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Laboratory study to measure the swelling potential of fine-grained clay soils: A case study for Malekan city

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ABSTRACT

Swelling potential is one of the most important effect of fine-grained clay soils which causes damage to the soil texture and structures built with/or on it. The ability to absorb water and swelling in clay soils is directly related to the clay types and properties where this increases with increasing clay complexity. Presented article attempted to provide the empirical relation between physicochemical properties of the clayey soils and swelling potential of Malekan city's soils. For this purpose, a laboratory tests series including physical properties, XRD, chemical ratio, atterberg limits and fine-grained particles and hydrometery analysis was conducted on 25 clayey soils samples. The tests results are classified by United States Department of Agriculture (USDA) systems and swelling activity charts to provide the clay minerals activities in Malekan. According to the results, the swelling potential of clays is medium to high and very high which must be considered as high risk for soil inflation.

1. Introduction

Clay minerals are known as hydro-aluminum phyllosilicates with variable elements quantities which with water presence is changes and make different behavior were is very important to agricultural engineering. The clays structures are the sheet form and common weathering products form rock and soils were mostly composed of phyllosilicate minerals containing different amounts of water. Clays has plastic behavior due to them fine-grained particle size and geometrical conditions as well as water content which originates from the clays structures and make hard, extensive and unpredictable behaviors (Savage, 2007).

Clay minerals based on the sheet structures classified in the 1:1 or 2:1 groups where originates because they are fundamentally built of tetrahedral silicate sheets and octahedral hydroxide sheets. A 1:1 class consists of a tetrahedral sheet and an octahedral sheet; and a 2:1 class consists of consists of an octahedral sheet sandwiched between two tetrahedral sheets. As to this classification, the clay minerals are categorized in Kaolin, Illite, Mica, Serpentine, Talc, Chlorite, Vermiculites and smectite (montmorillonite) main groups where each groups can be divided in several sub-groups (Bergaya and Lagaly, 2013; Azarafza et al., 2018). Montmorillonite is the most common and the best studied clay, which has been used in polymer nanocomposites for almost three decades which is, belongs to the smectite family of clays and it has 2:1 layer structure (Jayrajsinh et al., 2017). The montmorillonite is faced with high swelling activity were known as expansive clay (Farrokhpay et al., 2016). Expansive clay is a clay soils phenomenon related to montmorillonite which that is prone to large volume changes (swelling-shrinking) directly by water content variations (Yazdandoust and Yasrobi, 2010). Nagaraj et al. (2010) mentioned the montmorillonite and bentonite has the highest value of shrink-swell capacity among other clay groups. In this regard, if clayey soils have different value of these minerals can be faced with swelling potential. If this potential cross limit lines can damage to the soil texture and structures built with/or on it.

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The swelling activity in geo-engineering is named 'expansive soil' which is one special type of problematic soils that was highly sensitive to the water content changes in fine-grained clay soils. Theses soils swells and shows volumetric deformation in response to moisture content especially in clay minerals were faced with water (Punthutaecha et al., 2006) which can be responsible for various scale damage and distortion to structures like as pavements, light buildings, roads, farms, etc. (Chen, 1988).

The different direct / indirect techniques are used to estimate the swelling potential for clayey soils which provided valuable results to swelling classification and risk potential evaluations. As commonly, the indirect methods used as well as direct methods to achieving the results (Yilmaz, 2006). The presented study was attempted to use the indirect techniques to swelling potential for Malekan city.

2. Material and Methods

2.1. Study location

Malekan is a city and capital of Malekan County, East Azerbaijan Province, Iran. This city with a population of 27431 people based on 2016 census is ranked as the thirteenth most populous city in the province (Statistics Center of Iran, 2016). Malekan is located in the southeast of Lake Urmia, at the junction of East and West Azerbaijan provinces. This city has an area of 1007 square kilometers and its distance from the Tabriz is 144 km. The location of the studied area is illustrated in Fig. 1. The Malekan people are Azerbaijani landlords and speak Azerbaijani Turkish. Malekan climate is influenced by the Urmia Lake which currents cause rain and sometimes snow in spring, autumn and winter (Azarafza and Mokhtari, 2013). The most important industry in Malekan is agriculture and people are generally farmers and ranchers. In term of geological aspect, the Malekan located on the Quaternary alluvial which include detached sediments and organic/inorganic soils. The alluvium is the main in agricultural pastures classified in the fine-grained soil included clay to silt soil and sand. The clayey soil is the most important part of the described soils and mainly contained smectite group (Azarafza and Ghazifard, 2016).

Figure 1. Location of the Malekan city in Iran

2.2. Experimental procedures

The presented article is provided an experimental survey on Malekan city's soils about swelling potential which is causes some damage on agricultural facilities and farms. For this purpose, several laboratory tests series including soil physical properties (ASTM D7263; ASTM D2216; ASTM D854), XRD (Drits and Tchoubar, 2012), chemical ratio, atterberg limits (ASTM D4318), fine-grained particles and hydrometery (ASTM D7928) analysis was conducted on 25 clayey soils samples.

From a laboratory point of view, by identifying susceptible areas, 25 samples of fine-grained soil were taken from these areas. Samples were prepared after transfer to the laboratory and physico-chemical and mechanical tests were performed on them. All tests are performed according to the ASTM instructions in Soil Laboratory of the Department of Agriculture, University of Mohaghegh Ardabili. The results of the experimental studies have been used to evaluate the studied soils swelling potential. For swelling potential evaluations, indirect methods were used which has been thoroughly reviewed by Yilmaz (2006).

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 and pH tests were performed to determine the chemical characteristics and the sieve analysis, hydrometer, plastic limits, clay particles, swelling tests performed to determine the mechanical characteristics of Malekan city's soils. The samples were classified by United States department of agriculture (USDA) classification system. Finally, the results of the laboratory tests were evaluated, classified and used to investigation of the swelling potential of Malekan clay.

3. Results and Discussions

By considering the results of the experimental tests were conducted on the Malekan fine-grained samples, it is recognizing the soil characteristics were wide which is related to the climatic and geological conditions of the studied region. Table 1 is presented the physical properties of studies soils. In chemical evaluations, the XRD results and chemical ratio of materials was considered to estimate pH, sulfide and chloride concentration. Table 2 is presented the results of the chemical evaluations of studied soils. By conduction soil mechanical tests on the soil samples, the mechanical properties are estimated for clayey soils of the Malekan city. The Table 3 is presented the results of soil mechanical evaluation of the studied soils which is classified by USDA classification system.

Table 1 The physical characteristics of studied soils

Parameters	Max	Min	Ave.
Water absorption (%)	18.8	9.5	14.1
Porosity (%)	77.3	45.6	61.5
Dry density (kN/m^3)	23.9	17.9	20.9
Saturated density (kN/m^3)	26.1	20.6	23.3
Specific gravity (G_s)	2.73	2.48	2.60

Table 2 The chemical characteristics of studied soils

#	pH	Cl^-	SO_4^-	XRD results (%)		
				Smectite	Kaolinite	Illite
1	7.3	0.02	0.06	66	12	22
2	7.5	0.01	0.09	59	7	34
3	7.7	0.01	0.12	52	21	27
4	7.7	0.04	0.15	58	1	41
5	7.1	0.02	0.06	74	8	18
6	7.4	0.04	0.08	77	9	14
7	7.7	0.02	0.07	71	8	21
8	7.1	0.01	0.07	69	12	19
9	7.1	0.01	0.09	66	10	24
10	7.3	0.06	0.11	61	15	24
11	7.5	0.04	0.12	58	15	27
12	7.7	0.05	0.06	55	10	35
13	7.6	0.05	0.07	31	36	33
14	7.3	0.02	0.08	37	31	32
15	7.3	0.02	0.09	45	32	19
16	7.4	0.01	0.08	49	15	36
17	7.6	0.01	0.12	67	4	29
18	7.6	0.03	0.11	71	4	25
19	7.7	0.03	0.17	65	13	22
20	7.7	0.02	0.09	67	9	24
21	7.7	0.01	0.08	63	13	24
22	7.7	0.01	0.12	61	18	21
23	7.1	0.02	0.15	67	0	33
24	7.1	0.06	0.17	73	6	21
25	7.6	0.04	0.17	53	11	36
Max	7.7	0.06	0.17	77	36	41
Min	7.1	0.01	0.06	31	0	14
Ave	7.46	0.02	0.103	60.0	12.9	26.4
SD	0.23	0.01	0.03	11.3	9.46	6.89
VR	0.05	0.001	0.001	128	89.5	47.5

SD = Standard deviation; VR= Variance

Table 3 The soil mechanical properties of studied soils

#	USDA class	Grained particles (%)			Atterberg limits (%)		
		#200	Clay	Silt	LL	PL	PI
1	Clay	63	44	19	73	35	38
2	Clay	51	39	12	64	30	34
3	Clay	47	40	7	58	27	31
4	Clay	58	43	15	50	22	28
5	Silty clay	22	10	12	50	29	21
6	Clay	39	31	8	67	37	30
7	Clay	53	35	18	66	36	30
8	Clay	55	38	17	73	39	34
9	Clay	48	36	12	69	31	38
10	Clay	42	30	12	52	27	25
11	Silty clay	33	14	19	50	22	28
12	Clay	59	38	21	43	27	16
13	Clay	61	39	22	55	25	30
14	Clay	62	33	29	41	19	22
15	Clay	54	37	17	71	38	33

Table 3 Continuance

#	USDA class	Grained particles (%)			Atterberg limits (%)		
		#200	Clay	Silt	LL	PL	PI
16	Clay	54	37	17	70	33	37
17	Clay	51	39	12	65	36	29
18	Clay	61	46	15	55	31	24
19	Clay	33	24	9	51	27	24
20	Clay	28	18	10	50	37	13
21	Clay	64	42	22	50	35	15
22	Clay	61	34	27	63	35	28
23	Clay	58	41	17	69	30	39
24	Clay	51	32	19	71	38	33
25	Clay	47	35	12	61	28	33
Max	Clay	64	46	29	73	39	39
Min		22	10	7	41	19	13
Ave	-	50.2	34.2	16	59.4	30.9	28.5
SD	-	11.5	9.05	5.5	9.83	5.61	7.15
VR	-	133	1.9	31.2	96.6	31.5	51.1

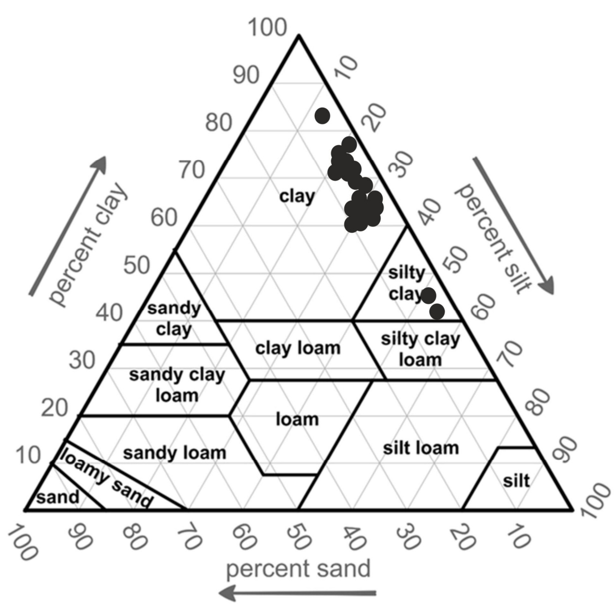

Figure 2. USDA classification of the Malekan soils

As known the swelling potential is related to clay materials in soils were faced with water contents. So, having a proper view of clay minerals characteristics help to know the swelling phenomenon. In order to quantitative evaluations of clay particles and clay types where effected on swelling potential of fine-grained soils, the swelling chart are developed by several scholar by using the empirical methods which is clearly measurable element from clayey soil behaviors assessment. Yilmaz (2006) presented empirical charts to evaluate the swelling potential of clayey soils based on indirect procedures. Figure 3 is presented the swelling potential charts where used to evaluate the clay activities related to Malekan soils. As seen in this figure, the swelling potential of the studied soils is medium to high and very high which must be considered as high risk for soil inflation.

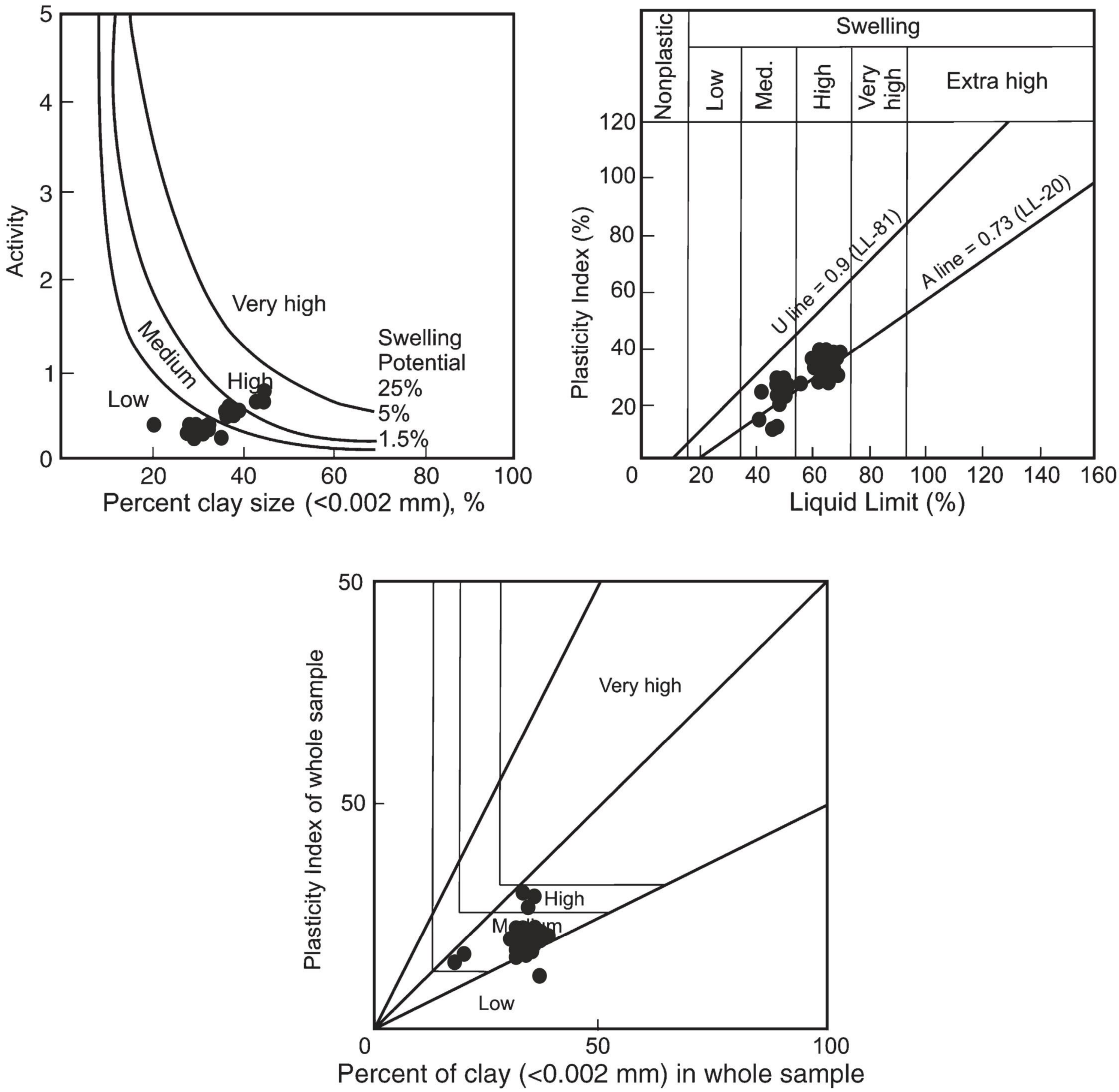

Figure 3. The swelling activity charts for Malekan soils

4. Conclusion

Expansive soils is the most swell-able soils which causes damage to the soil texture and structures built with/or on it. The ability to absorb water and swelling in clay soils is directly related to the clay types and properties where this increases with increasing clay complexity. Present study tried to provide the experimental view of the Malekan's fine-grained clayey soils for swelling potential and soil activities. For this purpose, a laboratory tests series including physical properties, XRD, chemical ratio, atterberg limits and fine-grained particles and hydrometery analysis was conducted on 25 clayey soils samples. The tests results are classified by United States Department of Agriculture (USDA) systems and swelling activity charts to provide the clay minerals activities in Malekan. According to the results, the swelling potential of clays is medium to high and very high which must be considered as high risk for soil inflation.

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