain geological conditions and being on the Sahand alluvial fan, is considered as drainage path for Maragheh-Bonab plain and Urmia Lake basin. Maragheh city is covered by the Quaternary alluvials and recent soils which mostly is fine-grained contains different amounts of clay minerals where causes several events like swelling. So, it has been raised with considerable seriousness and requires full evaluations in this field. The presented paper, tried to understand the clayey soil's swelling potential related to Marageh city in East Azerbaijan Province, NW of Iran; by using comprehensive laboratory tests (concluded 25 samples from 10 different sampling location) which included physicochemical properties, USDA class of soil and clay mineralogical aspects. The experiment results was used by regression analysis for formulate the swelling based on laboratory indexes (i.e., water absorption, porosity, density, Gs, SO4-, Cl-, pH, Casagrande limits, UCS, XRD and clay content). According to the analysis results, the studied soil's (where classified as clay, clay loam and silty clay) swelling status is varied and located in moderate to high potential.

Acknowledgements

The authors wish to thank the Department of Agriculture management, University of Mohaghegh Ardabili for giving the soil tests lab and preparing experiments studies.

References

Aghanabati A., 2007. *Geology of Iran*. Geological Survey & Mineral Explorations of Iran press, 708 p.

Ahadi-Ravoshti D., Hashemimajd K., 2017. Evaluate the clay minerals physicochemical properties on Bonab swelling soils. *Journal of Geotechnical Geology*, 13(2): 69-74.

Azarafza M., Ghazifard A., Asghari-Kaljahi E., 2018. Effect of clay minerals on geotechnical properties of fine-grained alluviums of South Pars Special Zone (Assalouyeh). In: *Proceedings of the 36th National and the 3rd International Geosciences Congress of Iran*, Tehran, Iran, Feb. 2018 [In Persian]

Charlie W.A. Osman M.A., Ali E.M. 1984. Construction on expansive soils in Sudan. *Journal of Construction Engineering and Management, American Society of Civil Engineers, Construction Division*, 110(3): 359-374.

Chen F.H., 1988. *Foundations on expansive soils*. Elsevier Science Publishers, 255 p.

Coduto D.P., 2001. *Foundation design: principles and practices (2nd Edition)*. Prentice Hall, 883 p.

Das B.M., 2008. *Advanced Soil Mechanics (3rd Edition)*. CRC press, 600 p.

Day R.W., 2001. *Soil testing manual: procedures, classification date and sampling practices*. McGraw-Hill, Inc, 624 p.

Driscoll R.M.C., Crilly M., 2000. *Subsidence Damage to Domestic Buildings. Lessons Learned and Questions Asked*. IHS BRE Press, 132 p.

Drits V.A., Tchoubar C., 2012. *X-Ray Diffraction by Disordered Lamellar Structures: Theory and Applications to Microdivided Silicates and Carbons*. Springer Science & Business Media, 371 p.

Farrokhpay S., Ndlovu B., Bradshaw D., 2016. Behaviour of swelling clays versus non-swelling clays in flotation. *Minerals Engineering*, 96-97: 59-66.

Geological Survey and Mineral Exploration of Iran, GSI., 2009. *Maragheh Geological map - scale: 1:100,000*. Geological Survey of Iran, the maps unit, Tehran, Iran.

Ghazifard A., Nikoobakht S., Azarafza M., 2016. Municipal Waste Landfill Site Selection based on Environmental, Geological and Geotechnical Multi-criteria: A Case Study. *Iranian Journal of Environmental Technology*, 2(3): 49-67.

Grunwald S. 2006. *Soil and water. University of Florida: Secondary Silicates*. http://grunwald.ifas.ufl.edu/Nat_resources/silicates/silicates.htm. Date of access: 24th January 2007.

Jones D.E., Holtz W.G. 1973. Expansive soils – the hidden disaster. *ASCE Civil Engineering*, 43(8): 49-51.

Lucian C. Hintze S., Stille H., 2006. Damage to buildings on expansive soils in Kibaha, Tanzania. *Journal of Building and Land Management*, 13(2): 39-47.

Meehan R.L., Karp L.B. 1994. California housing damage related to expansive soils. *Journal of Performance of Constructed Facilities*, 8 (2): 139-157.

Murray H.H. 2006. *Applied Clay Mineralogy: Occurrences, Processing and Application of Kaolins, Bentonites, Palygorskite-Sepiolite, and Common Clays*. Elsevier Science, 180 p.

Yilmaz I., 2006. Indirect estimation of the swelling percent and a new classification of soils depending on liquid limit and cation exchange capacity. *Engineering Geology*, 85: 295-301.