Indian Geotechnical Journal, 37(2), 2007, 143-154

Some Geological and Geotechnical Features of Tabriz Marl

J. Sadrekarimi* and A. Zekri**

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 consideration, Azerbaijan is located in western Alborz–Azerbaijan structural zone. This zone is bounded by Caspian depression block to the north and central Iran plateau to the south. Its western part has a NW-SE trend consistent with Zagros, lesser Caucasus and greater Caucasus trends. Its eastern part has a NE-SW trend consistent with the Darouneh fault.

The structure of zone is the resultant of Precambrian and 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 (NGIDR 2004).

Not only is Iran located along the seismic ring of the earth, but also Tabriz is located near North Tabriz Fault (Figure 1). 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 frequently earthquakes, some surface ruptures have been shown along this fault (Hessami et al. 2003).

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, outcrops 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 excavated soil, from numerous on going projects of urban area and industrial zones, are inevitably dumped in valleys, low lying areas, and also on hillsides. Besides the potential earthquake hazards, this trend of soil dumping causes man-made settling and sliding of soil masses which are causing considerable losses to property and damage to buildings. Figure 2 shows an example of a construction site and the resulting problem. The outcrop areas of Tabriz marl are shown in

* Associate Professor, Civil Engineering Faculty, Tabriz University, IRAN. Fax: 98 411 5403492. Email: jsadr@tabrizu.ac.ir

** M. Sc., Geotechnical Engineer, Civil Engineering Faculty, Tabriz University, IRAN. E-mail: ashraf_zekri@ yahoo.com

Figure 3 (Sadrekarimi 2002). In fact, Tabriz area is underlayed by recent alluvium in central urban area and a complex conglomerate, fine sediment, red sandstone and alternate greenish and dark grey marl are the general formation 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.

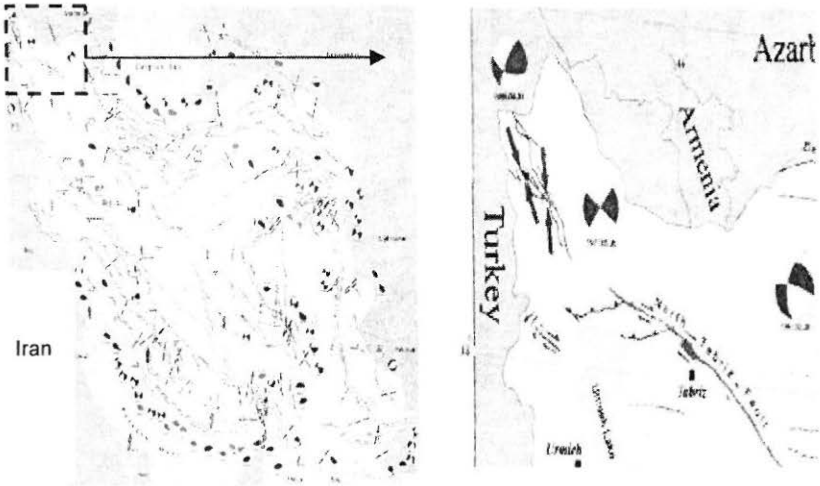

Fig. 1 Location of Tabriz Fault and Tabriz City

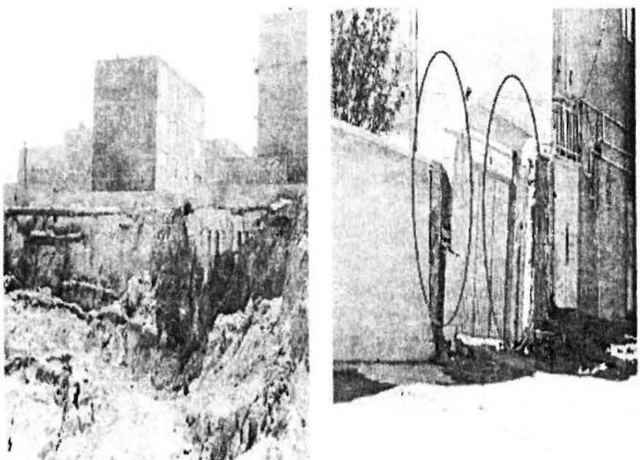

Fig. 2 Construction on a Fill Area and Large Settlements and Slides

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 et al. (1996), 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 Higginbttom (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.

The main chemical constitutions of Tabriz marl 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 a 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 (Figures 5 and 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 the Tabriz marl in different directions, causing a complicated anisotropy. Although the compression index (C_c) and sell index (C_s) values are not quite consistent, however, the C_s value ranges from $0.1C_c$ to $0.2C_c$, which is common for most soils (Das 1985). The results of insitu dry density and natural moisture content, which are shown in Figure 7, show a clear trend of change of dry density against moisture content (Sadrekarimi 2002).

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;/////: Tabriz marl outcrops on urban areas, studied for geotechnical properties, 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.

Fig. 3 Tabriz Area and Marl Outcrop

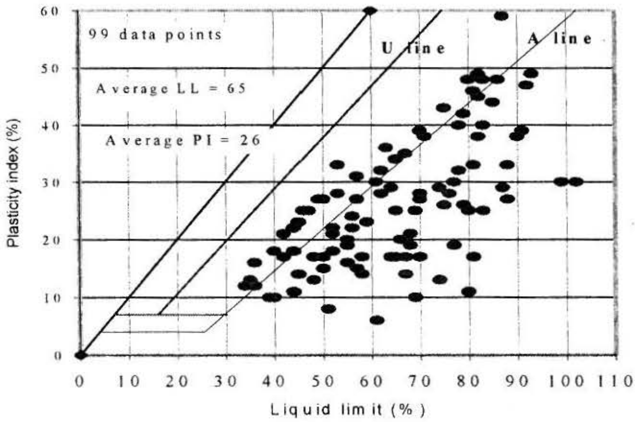

Fig. 4 Atterberg Limits of Samples

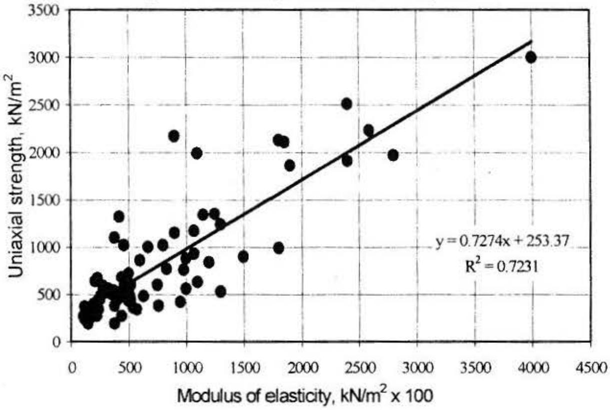

Fig. 5 Modulus of Elasticity Vs. Uniaxial Strength

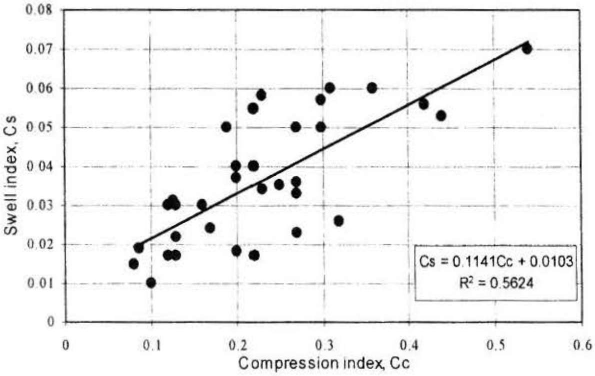

Fig. 6 Compression and Swell Indexes Correlation

The correlation between specific gravity (G_s) and insitu dry density (Figure 8) shows agreement with most soils. The G_s value of Tabriz marl is not significantly affected by dry density and its average value of 2.8 - 3.0 may be concluded from the data of this figure. This range of G_s value may also be inferred with careful scrutiny of Figure 7. The average value of void ratio (e), drained frictional angle and cohesion are 1.2, 22 degrees and 75 kN/m^2, 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 the anisotropy. The engineering properties of Tabriz marl are affected by the complicated stress history due to tectonic activities. For this reason, there are cases in which the dry densities of natural undisturbed specimens are even higher than that of the compacted representative specimen (Table 1).

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

$$C_C = 0.009\,LL - 0.09 \tag{1}$$

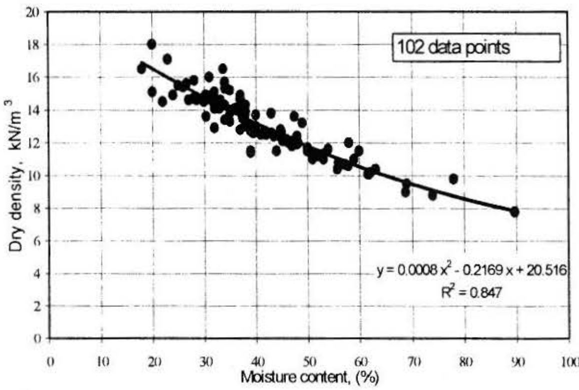

Fig. 7 Dry Density and Natural Moisture Correlation

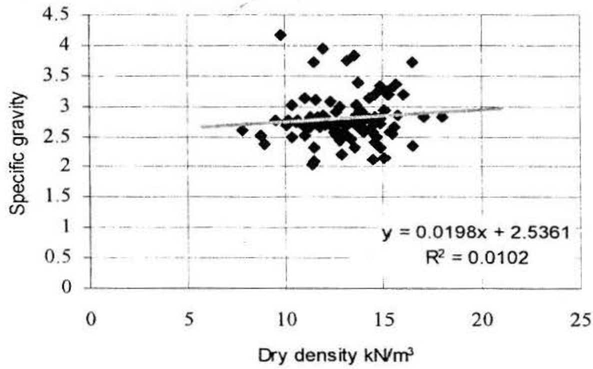

Fig. 8 Specific Gravity Vs. Dry Density

In order to study the correlation of C_c and LL values for Tabriz marl, several undistributed samples were subjected to standard consolidation test (ASTM 1994b) and the compression index values were worked out. The results together with the corresponding LL values are depicted in Figure12. It is noted from the figure that for the Tabriz Marl, Equation (1) is not a good approximation and it may be replaced by

$$C_C = 0.0021\,LL + 0.0675 \tag{2}$$

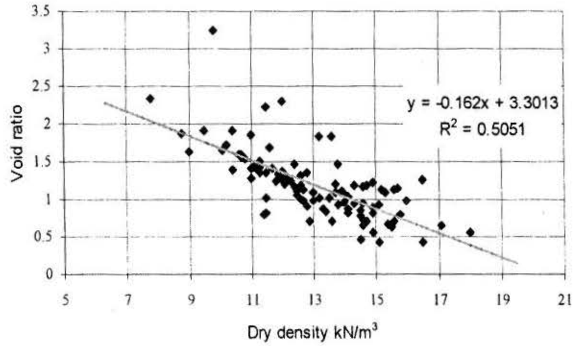

Fig. 9 Void Ratio Vs. Dry Density

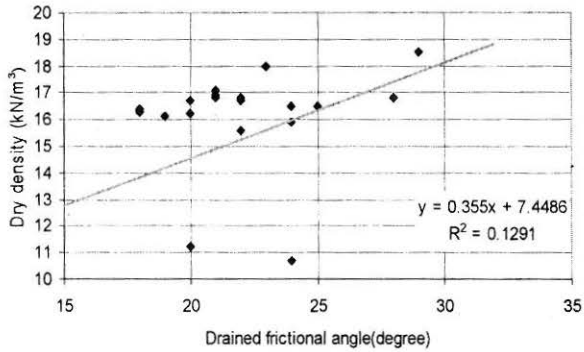

Fig. 10 Dry Density Vs. Drained Frictional Angle

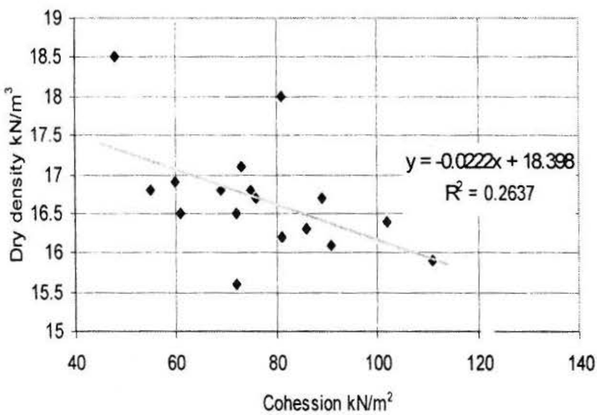

Fig. 11 Dry Density Vs. Drained Cohesion

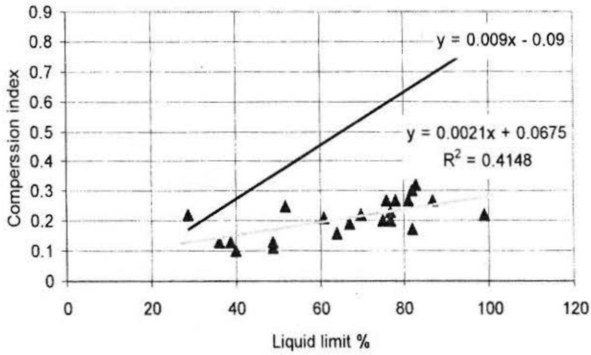

Fig. 12 Liquid Limit and Compression Index Correlation for Tabriz Marl

TABLE 1: Properties of Natural Marl Provided for Acid Washing

(Sampling Depth = 5 m)

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
Classification	---	MH	ASTM 19994a
Natural moisture content (w)	%	27.2	
Mod. Compaction dry unit weight ($\gamma_{d\ max.}$)	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	

There are several instabilities in areas filled with Tabriz marl and also minor slip surfaces with slickensides were found 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, 5 meters into the natural Tabriz marl ground. In spring 2001 following intensive rainfalls and gradual seeps of sewerage water into the underlying fill soil, a sudden mud flow type slide occurred. Figure 14 presents an undisturbed specimen provided from a minor slip surface. This type of slip surfaces may be encountered even in horizontal and/or in gently sloped places. The 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.

The Effect of Acidic and Low TDS Water Seepage

As mentioned above, one of the main components of Tabriz marl is the calcium carbonate (Calcite). The calcium carbonate is diluted by acidic water and also tends to be dissolved in water with low total dissolved salts (TDS). Accordingly, precipitations of low pH and/or low TDS water, such as rainfall or used tap water in residential areas tend 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 where used tap water ɔr rainfall is discharged into the local wells, leaching of carbonated soil may also ɔccur. The tap water in Tabriz is drinking water and acts as very low TDS water.

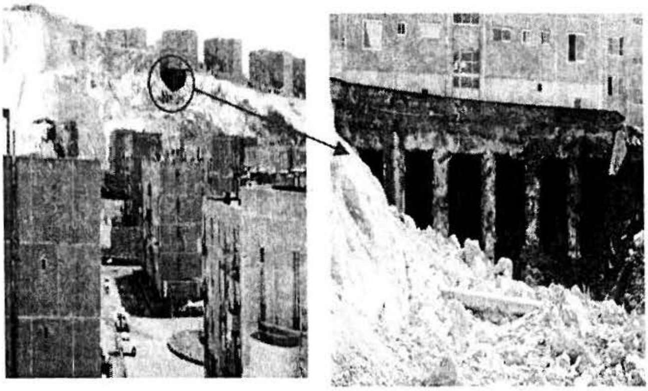

Fig. 13 Mud Flow Type Slide Occurred in Tabriz Marl

Fig. 14 Samples of Slip Surfaces

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 hydrochloric acid (HCl) having 12 eq./lit. concentration 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 bonds were fully disintegrated. The ultimate state was distinguished when no further gas bubbles were observed during agitation. The initial properties of the tested soil are listed in Table 1.

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

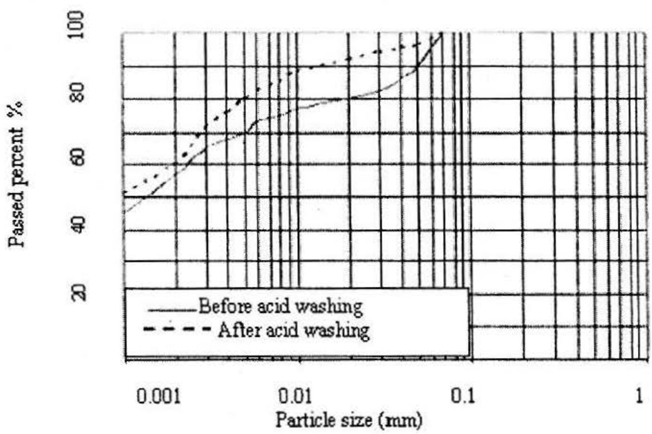

Fig. 15 Effect of Acidic Water on Grain Size Distribution

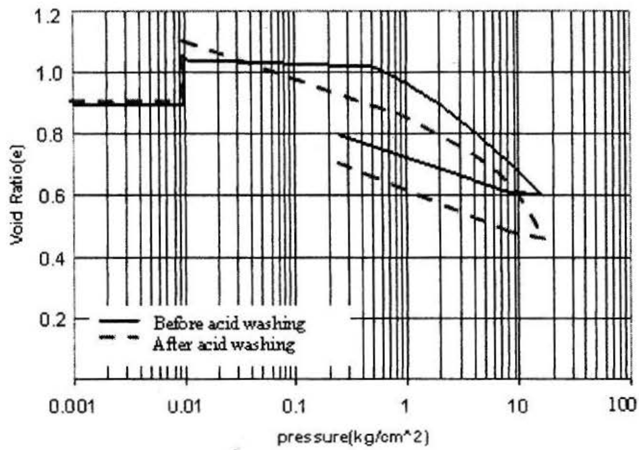

Fig. 16 Effect of Acidic Water on Compressibility

Tabriz Marl Improvment

The poor property of Tabriz marl as a fill soil encourages engineers to study and use soil improvement methods. In the previous study attempted by the first author, the effect of lime addition was investigated. According to Sadrekarimi (2002) addition of lime increases plastic limit (PL) and decreases liquid limit (LL), and causes the plasticity index to decrease both in short (18 hours) and long term (3 years) observations. In short term, the lime fixation point was measured to be 3 %, beyond which no remarkable changes occur in Atterberg limits. In long term, however, the lime fixation point tends to 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 treatment. For instance, addition of just 1 percent lime decreased the swell potential from 13.7 to 5.1 % when the treated soil was compacted to the same density as the air dried soil. Low swell occurred if each treated soil was compacted according to the relevant compaction test results;

with 3 % lime, the plasticity index and swell potential 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 the effect of fiber reinforcement on the compressibility of Tabriz marl, some samples were reinforced with 0.1 to 0.4% by weight of monofilament polypropylene fibers and subjected to standard one-dimensional consolidation test. A typical fiber used was 0.1 mm in diameter and 12 mm in length. Applied pressure varied from 2.5 to 320 kPa. Initial void ratio and initial moister content of samples were 0.6 and 22%, respectively. 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.

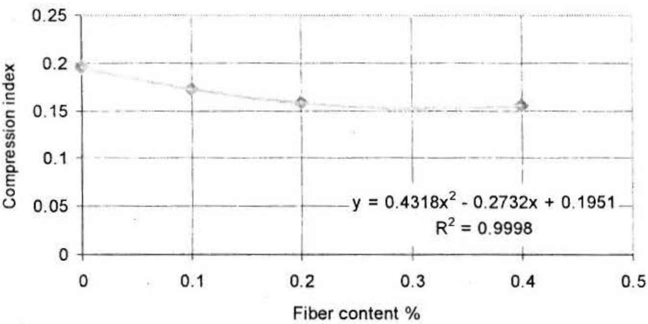

Fig. 17 Effect of Fiber Reinforcement on C_c

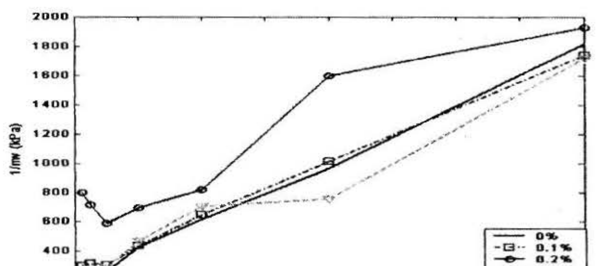

Fig. 18 Effect of Fiber Reinforcement on m_v^{-1}

Referring to Figure 17 it is observed that the addition of fiber decreases the compression index C_C. However, it appears that the remedial effect of fiber ceases as the fiber content exceeds 0.2 %. The same effect may be observed in Figure 18. Although the m_v^{-1} value increases as the stress level is increased, the best effect is achieved at 0.2% fiber content. With 0.4 % fiber content the results tend to turn down. It seems that in conjunction with lime treatment method, there is a fiber content beyond which no remarkable changes occur in the engineering properties of the marl. This point may be called optimum fiber content or fiber fixation point.

Conclusions

The geological and geotechnical features of Tabriz marl are explained and characterized in this paper using field evidences and laboratory tests. Some correlations between the engineering properties and the effects of precipitation of acidic water and addition of fiber on the engineering properties of representative marl specimens were introduced. It is concluded that:

1. Tabriz marl may be considered as high liquid limit silt MH or clay CH.
2. For Tabriz marl, the compression index C_c and liquid limit LL may be correlated as: $C_c = 0.0021LL + 0.0675$
3. Acidic water increases plasticity index, compressibility and swell potential; and decreases swell pressure.
4. Addition of fiber enhances the engineering properties of marl through decrease of compression index and improving oedometer modulus. However, it seems that in agreement with lime treatment method there is a fiber content beyond which no remarkable changes occur in the engineering properties of the marl.

Notations

C_c	= Compression Index
C_s	= Swell Index
CH	= Highly Plastic Clay
e	= Void Ratio
G_s	= Specific Gravity
LL	= Liquid Limit
m_v^{-1}	= Oedometer Modulus
MH	= Highly Plastic Marl
pH	= pH Value
PL	= Plastic Limit
PI	= Plasticity Index
R^2	= Degree of Determination
TDS	= Total Dissolved Salts
w	= Natural Moisture Content
w_{opt}	= Optimum Moisture Content
$\gamma_{d\,max}$	= Mod. Compaction Dry Unit Weight.

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