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Assessment of the swelling potential of Baghmisheh marls in Tabriz, Iran

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Abstract. Tabriz is a large Iranian city and the capital of the East Azerbaijan province. The bed rock of this city is mainly consisted of marl layers. Marl layers have some outcrops in the northern and eastern parts of city that mainly belong to the Baghmisheh formation. Based on their colors, these marls are classified into three types: yellow, green, and gray marls. The city is developing toward its eastern side wherein various civil projects are under construction including tunnels, underground excavation, and high-rise building. In this regard, the swelling behavior assessment of these marls is of critical importance. Also, in lightweight structures with foundation pressure less than swelling pressure, several problems such as walls cracking and jamming of door and windows may occur. In the present study, physical properties and swelling behavior of Baghmisheh marls are investigated. According to the X-ray diffractometer (XRD) results, the marls are mainly composed of Illite, Kaolinite, Montmorillonite, and Chloride minerals. Type and content of clay minerals and initial void ratio have a decisive role in swelling behavior of these marls. The swelling potential of these marls was investigated using one-dimensional odometer apparatus under stress level up to 10 kPa. The results showed that yellow marls have high swelling potential and expansibility compared to the other marls. In addition, green and gray marls showed intermediate and low swelling potential and swelling pressure, respectively.

Keywords: Tabriz; swelling; swell pressure; Baghmisheh marls

1. Introduction

Marls are identified as geological materials (as soil or rock) generally composed of clay minerals and carbonate with different proportions, normally between 35 and 65% (Pettijohn 1975). High deformation potential and time-dependent behaviors including consolidation, settlement, and swelling phenomenon are among the serious problems associated with marls. Structural and pavement damage due to expansive clays as a composition of marl layers have been observed worldwide, for example in Australia, Poland, and Turkey. The city of Tabriz from the east part is developing by constructing various civil projects such as high-rise buildings, tunneling, underground spaces, deep excavation, and highways. Swelling behavior assessment of marls in urban areas such as Baghmisheh formation is very important and directly affects the safety of structures. Several studies have been conducted so far on the specification of marls (generally expansive clays) and their swelling potential and expansiveness in different regions around the world; however, there are few efforts about this subject in Iran. The focus of these works is investigating some certain properties such as stabilization of marly and expandable soil by lime and other additives (Yong and Ouhadi 1997 and 2007). Jalali-Milani *et al.* (2017) investigated the consolidation behavior of Baghmisheh marls on the Tabriz city in Iran. The influence of clay minerals on the stability of marls was studied by Mohamed (2000). Tang *et al.* (2009) analyzed the occurrence of railway heave due to swelling on a site in southern France.

Sadrekarimi *et al.* (2006) studied the geotechnical features of Tabriz marls. In this study, representative specimens were tested for swelling potential assessment and found that swelling percentage and pressure are as high as 13.6% and 1020 kPa, respectively. In this research, the results of the addition of lime and fibers over the compacted specimens, as a fill material, were presented.

Zumrawi (2013) studied geotechnical aspects for roads construction on expansive soils and concluded that before paving expansive soils, a geotechnical site investigation is necessary and structural problems. Moreover, they stated that premature failures of roads settled on expansive soils are mainly due to poor drainage, age, climatic conditions, and neglected maintenance.

Shaqour *et al.* (2008) investigated the geotechnical and mineralogical characteristics of marl deposits in Jordan. The test results showed a positive linear relationship between the clay content and both liquid limit (LL) and plastic limit (PL), as expected. The tests results also proved an inverse linear trend between the clay content and the maximum dry density in both standard and modified compaction. This result is attributed to the adsorption of water by the clay minerals.

Fernandes *et al.* (2015) studied in situ behavior of the shrinkage-swelling of a clay soil over several cycles of dry-rewetting. In this study, an in situ experimental tool was used for analyzing the shrinkage-swelling movements of

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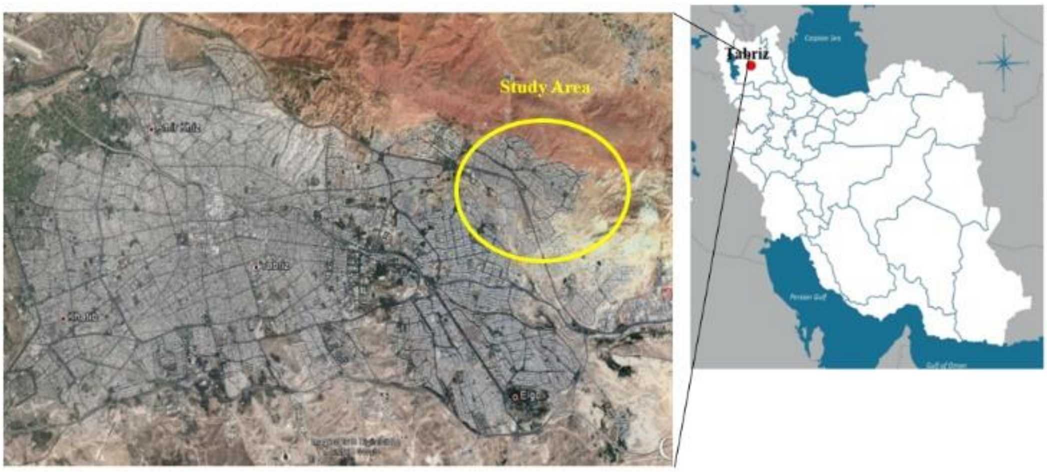

Fig. 1 The location of the study area in Tabriz, NW of Iran

clayey soil in relation to the water content and temperature variations. The results revealed considerable variation in temperature and water content at a depth of 3 m. Elert *et al.* (2018) investigated Smectite formation upon lime stabilization of expansive marls. Also, Angin and İkizler (2018) and Aziz *et al.* (2015) searched on treated expansive soils.

Athmania *et al.* (2010) investigated the susceptibility of clay and marl formation in Mila Province. They suggested a characterization methodology for the shrinkage-swelling potential of clay and marl formations, mainly the geotechnical profile of Mila Province located in the northeast of Algeria.

Azarafza *et al.* (2018) investigated the effect of clay minerals on geotechnical properties of fine-grained alluviums of Pars Special Economic Energy Zone (Assalouyeh). In order to evaluate the relationship between mineralogical and chemical features with engineering properties of the studied area, some laboratory tests (e.g., grain size analysis, hydrometer, Atterberg limits, specific gravity, and direct shear tests) and chemical analyses (e.g., XRF, Sulfate-Chlorate contents, organic material content, and pH) were conducted.

Djellali *et al.* (2017) studied indirect estimation of swelling pressure of clayey subgrade under pavement structures by various laboratories testing on 40 soil samples taken from a route in Tebessa city (Algeria). Finally, they developed a statistical model for the indirect estimation of swelling pressure.

In the present study, swelling potential and expansiveness properties of Baghmisheh formation marls are investigated. The aim of this study is to improve the understanding of the behavior of these soils in road subgrade and construction site for building and other structures. Location of the study area in Iran is shown in Fig. 1.

2. Marl swelling problems

The major problems on marls in the study area include their weathering and loosing of marlstones, consolidation,

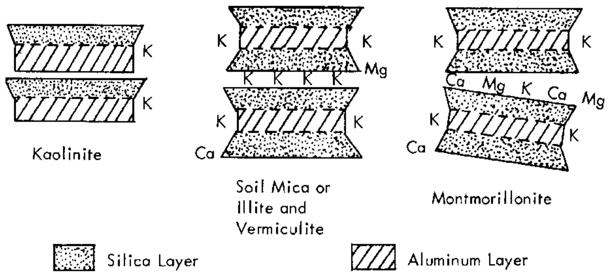

Fig. 2 Schematic of clay minerals structures

swelling and consequently differential settlement marls, road cracking and heaving due to uplifting pressure, and slope instability. It has been reported and observed occurrence rate of these phenomena increases after precipitation and water absorption. Repetitive wet-dry cycles have important impacts on marls behavior. Marls are classified as problematic materials in civil and geotechnical projects due to leading to structural damages.

Swelling or expansive soils are generally characterized by the presence of clay minerals of the Montmorillonite group. These soils are problematic mainly due to their tendency to water absorption, which leads to large volume changes in their moisture content (Zumravi 2013, Nelson and Miller 1992). Environmental change including stress releases due to excavation, desiccation caused by a temperature increase in the warm season, and volume increase due to absorption of moisture and water are the main factors affecting the volume changes of marls.

Soils with a high content of swelling clays have a very high affinity for water, partly because of their small size and positive ions (Zumrawi 2013). The swelling behavior is usually attributed to the intake of water into the Montmorillonite, an expanding lattice clay mineral in expansive soils. Identification of the presence of expanding clay minerals in expansive soil is possible by different methods such as X-ray diffraction (XRD), electronic microscopy, differential thermal analysis, and wet chemical analysis. In this study, clay minerals were identified by the XRD. Fig. 2 presents the structure of three types of clay mineral schematically. There are various methods for identification, determination, and classification of swelling

Fig. 3 Cracking on walls of residential buildings due to marls swelling phenomena in the Vali-Asr area

Fig. 4 Cracking walls in residential buildings located in Vali-Asr area of Tabriz (right) and desiccation cracks in the marls due to shrinkage (left)

soils properties. In this study, the following methods were applied for assessing the swelling potential of marly soils:

Swell measuring by Oedometer apparatus (direct method) according to the ASTM D4546 (2014); Atterberg limits of soil as proposed by Chen (1975) and also by Daksanamurthy and Raman (1973); and a method offered by Rao *et al.* (1987).

Marl layers as expansive soils cover a large area of the east part of Tabriz city and cause significant damages to buildings, roads, and other structures founded on these layers. Figs. 3 and 4 illustrate crack propagation on walls of a residential building and desiccation cracks in yellow marls due to the occurrence of swelling phenomena.

3. Geological setting

Tabriz with more than 2 million people is one of the largest industrial and metropolises cities of Iran. The city, which is located in western Alborz-Azerbaijan geology zone, is founded on alluvium deposits in the south and west parts and marly layers in the north and east parts. In terms of structural geology and tectonic status, Tabriz is located along Alpian-Himalayan active belt and has experienced several tectonic activities, leading to about 1,400 seismic events and earthquakes with often disastrous effects on rural and urban residential (Azarafza and Ghazifard 2016). Marl layers are characterized as red deposits along the north of the city, with salt and gypsum interlayers named Upper Red Formation (URF) (Rieben 1935). This formation in addition to marls consists of sandstone, mudstone, siltstone, and conglomerate beds with salt and gypsum interlayers. Baghmisheh formation, which contains marl-shale layers belonging to Miocene and Pliocene, is superimposed on the URF. Generally, Tabriz marls can be seen as yellow, green, and gray/black colors outcropped in the Baghmisheh area. In fact, Tabriz urban area is underlain by recent alluvium in the central part and a complex of conglomerate, fine sediments, red sandstone, and alteration of green and dark grey marl forms as the bedrock. Tabriz marl is generally known as a plastic and sticky, difficult to handle, and with very poor quality for engineering purposes. For these reasons, considerable volumes of construction waste produced due to numerous developing projects of the urban area and industrial zones are dumped over valleys, low-lying areas, and hillsides (Sadrekarimi *et al.* 2006). Geological map of the study area is presented in Fig. 5 and outcrops of mentioned marls are shown in Figs. 6 and 7.

A geological column of the study area is presented in Fig 8. As can be seen, the stratigraphy of Tabriz city consists of Cenozoic and Quaternary formations and there is no sign of Paleocene, Eocene, and Oligocene sediments.

The URF formation is overlain by Baghmisheh formation. Outcrops of this bed are visible in the northwestern parts of the city. Fish bed sediments lay on Baghmisheh formation with the same dip. These layers are covered by quaternary sediments including loose to hard conglomerates. Tabriz plain is covered by unconsolidated sediments (Mohammadi *et al.* 2015).

The URF with a thickness amounting to 2000 m has

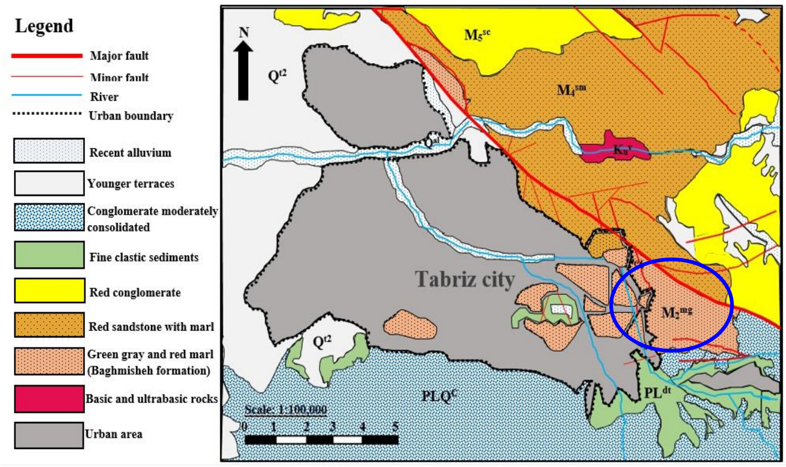

Fig. 5 Tabriz geological map (adapted from the National Geosciences Database of Iran, 2004)

Fig. 6 Outcrop of yellow, green, and gray marls in the east of Tabriz

Fig. 7 An outcrop of yellow and gray marls of Tabriz

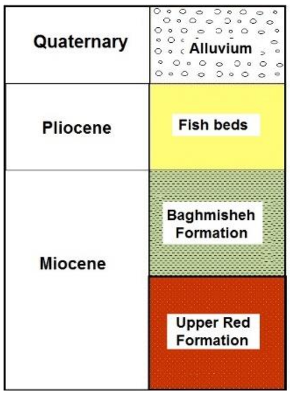

Fig. 8 A geological column of Tabriz area based on drilling data and field geology

formed the bedrock of the northern and eastern parts of Tabriz city. This formation consists of red-colored marls, sandstone, siltstone, claystone, and conglomerate with layers and veins of gypsum and anhydrite.

Baghmisheh formation is geologically located between the URF and fish beds belonging to Pliocene contain marls that have experienced folding and faulting due to the tectonic activities at the end of the third geological era (Pasadenan orogeny). The fish beds are overlain by Quaternary alluvial deposits. From the geological point of view, these beds belong to the Pliocene (Reichenbacher *et al.* 2011). The quaternary alluvial deposits are accumulated along the flowing stream and riverbeds of two main rivers named as Aji-Chay and Mehran-Rood that drain the region into Urmia Lake in the western part of the city (Barzegari *et al.* 2013).

4. Sampling

Tabriz is highly covered by dirty green and yellow marls in its eastern part. Gray type has rarely outcropped and mainly covered by the other type of marls layers. The outcrops of these marls in the surface appear as weathered soil but in the depth are as loose and fissured rock layers. To

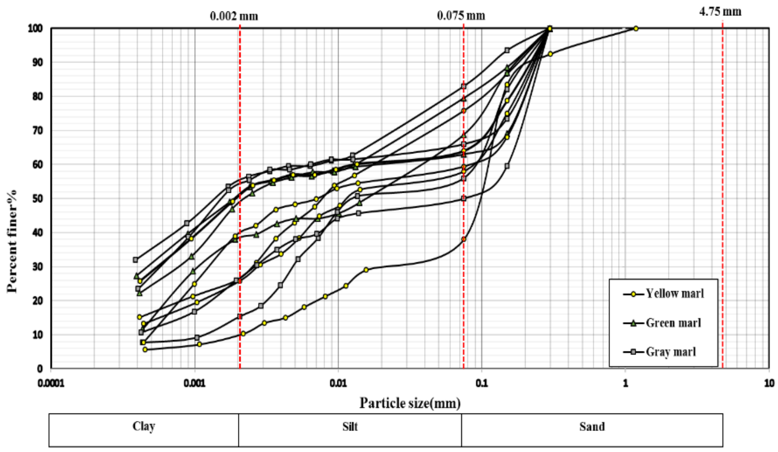

Fig. 9 Particle size distribution curve for some Baghmisheh marls samples

perform an experimental study on these marls, some samples were extracted from the drilling cores from subsurface exploration for constructing a high-rise building in the studied area. The depth of yellow, green, and gray/black marls in the studied site was from surface to depth 22 m, 22 to 30 m, and more than 30 m, respectively. In order to prevent disturbance, samples were covered by beeswax and plastic cover.

5. Testing

Laboratory tests including physical characterization, swelling test by odometer apparatus, swelling test proposed by Rao *et al.* (1987), and XRD were performed on some undisturbed samples.

5.1 Physical test results

Main physical characteristics of marls were determined by performing a series of experimental tests including Atterberg limits (ASTM D4318, 2017), particle size distribution and hydrometer tests (ASTM D422, 2017), specific gravity (ASTM D854, 2014), and natural moisture content (ASTM D2216, 2010). The results of physical test results are shown in Table 1. The particle size distribution of the studied marls is illustrated in Fig. 9. It can be seen that in three types of Baghmisheh marls (i.e., yellow, green, and gray), percentage of clay-size particles is in the range between 26 and 54%. With an increase in the sample extraction depth, the unit weight of gray marls increased as expected. Plasticity index of yellow, green, and gray marls was obtained in a range between 22 and 61%.

Atterberg limit tests carried out in accordance with ASTM D4318 (2017) were plotted on the Casagrande plasticity chart (Fig. 10). As can be seen, the soil type is CL and CH according to the unified soil classification system (USCS). Plotting the Atterberg limits on the chart proposed by Holts and Kovacs (1981) showed that the studied minerals are Montmorillonite and Illite (Fig. 11).

According to the XRD results in Fig. 12, clay minerals in the studied Baghmisheh marl mainly consist of Illite, Montmorillonite, Kaolinite, Chloride, and a small amount of other minerals such as Calcite, Dolomite, Quartz, Gypsum, Muscovite, and Feldspar. Dark color of gray marls can be attributed to existence of amorphous materials (i.e.,

Table 1 Physical parameters of Baghmisheh marls

Marl type	USCS	Gs	LL %	PI %	Fine material content %	Clay size particles %	Initial void ratio (e_0)
Yellow	CL	2.53-2.63	32-69	22-44	39-74	26-49	0.61-0.90
Green	CH	2.63-2.65	60-72	34-42	65-78	47-50	0.55-0.66
Gray	CH	2.66-2.70	40-84	32-61	52-80	26-54	0.54-0.56

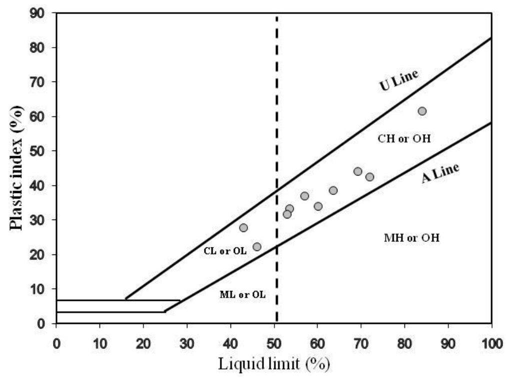

Fig. 10 The plot of Atterberg limits of studied marls on the Casagrande (1936) chart

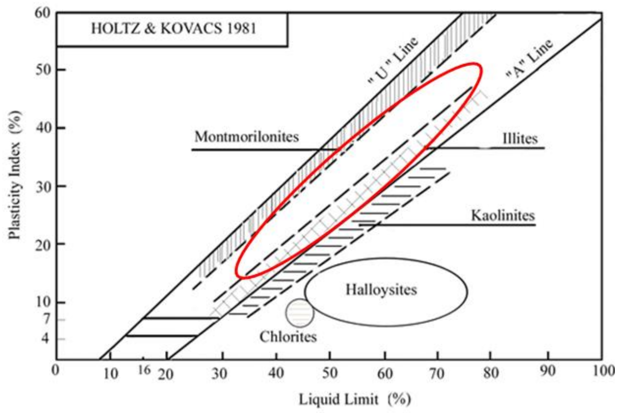

Fig. 11 Clay mineral type of studied marls on the chart of Holts and Kovacs (1981)

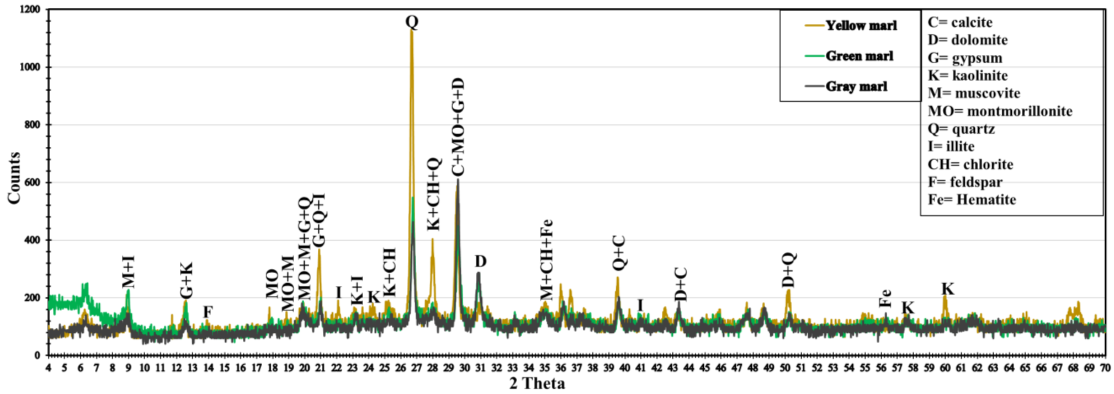

Fig. 12 XRD diagram for three types of Baghmisheh marls

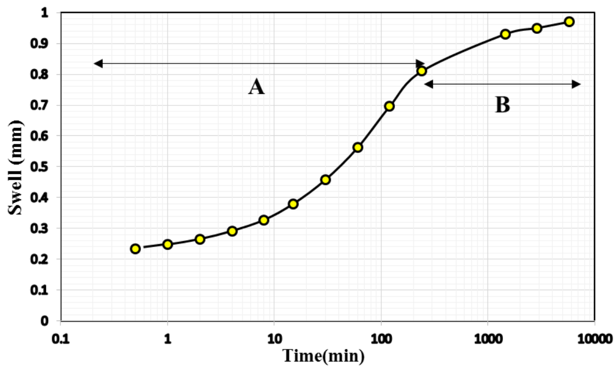

Fig. 13 The typical swell-time curve for marls

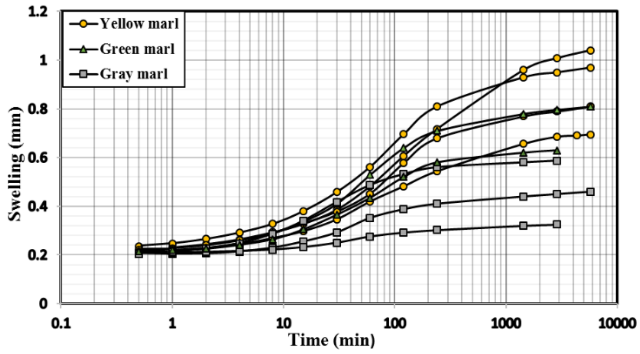

Fig. 14 Swelling-time curves for Baghmisheh marl specimens

Table 2 Results of the one-dimensional swelling tests

Marl type	Swelling percentage (%)	Swelling pressure (kPa)	End of primary swelling time (min)
Yellow	3.5-5.3	5-14	250-700
Green	2-4	9-10	150-180
Gray	1-2	4-9	90-110

organic materials). Other colors such as yellow and green are due to the oxidation/reduction of $Fe^{2+}$and Fe^{3+}.

5.2 Swelling tests

In this study, one-dimensional swelling of marls was investigated by performing a series of tests according to the ASTM D4546 on samples extracted from a borehole on the Baghmisheh marls. These testing methods cover three alternative laboratory methods for determining the magnitude of swelling or settlement of relatively undisturbed or compacted cohesive soil. These three alternatives test methods (i.e., A, B, and C) require a specimen restrained laterally and loaded axially in an oedometer in saturation condition. In method 'A' (used in this study), the specimen is inundated and allowed to swell vertically at the seating pressure up to 10 kPa applied by the weight of the top porous stone and load plate. Then, the load was applied to the specimen until its initial height was obtained. Based on the results of this test, two important parameters including swell percentage and swell pressure are calculated. Fig. 13 exhibits typical swell versus elapsed time. In this figure, part A and part B indicates of primary

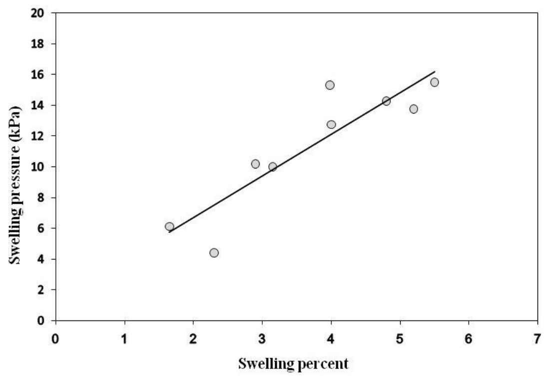

Fig. 15 Relationship between swelling percentage and swelling pressure

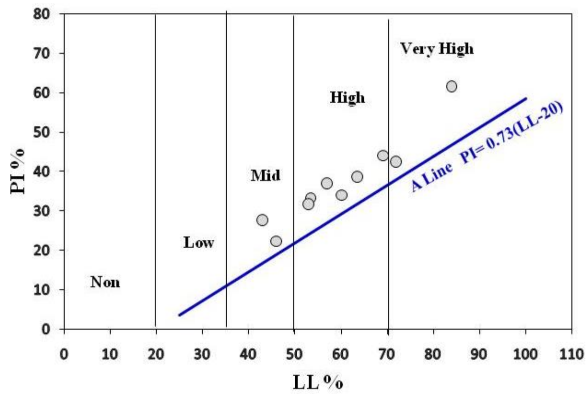

Fig. 16 Classification of expansive soils by PI-LL diagram after Daksanamurthy and Raman (1973)

Table 3 Results of the one-dimensional swelling tests

Expansiveness degree	Swelling pressure (kPa)	Total volume change (%)	LL (%)	Particle Finer than No.200 sieve (%)
Very high	>20	>10	>60	>95
High	5-20	3-10	40-60	60-95
Mid	3-5	1-5	30-40	30-60
Low	1	<1	<30	<30

Table 4 Swelling potential classification in terms of plasticity index (Chen 1975)

Plasticity index (%)	Swelling potential
0-15	Low
10-35	Mid
20-55	High
>35	Very high

and secondary swelling steps, respectively. The major quantitative results from oedometer swelling test are listed in Table 2. The diagram of swell versus time for various types of Baghmisheh marls is depicted in Fig. 14. As can be observed, yellow marls have the highest swelling potential among the other types of Baghmisheh marls. This high potential is attributed to the following reasons:

- Yellow marls have a high initial void ratio.
- From the surface to depth 20 m, they have been subjected to weathering and low density and consolidation due to limited overburden pressure.
- Low aging

As shown in Fig. 15, an increase in the value of swell percentage leads to an increase in swell pressure.

According to the classification method proposed by Daksanamurthy and Raman (1973), Baghmisheh marls are classified in three certain swelling categories: medium, high, and, very high (Fig. 16). Classification systems for expansive soils are based on the swelling problems caused in the construction of foundations. Achieving a satisfactory classification of expansive soils requires knowledge of the geotechnical parameters that characterize swelling. The difficulty of the classification is to define these parameters, i.e., pressure and swelling percentage (Yilmaz 2006).

Simple soil property tests can be used for evaluating the swelling potential of expansive soils. Such tests are easy to perform and should be included as routine tests in investigating construction sites in areas with expansive soil. In this regard, the plasticity index and liquid limit are useful indices for determining the swelling characteristics for most clay (Moosavi and Samani, 2017).

Chen (1975) proposed a useful indirect method for classifying expansiveness in soils. As presented in Tables 3 and 4, studied marls with plasticity index between 22 and 61%, LL between 32 and 84%, and fine material content more than 39% have medium to very high swelling potential. These results are in agreement with the results of Chen's method.

5.3 Swelling test results obtained from indirect test methods

Free swell tests are commonly used for identifying expansive clays and predicting the swelling potential. As proposed by Holtz and Gibbs (1956), this method suffers from inaccuracies in volume measurement of dry powder in the air. The free swell (also called as differential free swell and free swell index) is one of the simple experiments commonly performed by geotechnical engineers for estimating soils' expansion potential. Free swell index test is performed to measure the increase in the volume of soil without any external constraint in submerge state.

Rao *et al.* (1987) have proposed a method for obtaining the parameter called "modified free swell index" in soils. In this method, 10 gr of marl specimen is dumped in 100 ml of distilled water and the total volume of swelled soil is measured after 24 h (Fig. 17). Swelling potential in this method is calculated using the following equations

$$\text{Modified free swell index} = \frac{V - V_s}{V_s} \quad (1)$$

$$V_s = \frac{W_s}{G_s \gamma_w} \quad (2)$$

where V_s = volume of a solid particle of soil, V = volume of soil after swelling, W_s = dry weight of soil.

The obtained results are detailed in Tables 5 and 6. It can be observed that, based on the method proposed by Rao *et al.* (1987), all marls of Baghmisheh area are categorized in "medium" group from the swelling potential point of view. Using this method, three types of marls were classified in a similar group due to using disturbed samples in this test.

Fig. 17 Baghmisheh marls after 24 hours swelling based on Rao *et al.* (1987) method

Table 5 Tests results and classification of swelling soil after Rao *et al.* (1987)

Type of marl	Specific gravity	Swell potential	Modified free swell index
Yellow	2.53-2.63	Medium	2.8- 4.2
Green	2.63-2.65	Medium	3.25-4.1
Gray	2.66-2.70	Medium	2.7-4.0

Table 6 Swell potential classification presented by Rao *et al.* (1987)

Swell potential	Modified free swell index
Low	2.5
Medium	2.5-10
High	10-20
Very high	>20

Overall, based on the results of direct and indirect methods, it can be concluded that increasing parameters such as depth, overburden pressure, and stress history consequently leads to a decrease in swelling potential.

6. Conclusions

The studied marls of Baghmisheh formation from Tabriz urban area were classified into three types based on color as yellow, green, and gray. Swelling potential (i.e., expansiveness) of these marls was investigated using several methods including one-dimensional oedometer test (direct method), Rao *et al.* (1987) method, and other indirect methods.

Based on the results of physical tests, clay-sized particles content are in the range between 26 and 54% and plasticity index (PI) of yellow, green, and gray marls are in the range between 22 and 61%. Based on the results of Atterberg limits, plasticity in these marls is increased from yellow to the gray specimens. This characteristic depends on clay minerals types and percentage of clay size particles. According to the XRD tests, the main clay minerals of marls are Illite, Kaolinite, Montmorillonite, and Chloride. Based on the results of oedometer experiments, classification by Chen (1975) and also Daksanamurthy and Raman (1973), the swelling potential of Baghmisheh marls is generally classified as "medium" to "very high". Yellow marls have the highest swelling potential owing to a high void ratio and history of low stress. Meanwhile, gray marls have the minimum swelling potential due to high overburden history and low void ratio.

The test proposed by Rao *et al.* (1987) was carried out for evaluating swelling using a "modified free swell index". According to the results of this test, all types of Baghmisheh marls have a medium swelling potential.

The results of this study revealed that yellow marls have high expansiveness, and these marls may induce damages in lightweight structures road and highway subgrades. In comparison, green marls have an intermediate behavior and, subsequently, gray marls have low expansiveness and swelling potential.

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