GEOTECHNICAL PROPERTIES OF LACUSTRINE CARBONATE SEDIMENT

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Abstract   Results of laboratory tests on specimens produced from subsoil studies were evaluated to characterize geotechnical properties of Tabriz Marl. It was concluded that, Tabriz Marl may 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. Correlation between these properties has been introduced in this paper. A representative specimen was tested for swell potential after compaction and also for thermal and lime treatment effects. Swell percent and pressure as high as 13.6 % and 1020 kPa were measured and need for treatment was proved. It was shown that with thermal treatment substantial modification only starts as the temperature rises beyond 300° C. At 500° C the plasticity index and also the swell percent decrease to less than 5.0 % and 1.0 %, respectively. With lime treatment, plasticity index decreases as the lime content is increased until the lime fixation point is achieved at about 3 % lime content, beyond which, modification effects are not considerable. Addition of just 1.0 % lime to the soil decreased the swell potential to 5.0 %. Further results, merits and shortcomings of both treatment methods are introduced during the text.

Key Words   Marl, Swell Potential, Lime Treatment, Thermal Treatment

چکیده   بـرای تشــخیص دقـیق خواص ژئوتکنیکی مارن تبریز آزمایشات آزمایشگاهی متعدد روی نمونه‌های بدسـت آمـده از کاوشـهای زیر سطحی انجام داده شد و نتایج ارزیابی گردید. بر اساس این آزمایشات، می‌توان مـارن تبریز را اغلب به عنوان رس و یا سیلت با حد روانی زیاد و پتانسیل تورم بالا، حدود ۱۳/۶ درصد پس از تـراکم، در نظر گرفت. محدوده تغییرات خواص ایندکس، خواص فیزیکی و مکانیکی مارن تبریز نسبتاً گسترده اسـت. یـک تعـداد همنسـبتی بیـن ایـن خواص، و همچنین نتایج تحقیقات اصلاح خواص مهندسی یک نمونه شاخص، با استفاده از آهک و حرارت، در مقاله حاضر ارائه شده است. در درمان حرارتی اصلاح اساسی موقعی رخ مـی‌دهـد کـه درجـه حرارت از ۳۰۰ °C بالاتر رود. در ۵۰۰ °C دامنه خمیری و همچنین درصد تورم به ترتیـب به کمتر از ۵ و ۱ درصد کاهش پیدا می‌کند. در صورت استفاده از آهک، دامنه خمیری با افزایش درصد آهک تـا رسـیدن بـه نقطـه تثبیت آهک در ۳ درصد، کاهش پیدا می‌کند و پس از آن اثرات اصلاح قابل توجه نخواهـد بود. افزودن فقط ۱ درصد آهک مقدار تورم را به ۵ درصد کاهش می‌دهد. مقایسه دو روش اصلاح در مقاله ارائه شده است.

1. INTRODUCTION

Tabriz Marl   Large volumes of lacustrine carbonate sediment outcrops, locally known as Tabriz Marl, surrounds eastern and southern regions of Tabriz city in the Azerbaijan province of Iran as shown in Figure 1. The main chemical constitutions of Tabriz Marl are typically as 35 % calcite, 40 % quartz, 10 % feldspar and 4 % dolomite. 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. This trend causes man- made settling and sliding soil masses, which are causing considerable property losses and damage.
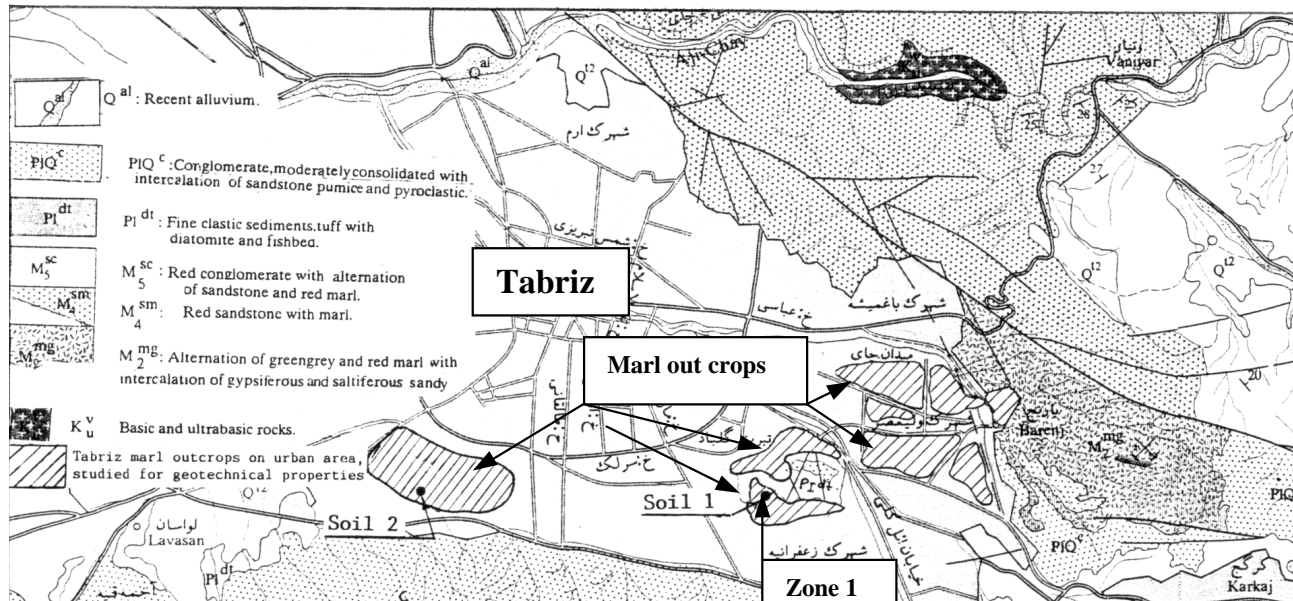
Figure 1. Tabriz area and marl out crops.

In order to classify and define the natural geotechnical properties of Tabriz Marl, specimens obtained from subsurface explorations over the past 10 years were collected and subjected to physical and mechanical tests. Research programs were also carried out on the thermal (heating) and also lime improvement of the Tabriz Marl for engineering use. In Iran, heavy gas fuel is comparatively cheap and could be used for thermal treatment. The results obtained are presented and discussed in this paper.

Literature Review   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 [1]. Pettijohn (1975) defined marl as a rock containing 35 to 65 percent carbonate and a complementary content of clay [2]. Fooks and Higginbottom (1975) mentioned that marl is a simple binary mixture of true clay and calcium carbonate, whilst marlite or marlstone is an indurate equivalent [3]. 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 [5]. McCarthy (1982) introduced marl as a soft limestone [6]. Mitchel (1985) defined marl as a soft calcareous clay-rich material, often barely consolidated, with or without distinct fragments of shale [7]. Qahwash (1989) referred to calcareous sediment of 55 to 80 percent carbonate as marl [8].

A substantial literature have documented and spelled out the severity and extent of difficulties and damages by soil deposits of swelling nature in many urban areas throughout the world [9, 10]. Of the several remedial measures of stabilization and modification of engineering properties of clay soils the lime application is increasingly developed and accepted being the most popular stabilizing and improvement method suited for high plasticity and expansive soils [11, 12]. Small amounts of lime enhance many of the engineering properties of clay soils. The changes, which occur to the fabric and properties of a clay soil, when lime is added, are modification and stabilization [13]. As soon as lime is added to clay, soil caution exchange occurs and clay particles adsorb ions by cation exchange [13-15]. This rapid process is called soil
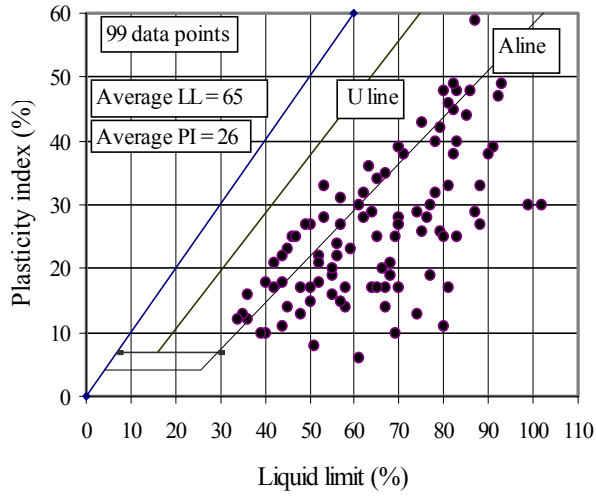
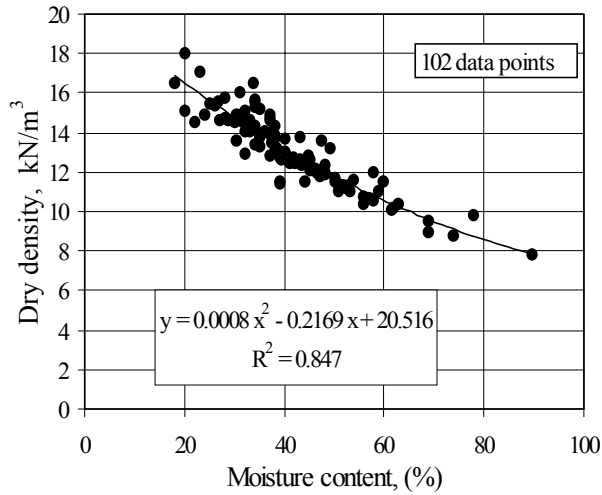**Figure 2**. Tabriz Marl Atterberg limit test results.

Figure 4. Uniaxial strength - modulus of elasticity correlation.

Figure 3. Dry density - natural moisture content correlation.
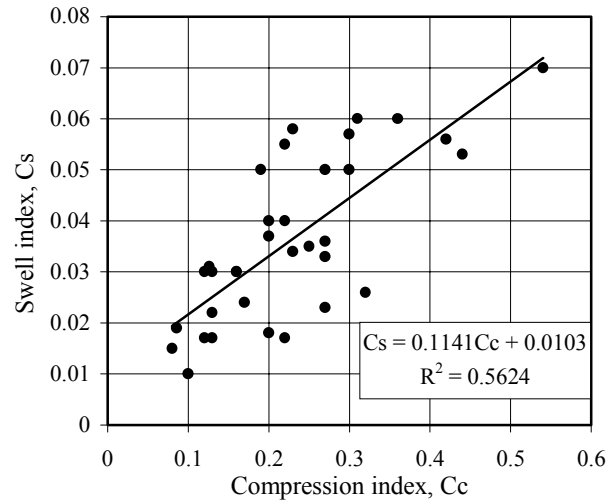

Figure 5. Compression and swell index correlation.

modification. Due to this process, soil particles attract each other and stick together in flocks. This in turn reduces the soil plasticity and swelling characteristics, and increases the permeability allowing easier water flow between particles [16-18]. The plastic limit exhibits a general increase with lime addition for all clay soils [19-21] but the change in liquid limit depends on the soil type [22,

23]. However, there is a point at which increased lime content produces no further marked change in plastic limit. This is known as the lime fixation point [24], which is normally of the order of 1-3 percent, by weight [25]. The lime fixation point is defined by McAlister (1992) as the lime content above which no significant improvement in plastic properties (Atterberg limits) occurs [22]. The

TABLE 1. Properties of Natural Marl Provided for Lime Treatment (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)	%	32	Air dried
Plasticity index (PI)	%	38	ASTM D 4318-93
USCS classification	---	MH	
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 after compaction due to soaking	%	13.7	Figure 7
Swell pressure of compacted soil	kN/m^2	1020	ASTM D 4546-90, method A
Calcite content	%	40.4	
Dolomite content	%	1.0	
Quartz content	%	40.6	

addition of lime also modifies the compaction properties [13]. In general, maximum dry density decreases and the optimum moisture content increases with increasing lime content [19, 26, 27]. It appears that under the lime fixation point there is only a slight decrease in unit weight with increase in the delay between mixing and compaction. However, above this point there is a significant decrease in unit weight with delay. This behavior is attributed to the phenomenon of carbonation [28]. Below the lime fixation point, lime addition steeply decreases the maximum dry density and marginally improves the strength [29]. In addition to the rapid chemical reaction between soil and lime there is a slow long-term chemical reaction, which is mainly cementation and carbonation. This process, which is called stabilization, increases the strength and gives additional volume stability, decreases permeability and produces remarked improvement in frost resistance [30]. The rate of cementation reaction is considerably sensitive to temperature and greatly enhanced rates of strength development maybe achieved by relatively small temperature increase [13, 31]. Also, strength development ceases if the moisture content falls below a critical level [13]. Both the percent of lime and curing time have influence both on compression and rebound indices Cc and Cs, but the effect is more pronounced on the rebound index [32]. Tests on compacted kaolin clay treated with lime specimens indicate that the coefficient of consolidation values Cv is generally equal or less than that of untreated clay at equal water content [33].

2. TABRIZ MARL GEOTECHNICAL PROPERTIES

Figure 1 shows a simplified geologic map of Tabriz area. The dashed zones indicate Tabriz Marl out crops over which several subsoil geotechnical investigations consisting several borings and trial pits were put down during past ten years. The boreholes and trial pits were sunk to between 3 to 30 meters below the ground level, and several disturbed and undisturbed samples were provided. In order to characterize Tabriz Marl some considerable numbers of the samples were tested for the possible physical and mechanical properties by the author. The results of these tests are shown
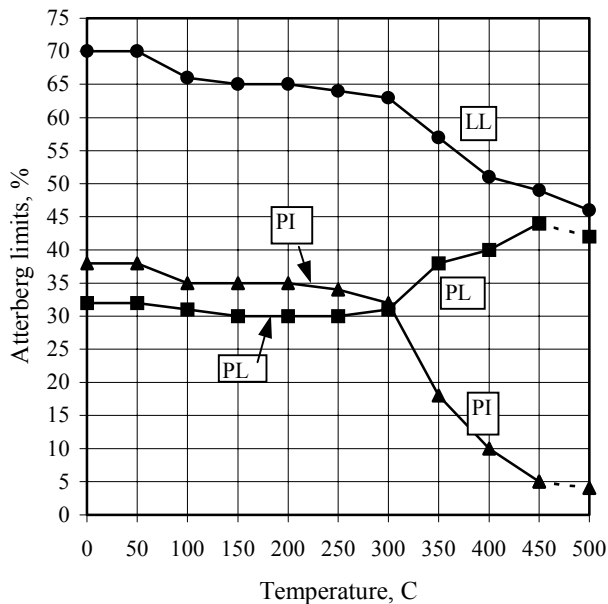
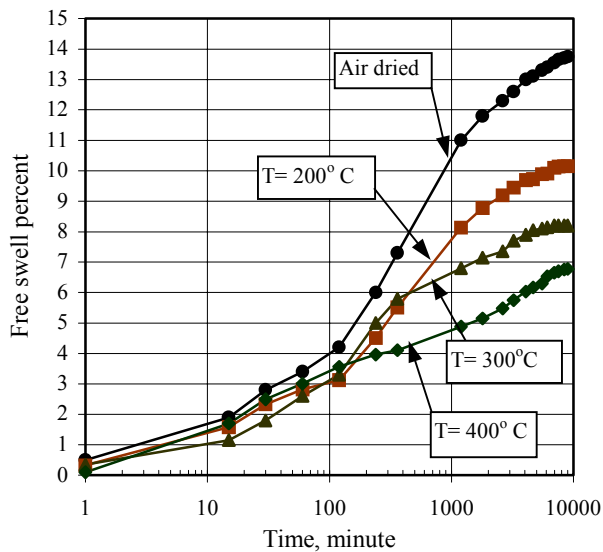**Figure 6**. Thermal treatment effects on Atterberg limits.

Figure 8. Heating effects on swell potential of specimens compacted to the maximum dry densities.

Figure 7. Thermal treatment effects on swell potential of specimens compacted to the same dry densities.
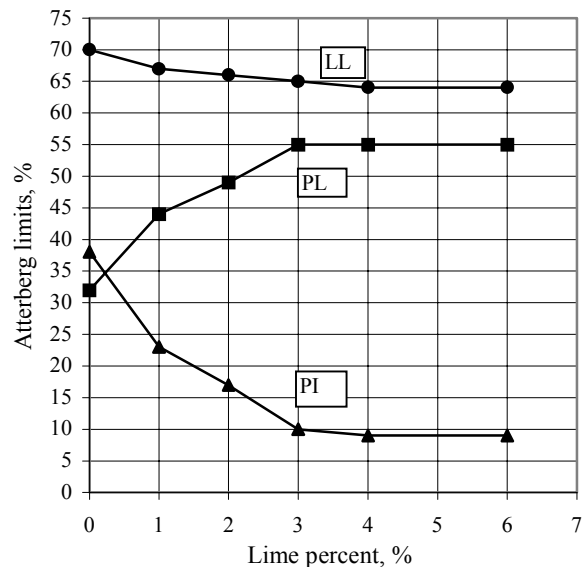
Figure 9. Lime addition effects on Atterberg limits (after 18 hours).

in Figures 2 to 5. The unconfined compressive strength and modulus of elasticity values q_u & E, obtained from uniaxial compression (A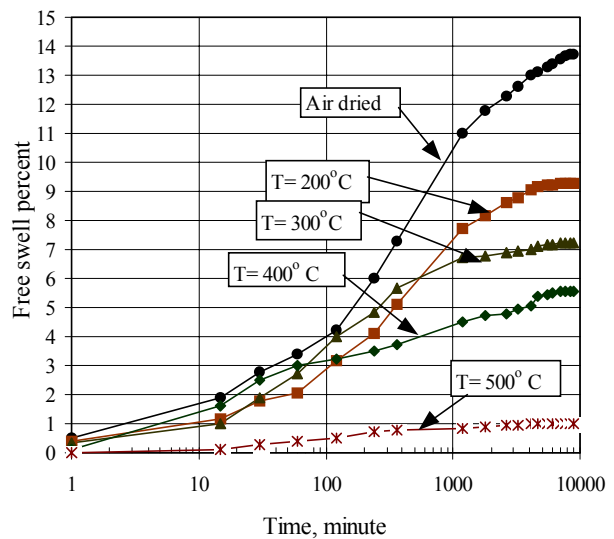STM D 2166-91) tests; and also the compression and swell indices Cc and Cs, which were determined using consolidation tests (ASTM D 2435-90) on undisturbed specimens [34], are depicted in Figures 4 and 5, respectively.

Figure 10. Lime addition effects on Atterberg limits, (after 3 years).

Figure 11. Lime addition effects on swell potential of specimens compacted to the same dry densities.

3. THERMAL AND LIME TREATMENT
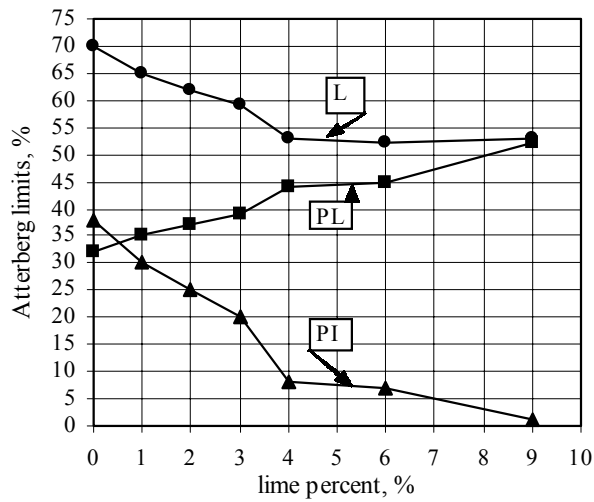
The Test Soil Properties   In order to evaluate the thermal and lime treatment effects on engineering properties of Tabriz Marl a representative soil sample was provided from zone 1. This zone, which is shown in Figure 1, locally is called "Zafaranieh place". The sample provided was first tested for appropriate properties, and the results are summarized in Table 1. According to the index test results the sample collected is classified as high liquid limit silt (MH) in accordance with the USCS classification system.

In order to evaluate the compacted soil swell percent and pressure due to soaking, some air dried soil was subjected to modified compaction test, and the optimum moisture content and maximum dry density were determined (ASTM D 1557-91), [34]. Then, 2 specimens were prepared using 75 mm diameter odometer rings with the same maximum density and optimum moisture content as obtained from compaction test. The specimens prepared were tested for swell potential and pressure (ASTM D 4546-90 method A) and results were averaged [34]. In method A, the ring with the specimen recessed in the ring is assembled to the consolidometer. The specimen is inundated and
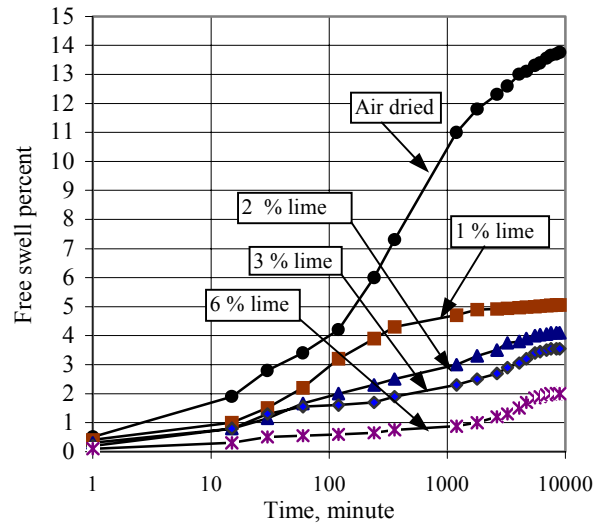
allowed to swell at the seating pressure at least 1 kPa until primary swell is complete. The specimen is loaded after primary swell has occurred until its initial height is obtained. The results of these tests are also summarized in Table 1. The swell rate of the compacted soil due to soaking against time is also shown in Figure 7. This test is valuable in that the results obtained can be employed as the basis to evaluate the efficiency of soil improvement process.

Thermal Treatment Tests   In order to evaluate the thermal treatment effects over the engineering properties of Tabriz Marl, ten air-dried and pulverized soil samples were first kept for 24 hours in ovens with inside temperatures ranging from 50 to 500° C at 50 degrees intervals. To comply with the definition of standard dry soil, each thermal treated soil specimen was cooled down and brought to liquid limit adding distilled water. The paste produced was dried again in a 104° C oven and then pulverized again to 100 percent passing sieve No 10. It was observed that the specimens which were treated at 400 and 500° C regained 1.1 and 1.5 percent moisture, when they were mixed with distilled water and dried again at 104° C. However, for specimens treated at a temperature

less than 300° C the moisture regains was quite less than 1 percent. The re-dried soil samples were then tested for the Atterberg limits, and also for swell percent and pressure tests. The results of the Atterberg limits tests (ASTM D 4318–93) are depicted in Figure 6. The plastic limit tests with soil treated at 500° C were somewhat erratic because of the soil paste rolling difficulties. For this reason the segments of PL and PI curves relating to 400 - 500° C, in Figure 6, are shown with broken lines.

In order to evaluate the swell characteristics, two series of oedometer specimens were prepared and subjected to the swell percent and swell pressure tests due to soaking (ASTM D 4546-90 method A). Each test was repeated for 2 times and the results were averaged. The specimens series 1 were all the same in dry density and moisture content as the specimen prepared with the air dried soil, i.e. $\gamma_d = 16.7$ kN/m^3 and $w = 22$ %. In fact, these specimens were the same in the initial voids ratios. With the soil samples treated at 450 and 500 ° C, the specimen containing 22 percent moisture was so dry of optimum that the compaction to the 16.7 kN/m^3 dry density was not possible. Each specimen in series 2 was prepared with each treated soil sample containing the relevant optimum moisture. Each treated soil sample was compacted to the corresponding maximum dry density. The results of these tests are shown in Figures 7 and 8, and summarized in Table 2.

Lime Treatment Tests Air-dried and pulverized soil masses were mixed with 1 to 9 percent by weight lime powder, and the mixtures produced were divided into smaller portions. In order to assess the short and long term effects of lime, the soil-lime mixtures were mixed with 22 percent by weight water and stored in air tight plastic bags, one half for 18 hours and the other half for 3 years. Having matured the stored soils, they were subjected to Atterberg limits, modified compaction, and swell potential tests. The 3 years old specimens were used for Atterberg limits tests only. The results of Atterberg limits tests are shown in Figures 9 and 10. It is seen that some changes in Atterberg limits have been occurred in long term.

In common with the thermal treatment tests, two series of oedometer specimens were prepared and subjected to swell potential tests (ASTM

D4546-90, method A). These tests, to comply with practice, were carried out only on mixtures cured for 18 hours. Each test was carried out for 2 times and the results were averaged. The specimen's series 1 were all the same in dry density and moisture content as the air-dried soil. In order to prepare specimens series 2 the moisture content of each soil-lime mixture was first brought to its optimum moisture content and then molded in a odometer ring and compacted to the corresponding maximum dry density. The results of these tests are summarized in Table 3 and Figures 11 and 12.

4. DISCUSSION

Figure 2 represents the results of numerous Atterberg limits tests (ASTM D 4318 - 93). It is seen that the ranges of changes of LL and PI values are comparatively wide. However, the average values of liquid limit and plasticity index are 65 and 26 indicating that Tabriz Marl maybe classified as CH & MH (ASTM D 2487). The dry density and natural moisture content test results, which are shown in Figure 3, are consistent and show a convincingly clear trend of change of dry density against moisture content. The trend line and the corresponding equation, which are shown on the same figure, appear to be useful for engineering judgment. It also should be noted that for the moisture content changing from 20 to 90 percent the dry density may decrease from 18 to as low as 8 kN/m^3, and in turn the void ratio may increase from 0.47 to as high as 2.30. A mass of marl possessing such a high void ratio can initiate a considerable consolidation settlement when loaded. In Figures 4 and 5 it is observed that the results of uniaxial and consolidation tests are somewhat scattered in both cases. This maybe 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. However, Figure 4 maybe regarded as a general hint to correlate the E and q_u values. In Figure 5, although the Cc and Cs values are not quite consistent, however, the Cs value ranges from 0.1Cc to 0.2Cc, which is common for most soils [35].
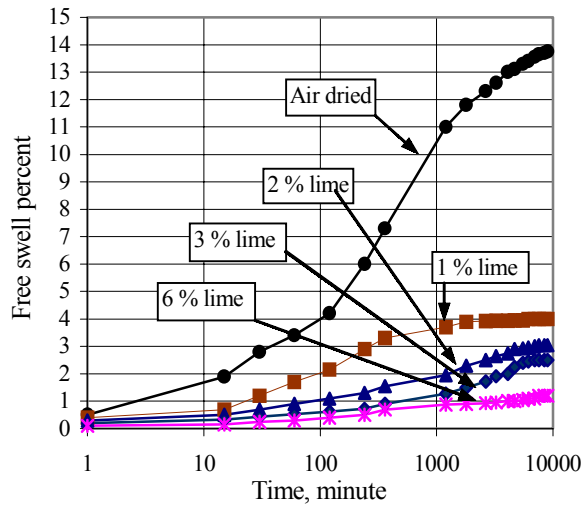
Figure 12. Lime addition effects on swell potential of specimens compacted to the maximum dry densities.

Referring to Figure 6 it is seen that the treatment effect substantially only starts beyond 300° C. The LL and PL values substantially decrease and increase, respectively, as the temperature passes beyond 300° C; and causes the PI value to decrease sharply, so as, at about 450 - 500° C the soil tends to be non-plastic. A small decrease in LL and PL values at about 50-100° C may be attributed to the organic effects, however. Referring to Figures 7, 8, and Table 1, it is seen that the compacted air dried marl may exhibit a swell percent and pressure due to soaking as high as 13.7 % and 1020 kPa, respectively. Such a swell potential may cause considerable damages to road embankments and other civil works. It is seen that with the specimens series 1 and 2, the swell percent and the swell pressure both decrease as the treatment temperature is increased. Comparing these results with Atterberg limits test results in Figure 6, it appears that with the thermal treatment process, beyond a certain temperature level, say 300 ° C, the PL value increases. Meanwhile, both the swell pressure and swell percent decrease. With the specimen's series 2, which are compacted at the optimum moisture contents, it is seen that as the treatment temperature increases the optimum moisture content also increases and causes the

maximum dry density to decrease. This phenomenon causes further reduction of swell potential in comparison with the specimen's series 1.

Figures 9 to 12 exhibit the results of lime treatment tests. Referring to Figures 9 and 10 it is observed that addition of lime increases plastic limit (PL) and decreases liquid limit (LL), and causes the plasticity index to decrease in short and long term. In short term (18 hours), the lime fixation point was measured 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 are shown in Figures 11 and 12 and summarized in Table 3. These figures both reveal the remarkable remedial effects of lime. Addition of just 1 percent lime decreases the swell percent from 13.7 % to 5.1 % when the treated soil is compacted to the same density as the air-dried soil. Lower swell percent occur if each treated soil is 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. Such achievement is quite satisfactory for the engineering purposes. The laboratory measured swell pressures, summarized in Table 3, show an increasing trend as the lime content is increased from 3 % to 6 %. These figures, however, cannot be attributed to the swell pressure due to the moisture uptake only. Because, beyond the lime fixation point the specimen rigidity further increases due to lime stabilization reaction during the soaking period.

A comparison between the results of thermal and lime treatment tests shows that, in lime treatment method addition of 1 % to 3 % lime causes substantial decrease in swell potential and also plasticity index. In thermal treatment, however, such a modification level is achieved when the temperature rises beyond 400°C. In practice, however, mixing of lime powder and wet soil to produce a homogenous mixture is not a simple job. Lumps of wet marl either remain uncrushed or produce a very sticky mass before the lime modification effect is established. With thermal treatment, a horizontal rotary burner is quite capable to warm up marl lumps beyond 400° C. Following which, the material produced will be

TABLE 2. Summary of Swell Tests on Thermal Treated Specimens.

T ° C	Same density and moisture content as the air dried specimen (series 1)					Compacted at optimum moisture content and Max. dry density (series 2)				
	Air dried	200	300	400	500	Air dried	200	300	400	500
γ_d, kN/m^3	16.7	16.7	16.7	16.7		16.7	16.2	15.7	15.1	14.9
w, %	22.0	22.0	22.0	22.0		22.0	24.1	25.3	26.5	27.8
Swell, %	13.7	10.15	8.2	6.8		13.7	9.3	7.25	5.6	0.9
P_s, kPa	1020	955	940	675		1020	670	620	470	25

TABLE 3. Summary of Swell Tests on Lime Treated Specimens (18 Hours After Addition of Lime).

Lime %	Same density and moisture content as the air dried specimen (series 1)					Compacted at optimum moisture content and Max. dry density (series 2)				
	0.0 %	1.0 %	2.0 %	3.0 %	6.0 %	0.0 %	1.0 %	2.0 %	3.0 %	6.0 %
γ_d, kN/m^3	16.7	16.7	16.7	16.7	16.7	16.7	15.3	14.4	13.8	13.4
w, %	22.0	22.0	22.0	22.0	22.0	22.0	25.8	30.2	25.5	37.2
Swell, %	13.7	5.1	4.1	3.5	2.0	13.7	4.0	3.05	2.5	1.2
P_s, kPa	1020	410	464	842	980	1020	290	290	412	694

a low plasticity material that is easy to spread, mix with water and compact. In order to make the final decision, these parameters should be evaluated from technical and economical viewpoints. It appears that with air dried marl the lime treatment precedes the thermal treatment method.

5. CONCLUSIONS

Results of laboratory tests on specimens produced from subsoil studies were first evaluated to characterize geotechnical properties of the Tabriz Marl. It was concluded that, Tabriz Marl might be considered as high liquid limit silt MH or clay CH. A satisfactory correlation was established between dry density and moisture content. However, due to complicated sedimentation features and stress history caused by tectonic activities a reasonable correlation cold not be established between the mechanical properties. Tabriz marl may exhibit high swell potential due to moisture uptake when compacted. In this research a representative specimen exhibited 13.7 percent swell and a 1020 kPa swell pressure. Accordingly, modification is required when used as a foundation or embankment material.

Thermal treatment tests on the representative specimen revealed that the plasticity index decreases as the temperature is increased. However, substantial treatment only starts when the temperature rises beyond 300° C. At 500° C the plasticity index and the swell percent decrease to less than 5 % and 1 %, respectively.

With lime treatment, the liquid limit decreases and the plastic limit increases as the lime content is increased, and causes the PI value to decrease, until the lime fixation point is achieved. The lime fixation point was obtained at about 3 %, beyond which modification effects were not remarkable. In the long term however, beyond this point, the plasticity index tends to vanish due to the lime stabilization effect. The swell percent decreases as the lime content is increased, however, substantial effect already occurs at lime content of 1 %.

A comparison between the results of thermal and lime treatment tests shows that, with the lime treatment method the addition of 1-3 % lime causes substantial decrease in swell potential and

plasticity index. In thermal treatment, however, such a modification level is achieved when the temperature rises beyond 400° C. In spite of the fact that thermal and lime treatment methods both are quite effective, both have some merit and shortcomings from a practical point of view.

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