Geomechanics and Engineering, *Vol. 12, No. 4 (2017) 561-577*
DOI: https://doi.org/10.12989/gae.2017.12.4.561

Consolidation deformation of Baghmisheh marls of Tabriz, Iran

Shahrokh Jalali-Milani [1a], Ebrahim Asghari-Kaljahi [*1], Ghodrat Barzegari [1b] and Masoud Hajialilue-Bonab [2c]

[1] *Department of Earth Sciences, University of Tabriz, Iran*
[2] *Department of Civil Engineering, University of Tabriz, Iran*

(*Received July 11, 2016, Revised November 06, 2016, Accepted November 26, 2017*)

Abstract. Vast parts of the east of Tabriz city have been covered by Baghmisheh formation marls. These marls can be classified into three types based on their color as identified in yellow, green, and gray marls. Many high-rise buildings and other projects were founded and now is constructing on these marls. Baghmisheh formation marls are classified as stiff soil to very weak rock, therefore they undergo considerable consolidation settlement under foundation loads. This study presents the physical properties and consolidation behavior of these marls. According to the XRD tests, major clay minerals of marls are Illite, Kaolinite, Montmorillonite and Chloride. Uniaxial compressive strength are 100-250, 300-480 and 500-560 kPa for yellow, green and gray marls, respectively. Consolidation and creep behavior of Baghmisheh marls investigated by using of one dimensional consolidation apparatus under stress level up to 5 MPa. The results indicate that yellow marls have high compressibility, settlement and deformation modules. Green marls have an intermediate compressibility and settlement and while gray marls have low compressibility and settlement and from the foundation point of view have high stability. According to the creep test results, all types of marls have not been entered to progressive creep phase up to pressure 5 MPa.

Keywords: Tabriz; consolidation; creep; Baghmishehmarls

1. Introduction

From a geotechnical point of view, marls are identified as a kind of problematic soil/rock which is encountered in several zones of Iran and the rest of the world, as well. Marl is a term to describe the mixture of calcium carbonate and clay, normally between 35 and 65 percent (Pettijohn 1975). One of the main problems of marls is their high deformability, long term time dependent behaviors and settlement. In spite of the good design of the structure and foundation on the marls, because of the lack of precise and reliable determination of deformability behaviors, cracks and damage were experienced in many buildings and structures which were constructed on these types of soils. Several studies has been carried out so far for the characterizations of marls and their engineering and geotechnical properties in different regions of the world and also in Iran. The major subjects of these studies were investigating some certain properties such as the stabilization of marly soil by

*Corresponding author, Associate Professor, E-mail: e-asghari@tabrizu.ac.ir
[a] M.Sc. Student, E-mail: shahrokh.jalali69@yahoo.com
[b] Assistant Professor, E-mail: gbarzegari@tabrizu.ac.ir
[c] Full Professor, E-mail: hajialilue@tabrizu.ac.ir

http://www.techno-press.org/?journal=gae&subpage=7 ISSN: 2005-307X (Print), 2092-6219 (Online)

lime (Yong and Ouhadi 1997 and 2007), the role of clay minerals on marl stability (Mohamed 2000), determining the amount of clay-carbonate content of marls, the influence of porosity on the shear strength of marls (Corthésy *et al*. 2003), investigation of consolidation and creep behavior and determination swell potential in marls.

Voottipruex and Jamsawang (2014) studied characteristics of expansive soils improved with cement and fly ash in Northern Thailand. Actually, this paper studies the swelling and strength characteristics of unimproved and improved expansive soils in terms of the swell potential, swelling pressure, rate of secondary swelling, unconfined compressive strength and California bearing ratio.

Tomanovic (2014) has been measured the stress and time dependent behavior of soft rocks. In this experimental research, the uniaxial marl creep testing was conducted on two groups with three prismatic specimens with 15×15×40 cm dimension. Moreover, in order to have good understanding on this case, also, Tomanovic (2006) carried out several uniaxial creep tests on the six undisturbed marl specimens. These results clearly shows that in stress level 2 MPa, marl's creep remain at steady phase until 185 days, while in the stress 4 MPa, strains can be reach to 0.006. Also, in the unloading phase, specimens loaded up to 2 and 4 MPa have been unloaded completely and partially respectively. The reversible strain for the stresses in 2 and 4 MPa, measured only 0.0015 and 0.001 respectively.

Hooshmand *et al*. (2012) generally studies on physical-mechanical characteristics of Tabriz marls. Based on the laboratory and in situ tests carried out on Tabriz marls, the following concluding remarks can be mention:

(1) Among the three types of Tabriz marls, yellow and gray/black marls have the lowest and the highest strengths, respectively.
(2) According to the US Department of the Interior (1998) criteria, yellow marl of Tabriz is considered to be stiff while the green and gray/black marls can be categorized as very stiff and hard marls, respectively.
(3) The parameters q_u (uniaxial compressive strength), N_{SPT}, and E_s (Young's modulus) have good correlation with depth.
(4) Yellow marls, among three considered types, have the maximum values of strain at the yielding and failure points while the gray/black marls have the minimum corresponding values of strain.
(5) Gray/black marls, among three considered types, have the maximum values of elastic and shear modulus while the yellow marls have the minimum corresponding values of deformation modulus.

Hornig (2010) has been investigated field and laboratory settlement of foundation on Couper weathered marls in Germany.

Sajjadi *et al*. (2016) investigated effect of soil physical properties on infiltration rate. From a hydrologic modeling perspective it is necessary to estimate infiltration rate in order to calculate the actual runoff discharge.

Kalıpcılar *et al*. (2016) investigated the effect of sulfate attack on cement stabilized montmorillonite. Results revealed that use of sulfate resistance cement instead of normal Portland cement is more plausible for soils under the threat of sulfate attack. Besides, it was verified that sulfate concentration is responsible for strength loss and permeability increase in cement stabilized montmorillonite.

Shaqour *et al*. (2008) investigated the geotechnical and mineralogical characteristics of marl deposits in Jordan. The test results showed a positive linear relationship as expected between the clay content and both liquid and plastic limits. The tests results also proved an inverse linear relationship between the clay content and the maximum dry density in both standard and modified compaction. This is attributed to the adsorption of water by the clay minerals. The relationship is more prominent in the case of modified compaction test. The results also indicate a similar relationship for the angle of internal friction. No clear correlation between cohesion and clay content was apparent.

Wang *et al*. (2015) have suggested an improved Maxwell creep model for salt rock. The creep property of salt rock significantly influences the long-term stability of the salt rock underground storage. Triaxial creep tests were performed to investigate the creep behavior of salt rock.

Cheng *et al*. (2016) have been performed a series of one-dimensional consolidation tests and triaxial creep tests were performed on Nansha clays, which are interactive marine and terrestrial deposits, to investigate their time-dependent behaviour.

Songhe *et al*. (2016) have been studied a novel modeling of settlement of foundations in permafrost regions. Settlement of foundations in permafrost regions primarily results from three physical and mechanical processes such as thaw consolidation of permafrost layer, creep of warm frozen soils and the additional deformation of seasonal active layer induced by freeze-thaw cycling.

In this paper, time dependent behavior (consolidation and creep), physical and geological properties of Baghmisheh formation marls have been investigated. The location of study area in Iran is shown in Fig. 1.

2. Properties of Marls and problems encountered

Main problems of structures founded on marls in the studied area are including weathering and erosion, foundation settlement and slopes failures. Observations and reports indicate the

Fig. 1 The location of Tabriz (study area) on Iran map

occurrence of these phenomena after precipitation and water absorption. Repetitive wet-dry cycles have important effects on marls behavior. Marls are as one of the most problematic materials in civil and geotechnical projects can be lead to structure damages from these two view points:

a) Swelling/settlement b) differential settlement.

2.1 Swelling/settlement

Swelling soils are generally characterized by the presence of clay minerals of the Montmorillonite group. Such soils give rise to problems in civil engineering works because of their tendency to lead to large volume changes in different moisturecontent (Zumravi 2013, Nelson and Miller 1992).

Swelling soils, dominantly "Marl", are distributed over a large area of east of Tabriz city and caused significant damages to buildings, roads and other structures founded on these soils. In Figs.

Fig. 2 Swelling in marls and creating crack on the walls

Fig. 3 Treatment of marls in the "Pasdaran highway" of Tabriz

2 and 3 crack propagation on walls of a residential swelling and treatment of soils beneath "Pasdaran Highway" is observed, also treatment operation in the "Pasdaran highway" on the north of Tabriz city.

2.2 Differential settlement

Settlement of structures occurs due to volume changes and deformation of earth material under stress and continues loading and unloading. Deformation under the constant and progressive effective stress defines as a terms of consolidation or compression and creep. Fine grained soils such as saturated or semi-saturated clayey soils and marls have low permeability coefficient, therefore consolidation and void ratio reduction is time consuming and prediction of settlement and its duration is very important for construction works. In the Tabriz city, development of the east and north east part of the city on marl layers induced many failures in engineering works as illustrated on the Fig. 4.

3. Geology

The city of Tabriz with about 2 million people is one of the industrial and metropolises of Iran. The city is located in western Alborz-Azerbaijan geology zone, and it is established on alluviums and marls. Red deposits along the north of the city, with salt and gypsum interlayers, called as Upper Red Formation (URF) (Rieben 1935). This formation consist of sandstone, marl, siltstone and conglomerate with salt and gypsum interlayers. Baghmisheh formation including marl-shale, belongs to Miocene and Pliocene, is superimposed on the URF. Generally, Tabriz marls can be seen as yellow, green and gray/black which have outcrops in the Baghmisheh area. In fact Tabriz area is underlain by recent alluvium in central urban area and a complex of conglomerate, fine sediments, red sandstone and alteration of green and dark grey marl is the bed rock. Tabrizmarl is generally known as a plastic and sticky, difficult to handle and a sub-grade and embankment

Fig. 4 Partial damage in building due to the differential settlement on marl layers

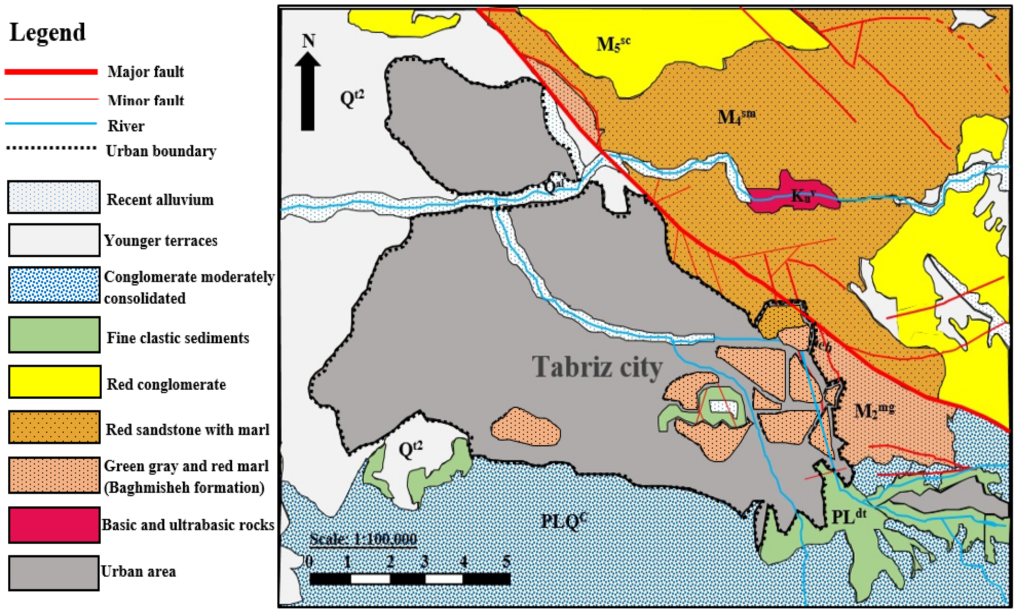

Fig. 5 Tabriz geological map (National Geosciences Database of Iran 2004)

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

material of very poor quality. For these reasons, considerable volumes of cut soil, produced due to numerous developing projects of urban area and industrial zones, are inevitably dumped over valleys, low lying areas, and also on hillsides (Sadrekarimi *et al*. 2006). The geology map of study area has shown in Fig. 5 and an outcrop of Marls has shown in Fig. 6.

4. Sampling

Vast part of the Tabriz east area is covered by filthy green and yellow marls. Gray type has rarely outcrop and mainly seen beneath the other marls types. These marls in the surface appear as weathered soil and in the depth is soft and fissured rock layer. In order to carry out an experimental study on these marls, some samples have been obtained from the drilling cores for site investigation of a high-rise building in the studied area. Average depth of yellow marls in this site are 0-10 m, green marl 10-15 m and gray/black marls is more than 30 m. In order to preventing from disturbance, samples were covered by beeswax and plastic cover.

5. Experimental study

Conducted laboratory test includes physical and mechanical tests, consolidation tests and also X-ray diffraction (XRD) study.

5.1 Physical and mechanical test results

Main physical characteristics of marls that were determined including: Atterberg limits according to ASTM D4318 (2010), particle size distribution and hydrometer tests according to ASTM D422 (2006 and 2007) unit weight, specific gravity (Gs)ASTM D854 (2010), natural moisture content ASTM D2216 (2010) and uniaxial compression strength (UCS) tests. The results of physical parameters of marls are shown in Table 1. The grain size distribution of marls are illustrated in Fig.7 and it can be seen that in three types of Baghmisheh marls (yellow, green and gray) clay size grains percent are: 25%, 50% and 55% respectively. The unit weight of gray marls is higher than the others. Plastic index (PI) of yellow, green and gray marls are 22.3%, 42.0% and 61.3% respectively.

Some UCS tests were conducted on undisturbed samples based on ASTM D2166 (ASTM 2014). Fig. 8 shows the picture of these samples after UCS tests. Failure mode of samples is

Table 1 Physical parameters of Baghmisheh marls

Marl type	USCS	G_S	LL%	PI%
Yellow	CL	2.63	46.1	22.3
Green	CH	2.55	72.1	42.0
Gray	CH	2.66	84.2	61.3

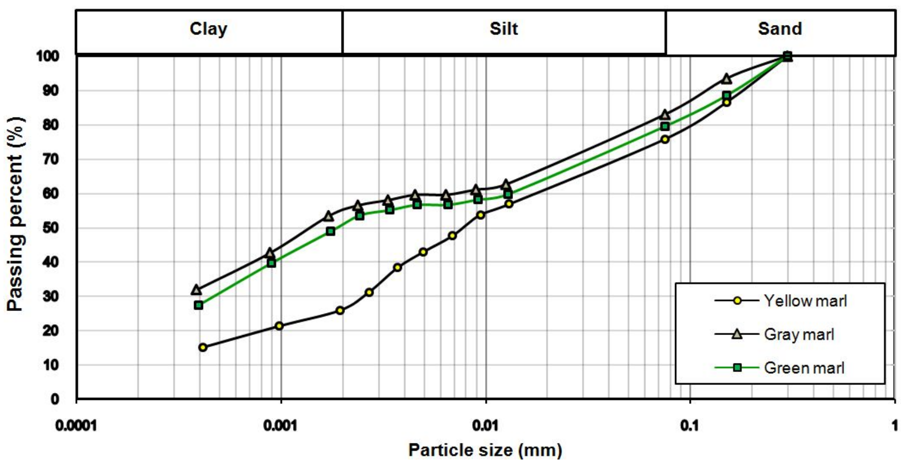

Fig. 7 Sieve and hydrometer particle size analysis of marls

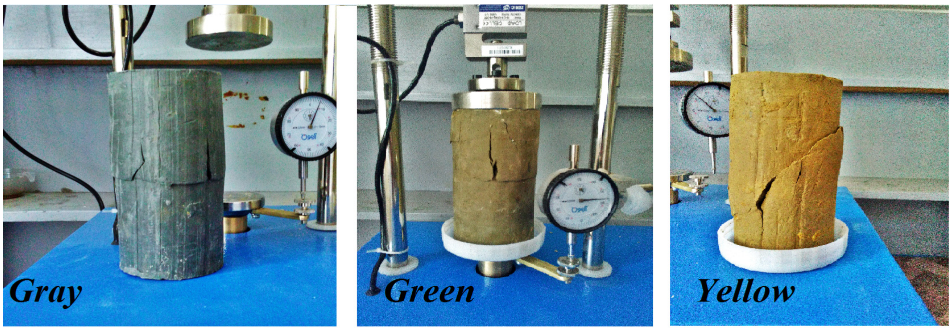

Fig. 8 Three types of marl sample after the UCS tests

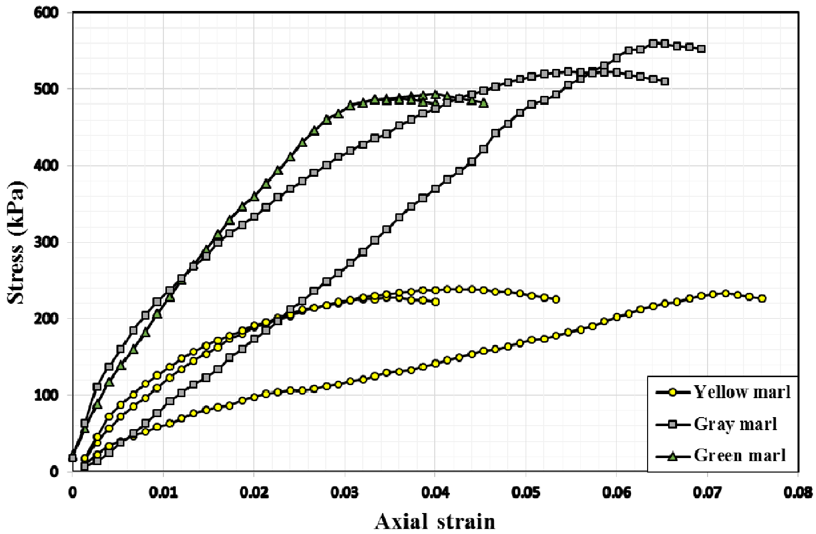

Fig. 9 Stress-strain curve for three types of Baghmisheh marls

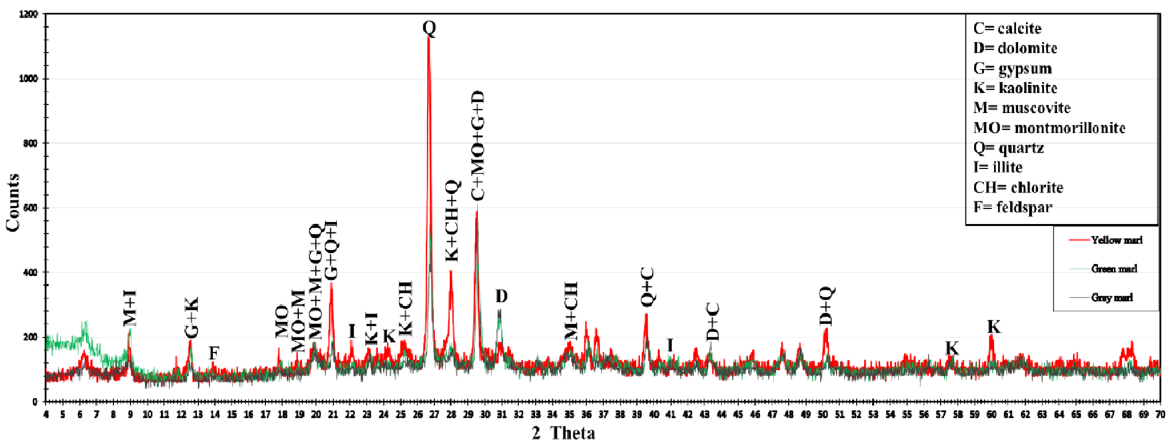

Fig. 10 X-ray powder diffraction diagram for three types of Baghmisheh marls

generally accompany with shear zone. Gray marl has maximum UCS (500-560 kPa) and yellow marl has minimum value of UCS (100-250 kPa). Axial strain corresponding to failure points for yellow marls are 0.04 to more than 0.07 and is less than 0.03 for gray marls (Fig. 9).

According to the XRD results (Fig. 10), major clay minerals in three types of Baghmisheh marl are Illite, Kaolinite, Montmorillonite and Chloride. As well as other minerals are including Calcite, Dolomite, Quartz, Gypsum, Muscovite and Feldspar. Also, with regard to the start points of diagrams, high amounts of amorphous materials as organic materials can be attributed to the graymarls. Other colors such as yellow and Green are attributed to the oxidation/reduction state of $Fe^{2+}$and Fe^{3+}.

5.2 Consolidation test results

One dimensional consolidation test (Odometer) has been conducted on cylindrical undisturbed specimens with diameter 50 mm and height 20 mm. Preferred vertical stresses for consolidation were 0.025-0.05-0.1-0.2-0.4-0.8-1.6 and 3.2 MPa for a period of 24 hours for each pressure. This test carried out according to ASTM D2435 (2011) method-B. The tests results for the each type of marl are as follows.

5.2.1 Consolidation test results on yellow marls

Fig. 11 shows the deformation (settlement) of specimen under various pressures. It can be seen the height of yellow specimen after consolidation up to 3.2 MPa has been reached to 14.98 mm. Some of the basic and consolidation parameters have been mentioned in Table 2. The *e*-pressure

Table 2 Consolidation test result of yellow marls

Natural moisture, ω%	Natural unit weight, γ_m kN/m^3	Dry unit weight, γ_d kN/m^3	Initial void ratio, e_0	Compression index, C_C	Swell index, C_S	Coefficient of consolidation, C_v, cm^2/min	Preconsolidation pressure, MPa
26.4	17.7	13.8	0.90	0.25	0.025-0.05	0.017-0.0034	0.18

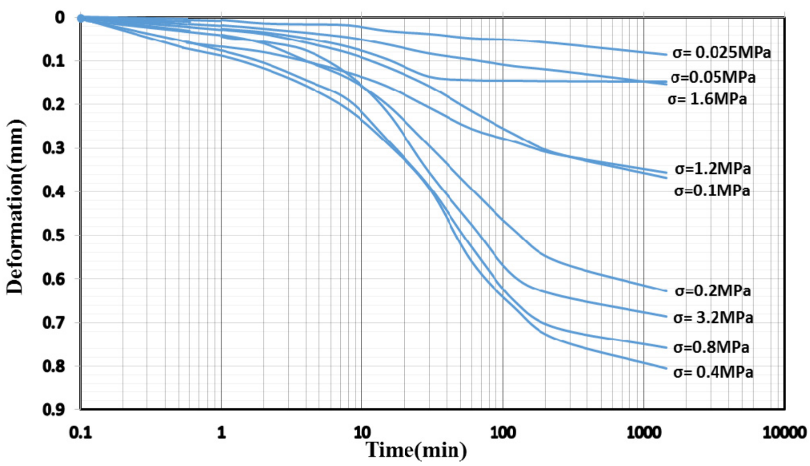

Fig. 11 Deformation- time curves under various pressures for yellow marl

curve is illustrated on Fig. 15. The preconsolidation pressure calculated about 0.18 MPa. As illustrated in Fig. 11, the maximum deformation for yellow marl is under pressure 0.4 MPa. Odometer deformation modules (E_{od}) under low pressures is about 2.7 MPa and in high pressures has been measured 53.7 MPa. Therefore soil stiffness is increasing by consolidation of specimen.

5.2.2 Consolidation test results on green marls

Table 3 shows the consolidation parameters of green marls. According to Fig. 12, the maximum deformation has attributed to the pressure 0.8 MPa. With regard to the Fig. 13, under 3.2 MPa pressure, the total settlement value has been measured 2.40 mm. Total strain under the same load has been measured as 12 percent. The *e*-pressure consolidation curve is illustrated on Fig. 15.

Odometer deformation modules (E_{od}) under low and high pressures are measured about 11 and 35 MPa respectively. Therefore soil stiffness is increasing with specimen consolidation.

5.2.3 Consolidation test results on gray Marls

According to the Fig. 13, it can be seen final height of gray marl specimen after consolidation

Table 3 Consolidation test result of green marls

Natural moisture, ω%	Natural unit weight, γ_m kN/m^3	Dry unit weight, γ_d kN/m^3	Initial void ratio, e_0	Compression index, C_C	Swell index, C_S	Coefficient of consolidation, C_v, cm^2/min	Preconsolidation pressure, MPa
27	19.5	15.6	0.68	0.16	0.016-0.032	0.012- 0.031	0.30

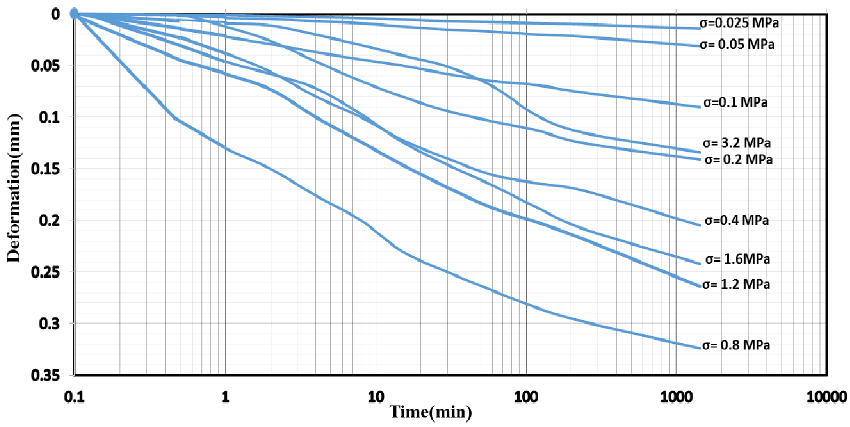

Fig. 12 Deformation- time curves under various pressures for green marl

Table 4 Consolidation test results for gray marls

Natural moisture, ω%	Natural unit weight, γ_m kN/m^3	Dry unit weight, γ_d kN/m^3	Initial void ratio, e_0	Compression index, C_C	Swell index, C_S	Coefficient of consolidation, C_v, cm^2/min	Preconsolidation pressure, MPa
25	20.4	17.0	0.56	0.11	0.011-0.02	0.016-0.019	0.35

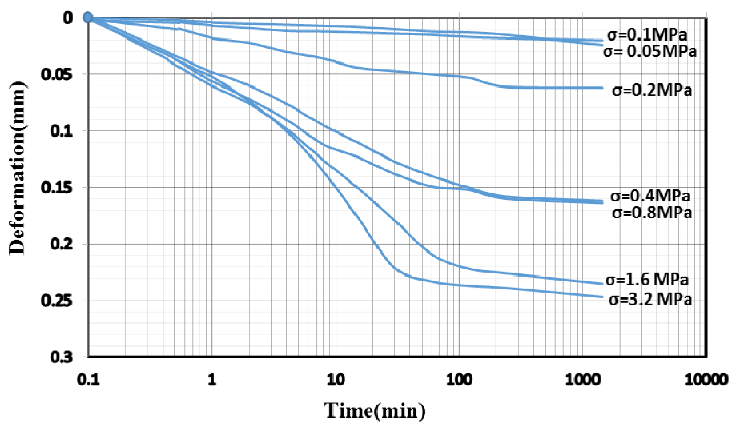

Fig. 13 Deformation- time curves under various pressures for gray marl

up to pressure 3.2 MPa has decreased to 18.22 mm. Therefore, gray marls have very low compressibility and settlement rather than two other types of Baghmisheh marls. For the gray marl, some of the basic and consolidation parameters have been mentioned in Table 4. As shown in Fig. 15 it can be observed that gray marls are preconsolidated and this is attributed to the overburden layers pressure. Odometer deformation modules (E_{od}) has been measured 24 MPa in low pressures and 132 MPa in high pressures. Therefore soil stiffness is increasing with specimen consolidation.

5.2.4 Comparison of various marls consolidation

As shown in Fig. 14, yellow marls have been shows high deformation and high compressibility in the saturation condition, while gray marls are vice versa. Deformation value has a reverse relation with depth of samples. Fig. 15 show the consolidation curves of three types of marls, it can be seen the maximum initial void ratio (0.87) had been related to yellow marl and minimum initial void ratio (0.54) had been related to gray marl. All the differences in time-deformation curves are belong to the stiffness of marls.

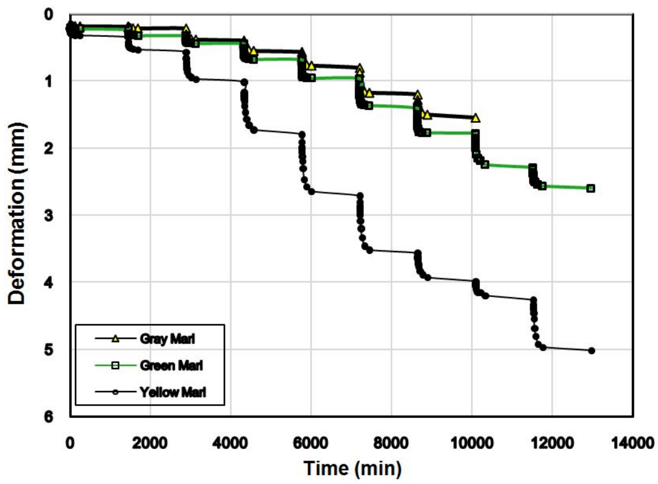

Fig. 14 Cumulative deformation- time curve for various marls

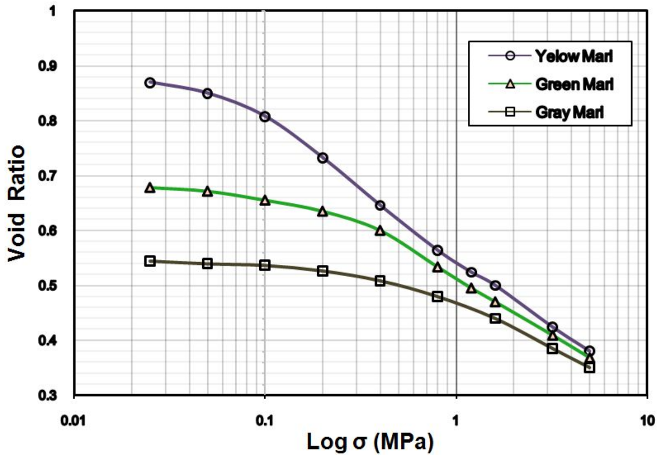

Fig. 15 Comparative *e*-pressure consolidation curve for three types of Baghmisheh marls

5.3 Creep test results

Rock or hard soil layers can bend with several degrees of severity. The most extreme deformation is in the overturned fold, where a rock layer bends back over itself. There are three stages of deformation (Goodman 1989). The first stage is elastic, if the stress is removed from the rock, it will return to its original shape and size. Once stress exceeds the elastic limit, the deformation is plastic. This simply means it will only partially return to its original state. When there is a continued increase in stress, it will eventually fail by "rupture".

The nature of the substance under stress determines the elastic limit and rupture points. Brittle substances will rupture before any significant plastic deformation takes place, whereas ductile substances can undergo a large amount of deformation before rupturing (Goodman 1989).

Obviously, rocks are folded much more than 25 percent in the real world. That is where time, temperature, and solution come into play. In the laboratory experiments, only pressure was measured, and that was done over a brief period of time. In the field, obviously we have millions of years to work with, not just hours. With the burial of rock layers within the earth, the temperature is also higher, a result of the layer receiving heat from the earth, which insulates it, and heat built up due to the increased pressure. The slow, continuous deformation with the passage of time is known as "creep". Creep can be measured on a creep curve (illustrated at Fig. 16). This curve is consisted of 4 phases:

a) Instantaneous or elastic strain (A)
b) Primary or transitional creep (B)
c) Steady or secondary creep (C)
d) Progressive or tertiary creep (D)

Generally, at lower stress levels, material behavior is "Viscoelastic" (primary creep phase), and all strains is completely reversible (Terzaghi and Peck 1967). But, at higher stress levels, behaviors become "Visco-plastic" and in spite of reversible strains, some parts of the strains completely become "Irreversible" (Tomanovic 2006, 2014). With regards to ideal creep curve and coefficients, generally can be writing the logarithmic creep Eq. (1) (Goodman 1989).

$$S = A + B\log t + Ct + D \tag{1}$$

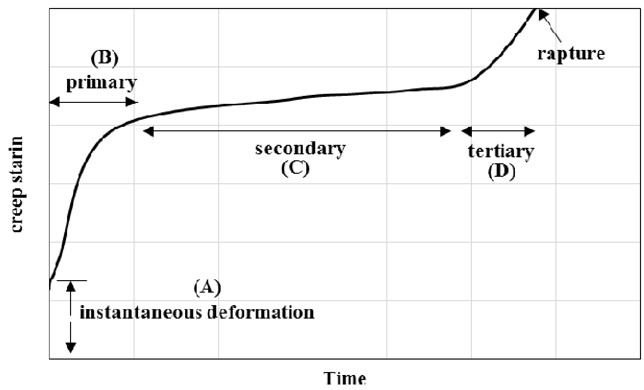

Fig. 16 Ideal creep curve for rock materials (Goodman 1989)

In this research, long term time dependent behavior has investigated with odometer apparatus after the end of consolidation strains. Test specimen has been set in the odometer apparatus under the pressures 3.2 and 5.0 MPa and creep behavior under each pressure for 8 days has been investigated. The results for various marls are as follow.

5.3.1 Creep in yellow marls

The results for the yellow marls, it is obviously observed that, for turning creep curve in to creep progressive phase, pressure should be enhanced to more than 5.0 MPa in further long-term periods as shown on Fig. 17. Along the accomplished experiments in this research, after 16 days, amount of settlement reach to 5.5 millimeter. Also, it can be seen that in pressure 3.2 MPa, specimen remain in primary creep phase. Also in pressure 5.0 MPa it deforms in secondary creep phase. Generally logarithmic creep equation for yellow marls can be proposed as below

$$S = 0.02173 + 0.002 \text{ Ln}t + 0.0000002 \, t + D \tag{2}$$

The range of the E_{od} has been measured along the creep 35 to 74 MPa.

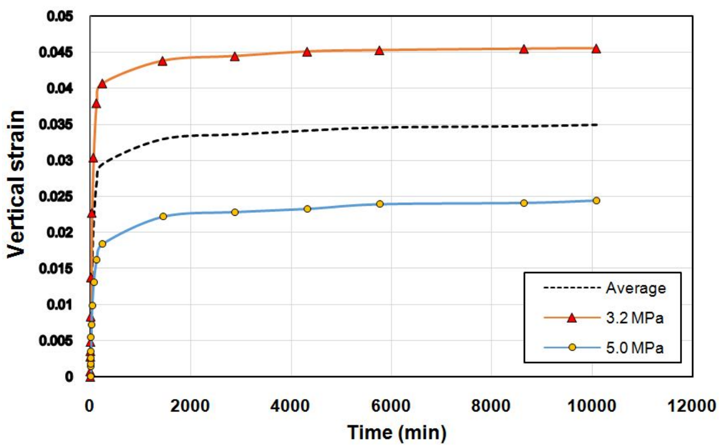

Fig. 17 Creep curves of yellow marls

5.3.2 Creep in green marls

It is obviously observed that, for convert of creep curve in to progressive phase, pressures should be enhanced to more than 5.0 MPa in a long-term period. In this research, after 16 days, amount of settlement reach to 2.7 millimeter. As shown in Fig. 18, it can be seen which in pressure 3.2 MPa, specimen remain in primary creep phase. Also in pressure 5.0 MPa it deforms in secondary creep phase. Generally can be writing the logarithmic creep equation for green marls as below

$$S = 0.0042 + 0.001 \, Lnt + 0.00000008 \, t + D \tag{3}$$

The range of the deformation modules has been measured along the creep, 170 to 200 MPa.

5.3.3 Creep in gray marls

Along the carried out experiments on this marl, after 16 days, amount of settlement reach to 2.2 millimeter. As shown in Fig. 19, it can be seen which in pressure 3.2 MPa, specimen remain in primary creep phase. Also in pressure 5.0 MPa it deforms in secondary creep phase. Generally

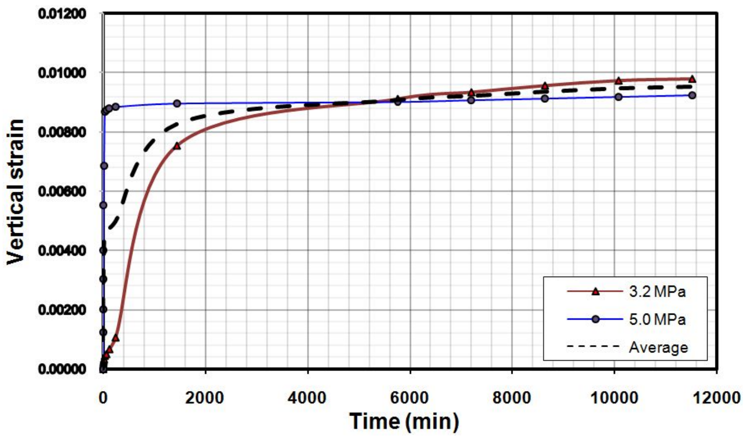

Fig. 18 Creep curves of green marls

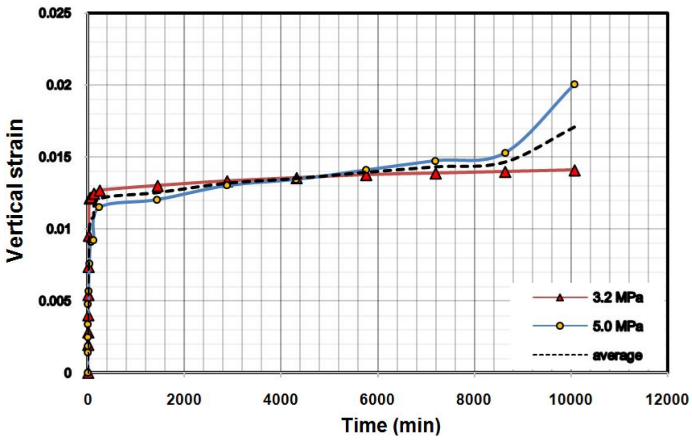

Fig. 19 Creep curves of gray marls

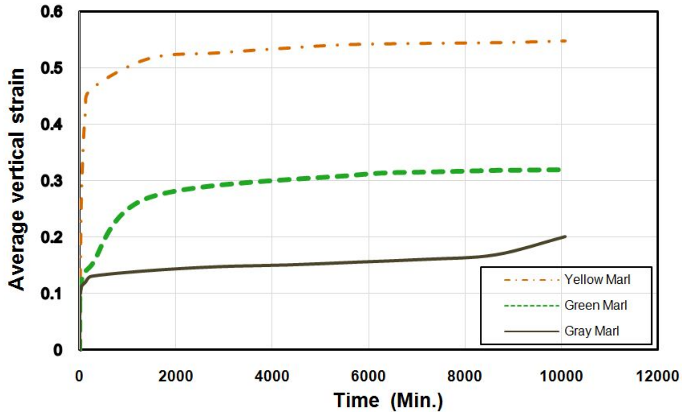

Fig. 20 Creep curves of three types of marls

can be writing the logarithmic creep equation for gray marls as below

$$S = 0.0076 + 0.001\ \mathrm{Ln}t + 0.0003\ t + 0.000002 \quad (4)$$

The range of the E_{od} has been measured along the creep 90 to 114 MPa.

5.3.4 Comparison of various marls consolidation

Fig. 20 presented the studied three creep curves for comparison. This figure clearly indicates that yellow marl because of high initial void ratio, shows high value of instantaneous strain ("A" in creep equation) and also high secondary creep phase. Gray marls have indicating stiff behavior more than two other types. According to the creep test results, all marl types have not been entered to progressive creep phase up to pressure 5.0 MPa.

6. Conclusions

There are three types of marls in the Baghmisheh formation of Tabriz in Iran: yellow, green, and gray marls. Consolidation and creep behavior of marls investigated by using of one dimensional consolidation apparatus under pressures up to 5.0 MPa. According to some physical and mechanical tests, the unit weight and the stiffness are low for yellow marls and intermediate for green marls and high for gray marls. The UCS of marls are 100-250, 300-480 and 500-560 kPa for yellow, green and gray marls, respectively. According to the XRD tests, major clay minerals of marls are Illite, Kaolinite, Montmorillonite and Chloride.

Basedon consolidation tests results, the compression index (C_c) are 0.25, 0.16 and 0.11 for yellow, green and gray marls, respectively and also the preconsolidation pressure are about 0.18, 0.30 and 0.35 MPa for yellow, green and gray marls, respectively. Maximum initial void ratio (0.87) had been related to yellow marls and minimum initial void ratio (0.54) had been recorded for gray marls.

The results indicate that yellow marls have high compressibility, settlement and deformation modules. Green marls have an intermediate compressibility and settlement and while gray marls have low compressibility and settlement.

Creep behavior equations of each type of Baghmisheh marls were developed. According to the creep test results, all specimens have not been entered to progressive creep phase up to pressure 5.0 MPa.

Acknowledgments

The authors are grateful to Teltav Consultant Engineers Co. and Mr. Nader Jahangir for their collaboration in providing samples.

References

ASTM (2006), Standard Classification of Soils for Engineering Purposes, D 2487; Annual Book of ASTM standards, 04. 08, *American Society for Testing and Materials*, PA, USA.

ASTM (2007), Standard Test Method for Particle-size Analysis of Soils, by Sieving/hydrometer Method, D422; 04. 08, *American Society for Testing and Materials*, PA, USA.

ASTM (2010), Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils, D4318; Annual Book of ASTM standards, 04. 08, *American Society for Testing and Materials*, PA, USA.

ASTM (2011), Standard Test Method for One Dimensional Consolidation Properties of Soils. D 2435; 04. 08, *American Society for Testing and Materials*, PA, USA.

ASTM (2014), Standard Test Method for Unconfined Compressive Strength of Cohesive Soil, D2166; 04. 08, *American Society for Testing and Materials*, PA, USA.

Cheng, Z.C., Zhu, H., Xiong, M.G., Shi, B. and Gao, L. (2016), "Prediction of one-dimensional compression behavior of Nansha clay using fractional derivatives", *Marine Georesour. Geotech.* DOI: 0.1080/1064119X.2016.1217958

Corthésy, R., Leite, M.H., Gill, D.E. and Gaudin, B. (2003), "Stress measurements in soft rocks", *Eng. Geol.*, **69**(3), 381-397.

Goodman, R.E. (1989), *Introduction to Rock Mechanics*, (2nd Ed.), pp. 179-200.

Hooshmand, A., Amin-Far, M.H., Asghari, E. and Ahmadi, H. (2012), "Mechanical and physical characterization of Tabriz Marls, Iran", *Geotech. Geol. Eng.*, **30**(1), 219-232.

Hornig, E.D. (2010), "Field and laboratory tests investigating settlements of foundations on weathered Keuper Marl",*Geotech. Geol. Eng.*, **28**(3), 233-240. DOI: 10.1007/s10706-009-9259-y

Kalıpcılar, İ., Aghabaglou, A.M., Sezer G.İ., Altun, A. and Sezer, A. (2016), "Assessment of the effect of sulfate attack on cement stabilized montmorillonite", *Geomech. Eng., Int. J.*, **10**(6), 807-826. DOI: 10.12989/gae.2016.10.6.807

Mohamed, A.M.O. (2000), "The role of clay minerals in marly soils on its stability", *Eng. Geol.*, **57**(3), 193-203.

Nelson, J.D. and Miller, D.J. (1992), *Expansive Soils Problems and Practice in Foundation and Pavement Engineering*, Wiley, New York, NY, USA.

NGIDR (National Geoscience Database of Iran) (2004), Azerbaijan-e-Shargi General Geology. URL: www.ngdir/States/StateDateil

Pettijohn, F.J. (1975), *Sedimentary Rocks*, *Harper and Row*, New York, NY, USA, 628 p.

Rieben, H. (1935), "Contribution a la geologie de I", Azarbaidjan person, These presentee a la Faculte des Sciences de I, *Universite de Neuchatel pour obtenirIe grade de Docteures sciences*, Neuchatel imprimerie central, S.A-142 P.

Sadrekarimi, J., Zekri, A. and Majidpour, H. (2006), "Geotechnical features of Tabriz Marl", *IAEG2006*, Paper No. 335.

Sajjadi, S.A.H., Mirzaei, M., Nasab, A.F., Ghezelje, A., Tadayonfar, Gh. and Sarkardeh, H. (2016), "Effect of soil physical properties on infiltration rate", *Geomech. Eng., Int. J.*, **10**(6), 727-736. DOI: 10.12989/gae.2016.10.6.727

Shaqour, M.F., Jarrar, G., Hencher, S. and Kuisi, M. (2008), "Geotechnical and mineralogical characteristics of marl deposits in Jordan", *Environ. Geol.*, **55**(8), 1777-1783. DOI: 10.1007/s00254-007-1128-5

Songhe, W., Jilin, Q., Fan, Y. and Fengyin, L. (2016), "A novel modeling of settlement of foundations in permafrost regions", *Geomech. Eng., Int. J.*, **10**(2), 225-245. DOI: 10.12989/gae.2016.10.2.225

Terzaghi, K. and Peck, R.B. (1967), *Soil Mechanics in Engineering Practice*, John Wiley and Sons, Inc., New York, NY, USA.

Tomanovic, Z. (2006), "Rheological model of soft rock creep based on the test on marl", *Mech. Time-Depend Mater.*,**10**(2), 135-154.

Tomanovic, Z. (2014), "Initial and time-dependent deformations in marl around small circular opening", DOI: 10.14256/JCE.1120.2014

Voottipruex, P. and Jamsawang, P. (2014), "Characteristics of expansive soils improved with cement and fly ash in Northern Thailand", *Geomech. Eng., Int. J.*, **6**(5), 437-453.

Wang, J.B., Liu, X.R., Song, Z.P. and Shao, Z.S. (2015), "An improved Maxwell creep model for salt rock", *Geomech. Eng., Int. J.*, **9**(4), 499-511.

Yong, R.N. and Ouhadi, V.R. (1997), "Reaction factors impacting on instability of bases on natural and lime-stabilized marls", Special Lecture; Keynote Paper In: *Proceeding of the International Conference on Foundation Failures*, Singapore, May, pp. 87-100.

Yong, R.N. and Ouhadi, V.R. (2007), "Experimental study on instability of bases on natural and lime/cement-stabilized clayey soils", *Eng. Geol.*, **35**(3), 238-249.

Zumrawi, M.E. (2013), "Geotechnical aspects for roads on expansive soils", *Int. J. Sci. Res.* (*IJSR*), **6**(14).

CC