Geotechnical features of Tabriz Marl

JAMSHID SADREKARIMI[1], ASHRAF ZEKRI[2], HAMID MAJIDPOUR[3]

[1] *Civil Engineering Faculty, Tabriz University, Iran. (e-mail: jsadr@tabrizu.ac.ir)*
[2] *Engineering Research Centre of Jahad, Tabriz, Iran.(e-mail: ashraf_zekri@yahoo.com)*
[3] *Civil Engineering Faculty, Tabriz University, Iran. (e-mail: hamid_m_p@yahoo.com)*

Abstract: In order to characterize the geotechnical properties of Tabriz Marl results of several laboratory tests on specimens produced from subsoil studies were evaluated. It was concluded that the Tabriz Marl might be considered as a high liquid limit silt or clay (MH & CH). Range of changes of index, physical and mechanical properties of the Tabriz Marl are comparatively vast. Correlations between these properties have been introduced in this paper. The liquid limit and plastic limit range from 32 to 100 and 7 to 60, respectively, depending on the silt and carbonate content of natural specimen. There is a very reasonable correlation between moisture content and dry density. However, the results of directional mechanical tests indicate that reasonable correlation between different mechanical properties of intact specimens is hardly possible. This is attributed to the anisotropy of Tabriz Marl. The degree of anisotropy is evaluated with directional loading of specimens. A representative specimen was tested for swell potential after compaction. Swell percent and pressure as high as 13.6 % and 1020 kPa were measured, and need for treatment was proved. The results of addition of lime and fibres over the compacted specimens , as a fill material, are presented.

An inspection of mass specimens and cut slopes and other Earth works in Tabriz Marl indicate that the Tabriz marl, in common with many other overconsolidated grounds, contains several discontinuities as beddings and tectonically planes and fissures. In addition, there are scattered pockets and lenses of gypsum that are being diluted into the plain water that is discharged into the ground through rainfall discharge wells. This in turn causes gradual changes in engineering properties of the mass marl ground. Results of laboratory and field observations are presented.

Résumé: Afin de caractériser les propriétés géotechniques de marne de Tabriz, les résultas de plusieurs essais en laboratoire sur des spécimens produits à partir des études de sous-sol ont été évaluées. On l'a conclu que la marne de Tabriz pourrait être considérée comme argile ou vase ayant une haute limite de liquidité (MH et CH). La gamme des changements des propriétés d'index, physiques et mécaniques de la marne de Tabriz est comparativement vaste. Des corrélations entre ces propriétés ont été présentées dans cet article. La limite de liquidité et la limite de plasticité s'étendent de 32 à 100 et 7 à 60, respectivement, selon la teneur en vase et en carbonate du spécimen naturel. Il y a une corrélation très raisonnable entre le contenu d'humidité et la densité sèche. Cependant, les résultats des essais mécaniques directionnels indiquent que la corrélation raisonnable entre différentes propriétés mécaniques des spécimens intacts est à peine possible. Ceci est attribué à l'anisotropie de la marne de Tabriz. Le degré d'anisotropie est évalué avec le chargement directionnel des spécimens. Un spécimen représentatif a été examiné pour le potentiel de gonflement après tassement. Le pour-cent et la pression aussi haut que 13.6 % et 1020 kPa ont été mesurés, et le besoin de traitement ont été prouvés. Les résultats de l'addition de chaux et de fibres sur les spécimens compacts, comme matière d'agrégation, sont présentés.

Une inspection des spécimens de masse et des pentes coupées et d'autres travaux de la terre en marne de Tabriz indiquent que la marne de Tabriz, en commun avec beaucoup d'autre terres surconsolidés, contiennent plusieurs discontinuités comme des stratifications et tectoniquement plans et des fissures. En outre, il y a les poches et les lentilles dispersées du gypse qui sont dilués dans l'eau qui est déchargée dans le sol par des puits de décharge de pluie. Ceci cause de transformations progressives des propriétés de masse de marne de terre. Des résultats des observations de laboratoire et de champ sont présentés.

Keywords: Atterberg limits, clay, compressibility, remediation, slope stability, uniaxial tests.

INTRODUCTION

Tabriz city, the centre of east Azerbaijan province, is one of the biggest industrial cities of Iran. More than 2 million people are living and many strategic factories are located in this mountainous city. From the geology view point, Azerbaijan is located in western Alborz–Azerbaijan structural zone. This zone is bounded by the Caspian depression block to the north & central Iran plateau to the south. Its western part has a NW-SE trend consistent with Zagros, lesser Caucasus & greater Caucasus trends. Its eastern part has a NE-SW trend consistent with the Darouneh fault.

The structure of the zone is the result of Precambrian & Alpine Orogeny. The consolidation of the basemen is pertaining to Cambrian Orogeny. It seems that the basement is the northern continuation of Arabian plate, covered with homogenous depositions of epicontinental nature in Paleozoic (Ngdir 2004).

Not only is Iran located along the seismic ring of the earth, but also Tabriz is located near North Tabriz Fault. This extended fault is a transtensioned active-earthquake fault which has moved repeatedly in recent geological time and has the potential for reactivation in the future. Associated with frequent earthquakes, some surface ruptures have been shown along this fault. (Hessami, Jamali & Tabassi 2003).

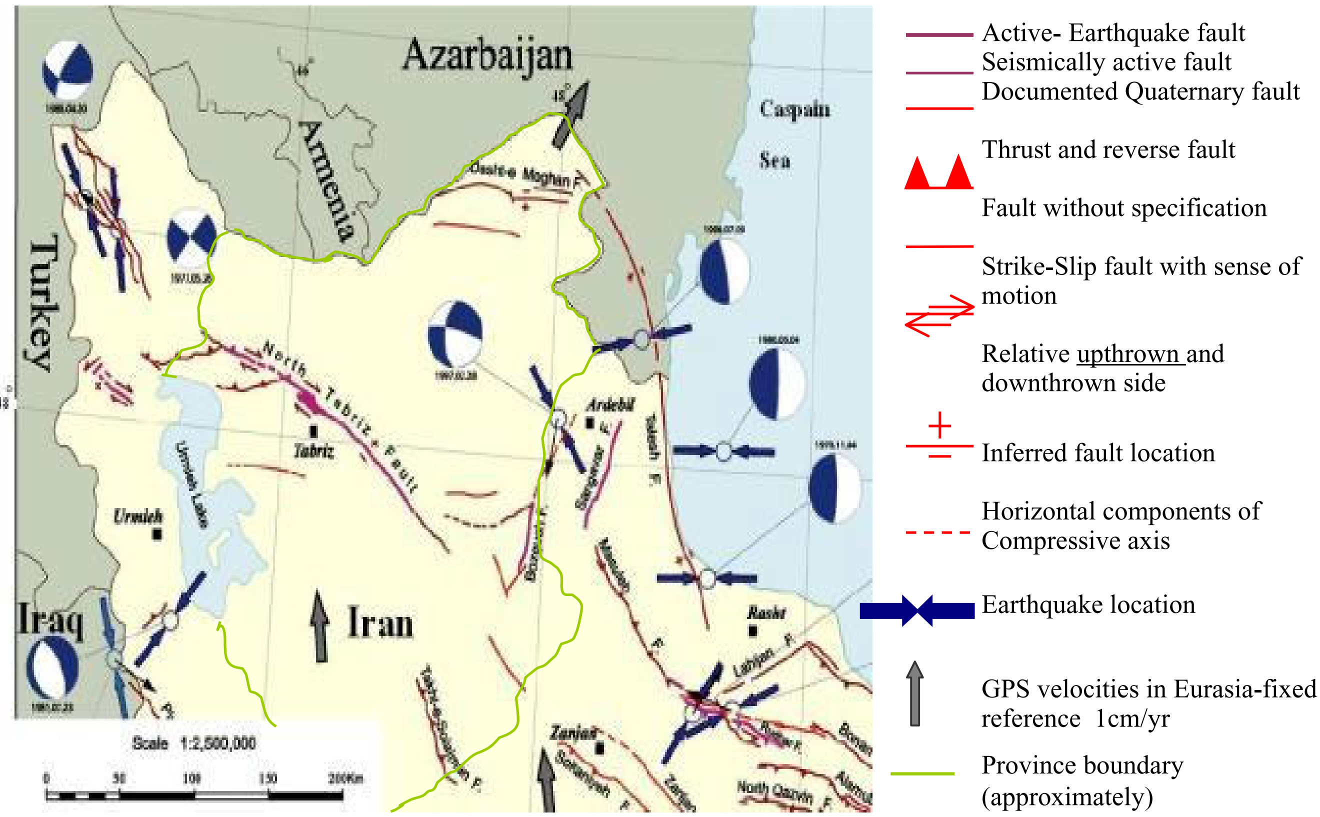
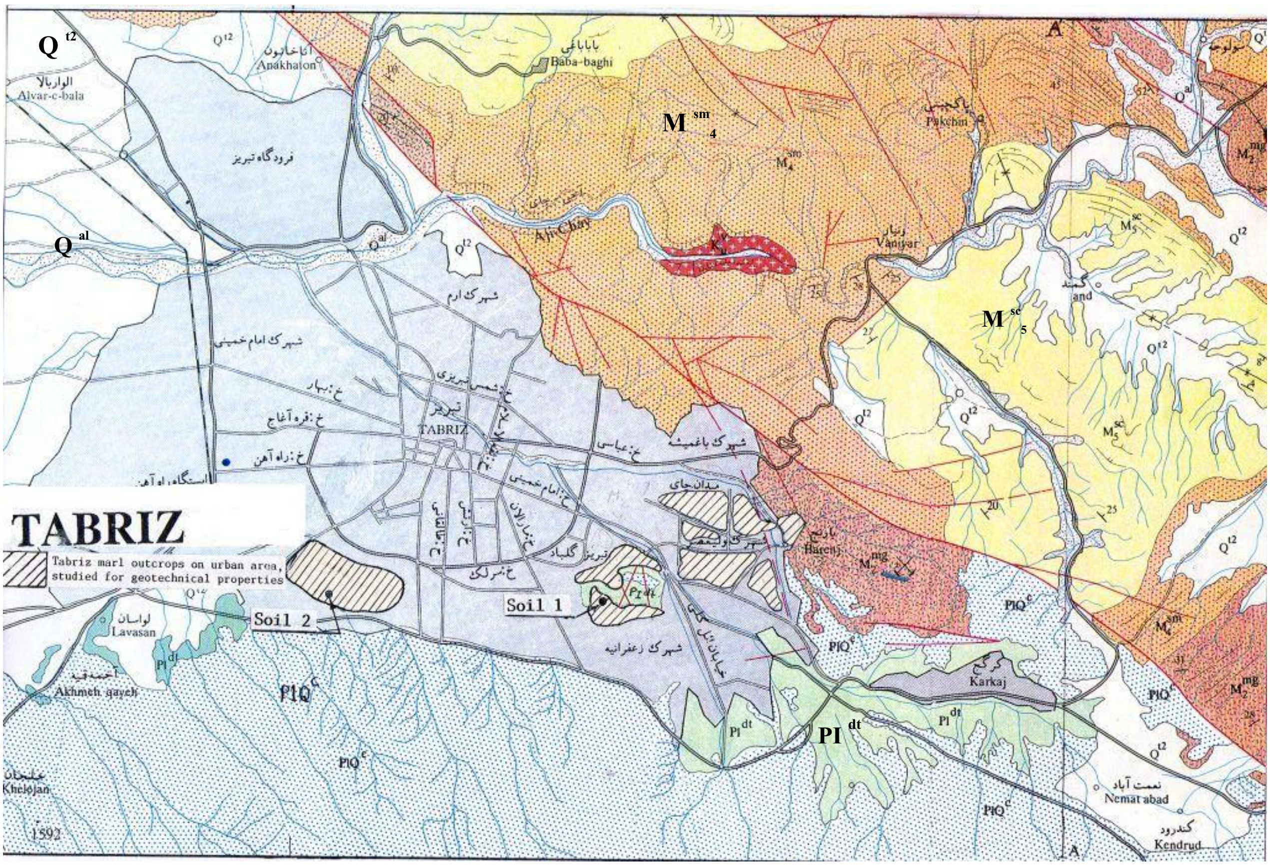


Figure 1. North Tabriz fault location

In order to evaluate the risk of heavy construction against potential earthquakes, The Tabriz Marl, a very common type of sub-grade and bedding soil of the city, was selected to study. Tabriz Marl, out crops at considerable parts of urban area and suburbia. Tabriz Marl is generally known as a plastic and sticky, difficult to handle, and a very poor quality sub-grade and embankment material. 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. Besides the potential earthquake hazards, this trend of soil dumping causes man- made settling and sliding soil masses which are causing considerable property losses and damage to buildings. Figure 2 shows an example of a construction site and produced problem. The out crops areas of Tabriz Marl are shown in Figure 3 (Sadrekarimi 2002). In fact Tabriz area is underlain by recent alluvium in central urban area and a complex of conglomerate, fine sediments, red sand stone and alteration of greenery and dark grey marl is the general bed rock in this region.

In this paper the range of the geotechnical parameters are presented, the effect of flow of low pH water (acidic) on the engineering properties of Tabriz Marl are discussed and the lime addition and fibre reinforcement improvement methods are reviewed.

Figure 2. Construction on a fill area and large settlements and slides



Q^{al} :Recent alluvium PIQ^{c}: Conglomerate, moderately consolidated with intercalation of sandstone pumice and pyroclastic
PI^{dt}: Fine elastic sediments, tuff with diatomite and fish bed
M^{sc}_{5}: Red conglomerate with alternation of sand stone and red marl
M^{sm}_{4}: Red sandstone with marl
M^{mg}_{2}: Alternation of green grey and red marl with intercalation of gypsiferous and saltiferous sandy
K^{v}_{u}: Basic and ultra basic rocks
////////: Tabriz marl outcrops on urban areas, studied for geotechnical properties

Figure 3. Tabriz area and marl out crops

GEOTECHNICAL PROPERTIES OF TABRIZ MARL

Marl is a simple binary mixture of clay and calcium carbonate. However, because of the vast differences in type and origin, there is no unified definition for marl. According to Terzaghi and Peck (1967) marl is a stiff to very stiff marine calcareous clay of greenish color. Pettijohn (1975) defined marl as a rock containing 35 to 65 percent carbonate and a complementary content of clay. Fooks and Higginbottom (1975) mentioned that marl is a simple binary mixture of true clay and calcium carbonate, whilst marlite or marl stone is an indurate equivalent. Akili (1980) defined marl as a binary mixture of calcium carbonate and clay. Bates and Jackson (1980) mentioned that marl is an old term loosely applied to a variety of materials, most of which consist of an intimate mixture of clay and calcium carbonate. McCarthy (1982) introduced marl as a soft limestone. Mitchel (1985) defined marl as a soft calcareous clay-rich material, often barely consolidated, with or without distinct fragments of shale. Qahwash (1989) referred to calcareous sediment of 55 to 80 percent carbonate as marl.

In the case of Tabriz Marl, the main chemical constitutions are typically as 35 % calcite, 40 % quartz, 10 % feldspar and 4 % dolomite. According to the previous studies by the first author the ranges of changes of Liquid limit (LL) and Plastic index (PI) values are comparatively wide(Figure 4), but the average values of LL and PI are 65 and 26 indicating that Tabriz Marl may be classified as high liquid limit clay (CH) or high liquid limit silt (MH) (ASTM 1994a). Also the results of uniaxial and consolidation tests are somewhat scattered in both cases (Figure 5, 6). This may be attributed to the fact that the Tabriz Marl has had a complicated stress history since its formation. Several tectonic activities must have stressed and folded Tabriz Marl in different directions, causing a complicated anisotropy. Although the Compression index (Cc) and Swell index (Cs) values are not quite consistent, however, the Cs value ranges from 0.1Cc to 0.2Cc, which is common for most soils (Das 1985).The dry density and natural moisture content test results which are shown in Figure 7 show a clear trend of change of dry density against moisture content (Sadrkarimi 2002).

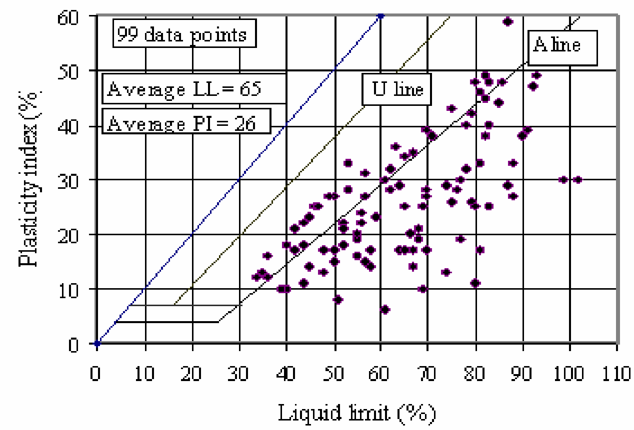


Figure 4.Tabriz Marl Atterberg limit range

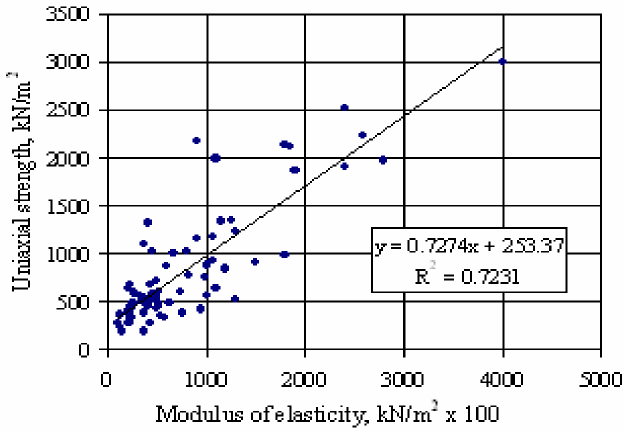


Figure 5. Modulus of elasticity versus uniaxial strength

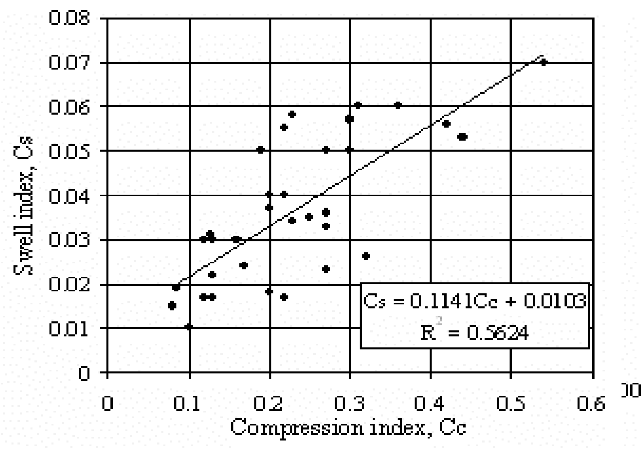


Figure 6. Compression and swell indexes correlation

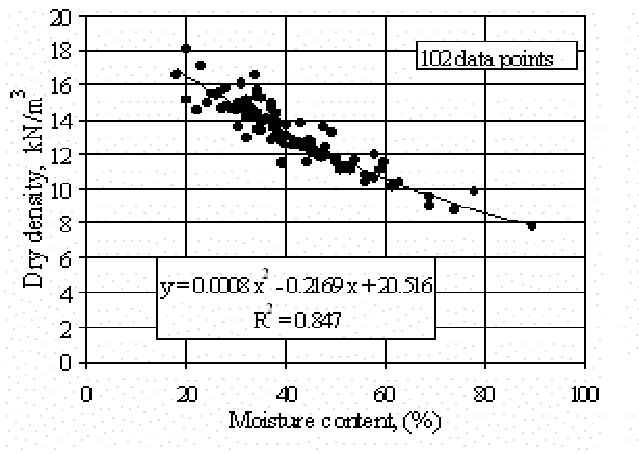


Figure 7. Dry density-natural moisture correlation

The correlation between specific gravity (Gs) and dry density (Figure 8) shows that in common with most soils, the Gs value of Tabriz Marl is not significantly changed by dry density and the average amount of 2.8-3 may be concluded from this figure. This range of Gs value also may be concluded with careful scrutinizing of Figure 7. The average amount of void ratio (e), drained frictional angle and cohesion are 1.2, 22 degrees and 75 kN/m², respectively (Figures 9-11). However, it should be noted that the shear strength parameters are highly shear stress direction dependent due to the anisotropy of Tabriz Marl. Also uniaxial strength is considerably affected by anisotropy effect.

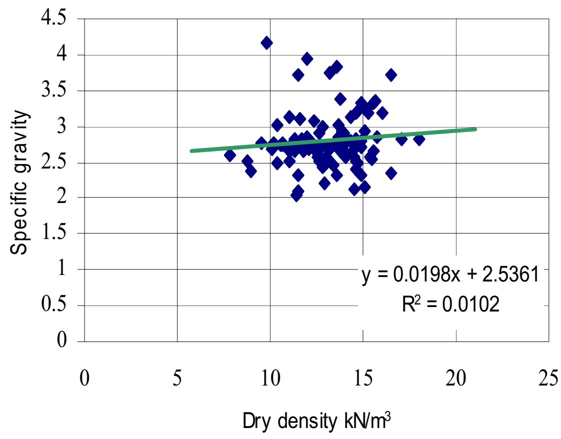


Figure 8. Specific gravity versus dry density

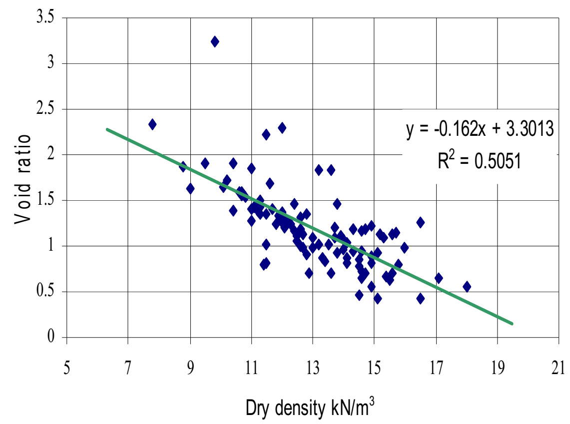


Figure 9. Void ratio versus dry density

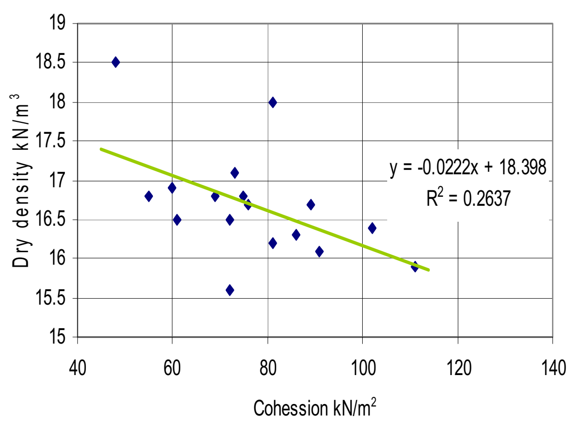


Figure 10. Drained cohesion versus dry density

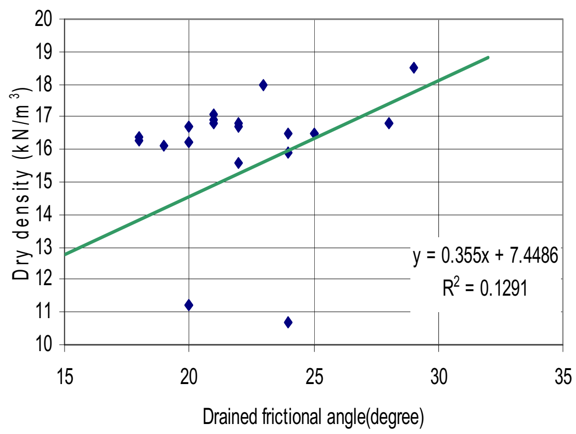


Figure 11. Drained friction angle versus dry density

The compression index of undistributed clays (c_c) and liquid limit (LL) are correlated as (Skempton 1944):

$$C_C = 0.009LL - 0.09 \quad (1)$$

In order to study the correlation of Cc and LL values for Tabriz Marl several undistributed samples were subjected to standard consolidation test (ASTM 1994b) and the compression index values Cc were worked out. The results together with the corresponding LL values are depicted in Figure 12. Referring to this figure it is disclosed that for Tabriz Marl equation 1 is not a good method of approximation and it may be replaced by:

$$C_C = 0.0021LL + 0.0675 \quad (2)$$

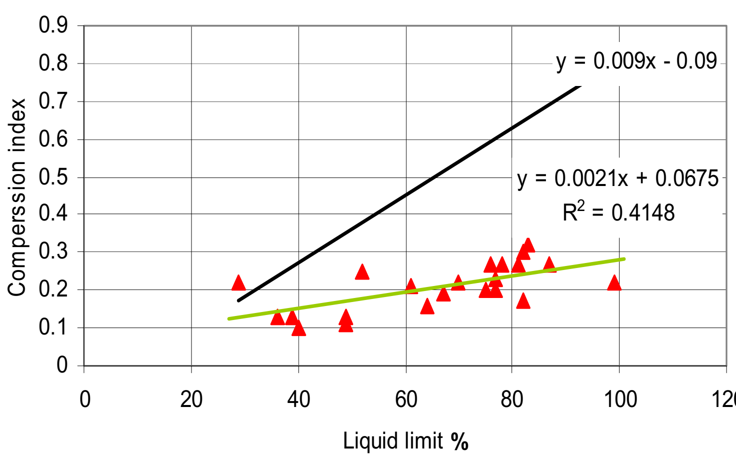


Figure 12. Correlation between liquid limit and compression index for Tabriz Marl

There are several instabilities in areas filled with Tabriz Marl and also minor slip surfaces with slikensided and oriented surfaces that are encountered in natural ground during subsurface explorations. Figure 13 shows a fill area that was developed some 15 years ago. Several residential buildings were founded on cast in place concrete piles that were put down through dumped fill soil some 5 meters into the natural Tabriz Marl ground. In spring 2001 following intensive rainfall and gradual seepage of sewerage water into the underlying fill soil a sudden mud flow type slide (Figure12) occurred. Figure 14 presents an undisturbed specimen taken from a minor slip surface. This type of slip surfaces may be encountered even in horizontal and/or in gently sloping surfaces where occurrence of instability is not theoretically possible. This phenomenon may be attributed to the propagation of tectonic forces initiated by the activities of Tabriz fault.

Figure 13. Mod flow type slide occurred in Tabriz Marl

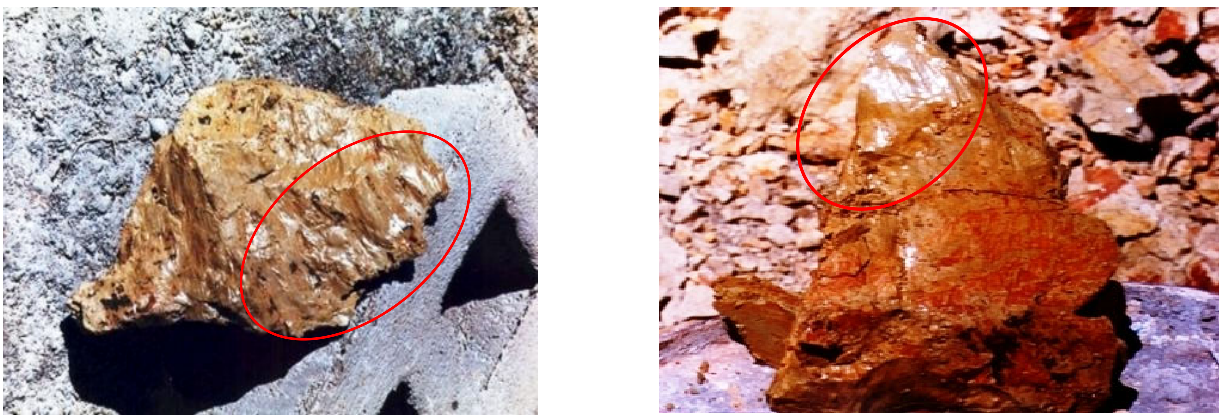


Figure 14. Samples of slip surfaces

THE EFFECT OF ACIDIC AND LOW TDS WATER SEEPAGE

As mentioned above one of the main components of Tabriz Marl is Calcium carbonate (Calcite). Calcium carbonate is diluted by acidic water and also tends to be dissolved in low TDS water. Accordingly precipitation of low pH and/or low TDS water, such as rainfall and consumed tap water in residential areas tends to weaken calcareous ground. Also in pollutant areas due to penetration of acidic rains or acidic sewerage water into the ground, engineering properties of the contaminated soil are subjected to gradual alterations. In residential and other urban areas that consumed tap water and rainfall are discharged into the local wells leaching of carbonated soil may also occur. The tap water in Tabriz is drinking water and acts as very low TDS water.

In order to study the extreme effect of carbonate dilution and disintegration on the engineering properties of Tabriz Marl, a representative specimen was washed by HCl and then subjected to geotechnical tests. The results are shown in Figures 15 and 16. The soil powder was mixed with water and then HCl acid solution was added gradually and agitated continuously until the carbonation bound was fully disintegrated. The ultimate state was distinguished when no further gas bubbles was observed during agitation. The initial properties of the tested soil are listed in Table 1.

Table 1. Properties of natural marl provided for acid washing (sampling depth = 5 m)

Test description	Unit	Result	Remarks
Passing 200 sieve	%	98	D_{max} = 0.5 mm
Liquid limit (LL)	%	70	Air dried
Plastic limit (PL)	%	33	Air dried
Plasticity index (PI)	%	37	ASTM 1994c
USCS classification	---	MH	ASTM 19994a
Natural moisture content (*w*)	%	27.2	
Mod. compaction dry density ($\gamma_{d\,max}$)	kN/m^3	16.7	
Optimum moisture content ($w_{opt.}$)	%	22	
Swell pressure of compacted soil	kN/m^2	1020	ASTM 1994b
Calcite content	%	40.4	
Dolomite content	%	10.0	
Quartz content	%	40.6	

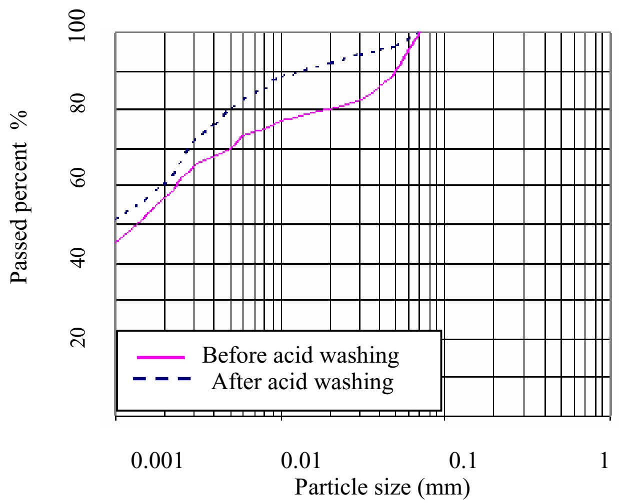


Figure 15. The effect of acidic water on the grain size

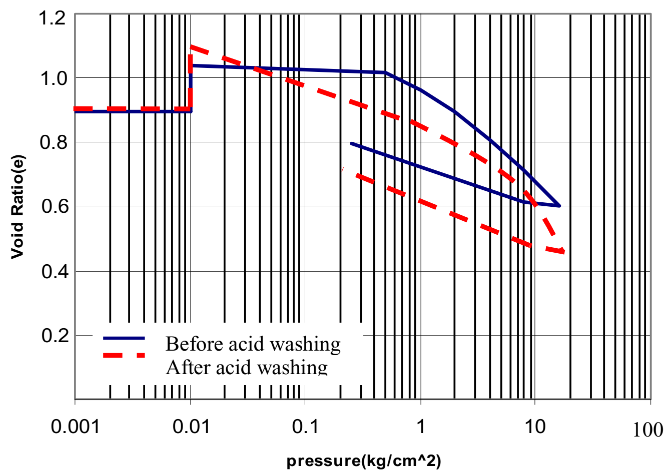


Figure 16. The effect of acidic water on compressibility

The results of the hydrometer (ASTM 1990) and one dimensional consolidation tests are presented in Figures 15 and 16. As shown in Figures, it is observed that fines content and compressibility have increased after acid washing. This means that the natural soil swell and compression potential increases as carbonate content is eliminated. This process causes some long-term geotechnical problems for structural foundations, slope stabilities and etc. For the representative specimen tested in the current study the PI increased from 37% to 42%, and the swell percent increased from 7.6% to 10.1%. While the swell pressure decreased from 230 kN/m^2 to 50 kN/m^2, the swell index increased from 0.09 to 0.11 and the compression index increased from 0.26 to 0.31.

TABRIZ MARL IMPROVMENT

The poor property of Tabriz Marl as a fill soil encourages engineers to study and use soil improvement methods. In a previous study by the first author the effect of lime addition was investigated. According to Sadrekarimi (2002) addition of lime increases the plastic limit (PL) and decreases the liquid limit (LL), and causes the plasticity index to decrease both in the short (18 hours) and long term (3 years). In the short term, the lime fixation point was measured to be 3 %, beyond which no remarkable changes occur in Atterberg limits. In the long term, however, the lime fixation point tends to show a small increase towards 4 %, beyond which the PI value continues to decrease and tends to vanish. Results of lime effects on swell potential reveal the remarkable remedial effects of lime. For instance addition of just 1 percent lime decreased the swell percent from 13.7 % to 5.1 % when the treated soil was compacted to the same density as the air dried soil. Lower swell percent occurred if each treated soil was compacted according to the relevant compaction test result; with 3 % lime, the plasticity index PI and swell percent decrease to 10 % and 2.5 %, respectively. The laboratory measured swell pressures exhibited an increasing trend as the lime content is increased from 3 % to 6 %.

In this study in order to evaluate effect of fiber reinforcement on the compressibility of Tabriz Marl, some samples were reinforced with different percents of polypropylene fiber and subjected to standard one dimensional consolidation test. Applied pressure varied from 2.5 to 320 kPa. Initial void ratio and initial moisture content of samples were 0.6 and 22%, respectively. Fibers were 12 mm in length. The tests were repeated twice and results were averaged and shown in Figures 17 and 18. In Figure 17 the changes of compression index against fiber content is depicted and Figure 18 presents variations of oedometer modulus m_v^{-1} against variations of effective stress level for specimens containing different fiber contents.

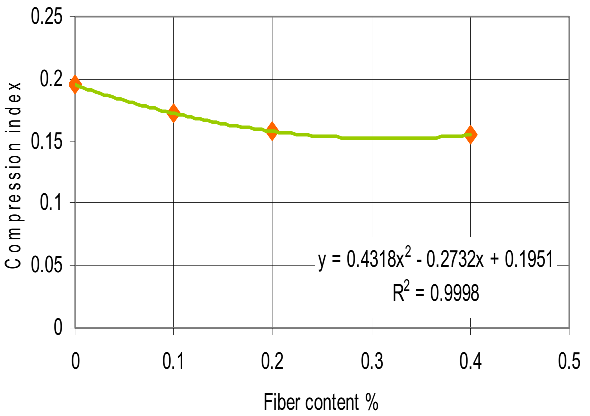


Figure 17. The effect of fiber reinforcement on C_c

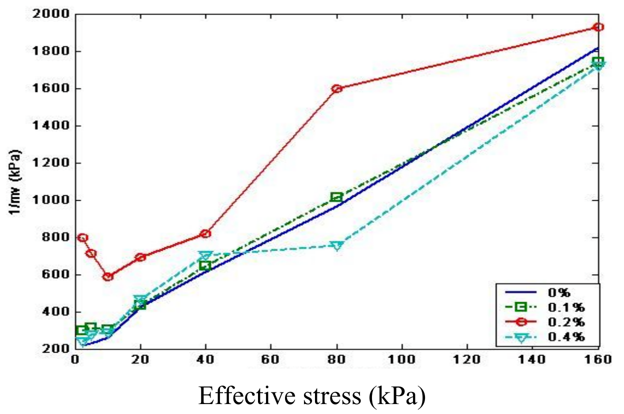


Figure 18. The effect of fiber reinforcement on m_v^{-1}

Referring to Figure 17 it is observed that addition of fiber decreases the compression index Cc. However, it appears that the remedial effect of fiber ceases as the fiber content precedes 0.2 %. The same effect may be observed in Figure 18. Although the m_v^{-1} value increases as the stress level is increased, however, the best effect is achieved at 2% fiber content. With 4 % fiber content the results tend to turn down. It seems that in common with lime improvement method there is a fiber content beyond which no remarkable changes occur in engineering properties. This point may be called optimum fiber content or fiber fixation point.

SUMMARY AND CONCLOUSION

The geological and geotechnical features of Tabriz Marl was explained and characterized in this paper using field evidences and laboratory tests. Some considerable correlations between engineering properties and also effects of precipitation of acidic water and addition of fiber on the engineering properties of a representative specimen were introduced. It was concluded that:

- Tabriz Marl may be considered as a high liquid limit silt MH or clay CH.
- For Tabriz Marl the compression index Cc and liquid limit LL may be correlated as $C_C = 0.0021LL + 0.0675$
- Acidic water increases plasticity index, compressibility and swell potential; and decreases swell pressure.
- Addition of fiber enhances engineering properties of soil through decreasing of compression index and improving oedometer modulus. However, it seems that in common with lime improvement method there is a fiber content beyond which no remarkable changes occur in engineering properties. This point may be called optimum fiber content or fiber fixation point.

Corresponding author: Dr Jamshid Sadrekarimi, Tabriz university, 29 Bahman Boulvard, Tabriz, East Azerbaijan, Iran. Tel: +98 411 3814084. Email: jsadr@tabrizu.ac.ir.

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