Resilient modulus lime-treated expansive subgrade

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Abstract. Proper design of lime-treated subgrade requires knowledge of the stress-strain behavior under repeated traffic load. Limited research exists regarding the resilient modulus (M_R) of lime-treated expansive soils. This study investigates the effect of lime treatment on the M_R of an expansive soil from city of Tabuk in Kingdom of Saudi Arabia. Tests were performed in accordance with AASHTO T-307. Tests variables included lime content (2%, 4% and 6% by dry weight of soil) and curing period (7 and 28 days). Experimental results mainly revealed an increase in M_R values due to lime treatment. In addition, the variation of M_R with deviatoric stress revealed trends of strain softening behavior in case of untreated soils and lime-treated soils cured for 7 days. However, lime treated soils cured for 28 days experienced some strain hardening behavior with high dependency on confining pressure. Furthermore, the M_R of lime treated expansive subgrade was observed to be highly dependent on lime content and curing period. Finally, results were fitted using the three-parameter model to determine the stiffness coefficients (k_1, k_2, k_3).

Keywords. Resilient Modulus, Expansive soil, Lime.

1. Introduction

Design and performance of pavement structures are dependent on the engineering properties of the subgrade. The resilient modulus of subgrade is the main engineering parameter that is used in the structural design and analysis of pavement structures (AASHTO 1993, M-EPDG). The resilient modulus represents the relationship between stress and strain of subgrade soils under a repeated dynamic loading environment. Typically, the resilient modulus is experimentally evaluated using a cyclic load triaxial test on representative samples. The resilient modulus, M_R is expressed in terms of the ratio of the maximum cyclic stress (σ_d) to the recoverable resilient strain (ε_r) in a repeated dynamic loading environment and this expression is presented as shown in the following equation:

$$M_R = \frac{\sigma_d}{\varepsilon_r}$$

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Construction of pavement structure on certain soils, example weak soils and expansive soils may have detrimental effects on the pavement structures. Expansive soils undergo significant volume change (swelling or shrinkage) due to changes in moisture. Expansive clays are located at different locations in Kingdom of Saudi Arabia (KSA). These soils vary in swelling characteristics depending on geological origin and forming environment. Damages to pavement structures due to expansive soils were extensively documented in the technical literature (Shamrani et al. 2010, Dafalla and Shamrani 2011). One of the common techniques used to mitigate the impact of expansive subgrade on pavements involves the treatment of soil with lime. The addition of lime results in arresting the swelling behavior of soils as a result of two chemical reactions: cation exchange and pozzolanic reactions. Cation exchange is considered to be a short-term reaction that takes place immediately after lime is added and tend to increase the workability of the soil. During pozzolanic reaction, alumina and silica dissolve out of the clay minerals and combine with the calcium from lime to produce the cementitious compounds that bond clay particles (Nalbantoglu and Tuncer 2001; Al-Mukhtar et al. 2010). This reaction is considered a time-dependent process that can extend for days, weeks or even years.

Several researchers have conducted experimental research evaluate the resilient modulus of lime-treated soils (Rout et al. 2012, Okyay and Dias 2010, Mohammad and Saadeh 2008). Most of these studies focused on non-expansive soil materials with limited research conducted for lime-treated expansive subgrade. Furthermore, there is a need to evaluate the resilient modulus of lime treated expansive subgrade soils as function of lime content and curing period.

The objective of the present study is to perform a series of the cyclic load triaxial laboratory tests on untreated and lime-treated expansive subgrade obtained from a local area in KSA. Testing was performed in accordance with AASHTO T-307 (2007) methods. Parameters considered included lime content and curing period. Finally a multiple regression analysis was performed to evaluate coefficients of the constitutive model used for both treated and untreated soils.

2. Materials

This section provides a description of materials and experimental techniques used in this study.

2.1. Material Used

Expansive clays used in this study were obtained from the city of Tabuk in Kingdom of Saudi Arabia (KSA). The city of Tabuk is located in the northwest region of KSA near the borders of Egypt and Jordan (latitude 28^o 23' 24" N and longitude 36° 34' 23"). Expansive clays were obtained from open pits excavated to depths 2.5 to 3.5 meters below ground surface and near structures were damages attributed to soil swelling were observed. Samples were bagged and transferred to King Saud Laboratory for full geotechnical characterization. A summary of geotechnical characteristics of Tabuk clay are presented in Table 1.

Lime used in this study was commercial grade calcium hydroxide (assay 90%), supplied by Saudi Lime, Riyadh, KSA. Estimation of the optimum lime content value for lime-clay mixtures was evaluated using ASTM D 6276 – 99a originally proposed by Eades and Grim (1996). The optimum lime content defines the lime content beyond which further increase in lime content will have negligible effect on improvement of soil. According to ASTM standard, the lowest percentage of lime that results in a soil-lime pH of 12.4 is considered the optimum lime content. Results of test performed on soil indicated that the optimum lime content was 4% by dry weight. Additional lime contents equivalent to ±2% of optimum lime content were considered in this study. In other words, the lime contents considered in this study was 2%, 4% and 6% by dry weight of clay.

2.2. Sample preparation

Clay samples transported to the laboratory were processed by air-drying, pulverizing and sieving using sieve No. 40 to develop clay powder. Lime was added to the clay powder and mixed dry until obtaining a homogenous mixture. Target water content was then added, thoroughly mixed and stored in hermetic plastic bags to mellow. After mellowing, specimens were statically compacted to target dry unit weight using BS standard EN 13286-53. Target dry unit weight and water content of lime-treated expansive clay corresponded to the maximum dry unit weight and optimum water content evaluated using standard compaction test (ASTM D698). The compaction curves for lime-treated Tabuk clay are shown in Figure 1. This figure shows that an increase in lime content resulted in a decrease in maximum dry unit weight and an increase in optimum water content. The final dimensions of the specimens were 50 mm in diameter and 100 mm high satisfying the 2:1 length to diameter ratio. After static compaction, specimens were cured by sealing them in plastic wrap and storing them in a high relative humidity environment (> 95%) for 7 to 28 days.

Table 1. Geotechnical Characterization Data for Tabuk Soil

Test	Standard	Value
Specific Gravity, Gs	ASTM D854	2.81
Liquid Limit, w_L (%)	ASTM D4318	42.6
Plastic Limit, w_P (%)	ASTM D4318	26.4
Plasticity index (%)	ASTM D4318	16.2
Shrinkage Limit, w_{sh} (%)	ASTM D427	19.5
% passing Sieve No. 200	ASTM D1140	92.8
Unified soil classification	ASTM D2487	CL
Swelling Characteristics	ASTM D	
Swelling potential (%)		7-10
Swelling pressure (kPa)		150 -250

3. Experimental Procedure

3.1. Resilient modulus test

The resilient modulus for lime-treated specimens was determined experimentally using the VJ tech® Resilient Modulus device. The device was developed to perform resilient modulus in accordance with AASHTO T-307 (2007) using a closed loop servo electro-mechanical loading system. Soil specimen was mounted inside a triaxial cell and repeated axial load was applied on the soil sample. The repeated applied axial load was measured using axial load cell and deformation was recorded using two external linear variable differential transducers (LVDT) attached to the loading ram. Air was used as the medium for applying confining pressure.

During testing, the soil specimen in the triaxial cell was subjected to loading sequences each with a deviatoric stress (σ_d) and static confining pressure (σ_c) as per AASHTO T-307 (2007) – subgrade material type 2. The test starts with a conditioning phase (sequence 0) by applying a minimum of 500 repetitions with haversine-shaped load equivalent to a maximum stress (σ_d) of 27.6 kPa and confining pressure (σ_c) of 41.4 kPa. This phase eliminates the effect of the interval between compaction and loading, and minimizes the imperfect contact between the sample cap and the test specimen. Subsequently, fifteen sequences of 100 repetitions each were then applied on the specimen with different levels of deviatoric and confining stress to measure the resilient modulus. The haversine-shaped load considered in this study had a 0.1 sec load duration and 0.9 sec rest period. During testing, a graphical plot of recorded data (repetitive deviatoric stress and axial deformation) was continuously displayed on the computer monitor to ensure that the system is performing normally.

The resilient modulus is calculated as the ratio of the maximum deviator stress (σ_d) over the recoverable elastic strain (ε_r) for the last five cycles of each sequence.

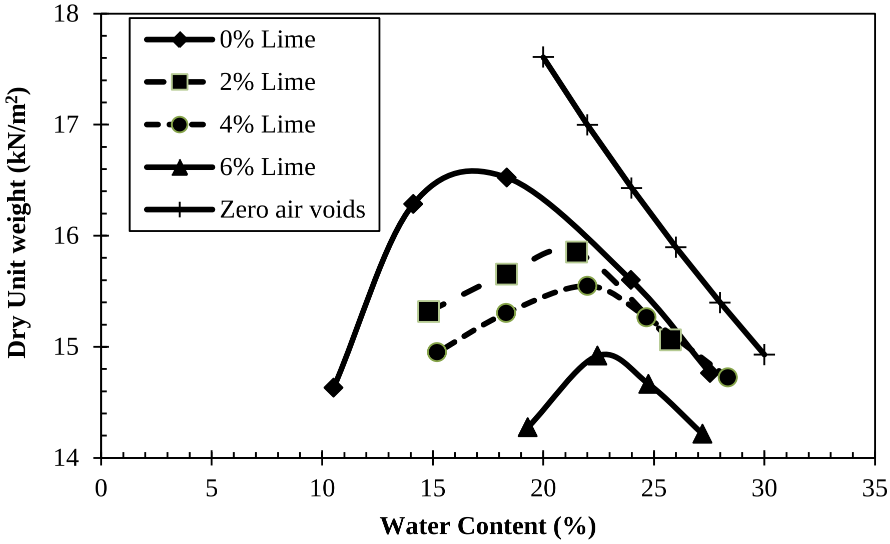

Figure 1. Compaction curves of lime-treated Tabuk clay.

4. Results and Discussions

4.1. Influence of stress state on the M_R

The average M_R value for the last five sequence for untreated and lime-treated samples are shown in Figure 2 and 3. These figures illustarte the varation of M_R with deviatoric stress (σ_d) at different confining pressures (σ_c) of 13.8, 27.6, and 41.4 kPa. For untreated soils (Figure 3), it is observed that M_R insensitive to confining pressures. Furthermore, The M_R vaules was observed to decrease as deviatoric stress increase. The trend for the variation in M_R with deviator stress for untreated soils represents strain softening behavior which is typical for fine grained soil.

Trends for the varaition of M_R with deviator stress and confiing pressure for lime-treated samples after 7 days curing (Figure 3 a, c, e) is similar to that observed for untreated soils. In other words, the M_R is insensitive to confining pressures and decreases with in increase in deviatoric stress. On the other hand, after 28 days curing (Figure 3 b, d, f), the M_R values was observed to be highy dependent on confining pressure. In addition, the M_R exhibited different trends depedning on confining pressure. Under low confining pressure (σ_c = 13.8 kPa), a strain hardening behavior of increase in M_R values with increase in deviator stress was observed. when the confining pressure is greater 27.6 kPa, the M_R values was observed to attenuate with deviator stress. The strain hardening and M_R dependency on confining pressure is considered a typical trends for granular material. The observance of these trends for lime-treated soils after 28 days curing indicate that this material is shifting to a non-plastic granular material due to cation and pozzolanic reactions with soil.

By comparing Mr values for untretaed and lime-treated samples (Figures 2 and 3), it is observed that resilient modulus for lime treated is higher than that for untreated expansive soil. The percentage increase in M_R ranges between 128% and 305% for 7-day curing period. For 28 days curing period, the percentage increase in M_R ranged between 360% to 370%.

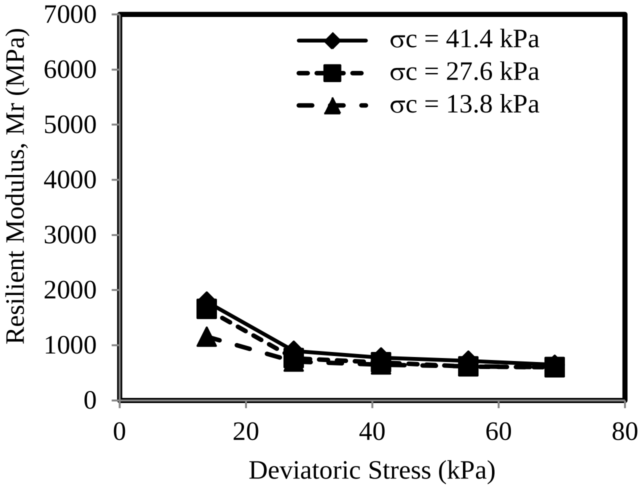

Figure 2. Variation of Mr of untreated Tabuk samples with deviortic stress

4.2. Effect of lime content and curing period on M_R

The variation of M_R with lime content and curing period is summarized in Figure 4. It should be noted that M_R shown in Figure 4 corresponds to maximum applied deviatoric stress of 37.3 kPa and confining pressure of 41.4 kPa. From Figure 4, it is apparent that the M_R increases with increase in lime content up to a 4% beyond which it decreases with increase in lime content. This indicates that 4% can be considered the optimum lime content for this lime-expansive clay mixture. This is consistent with optimum lime content determined using ASTM D 6276. Furthermore, the resilient modulus increased with increase in curing period.

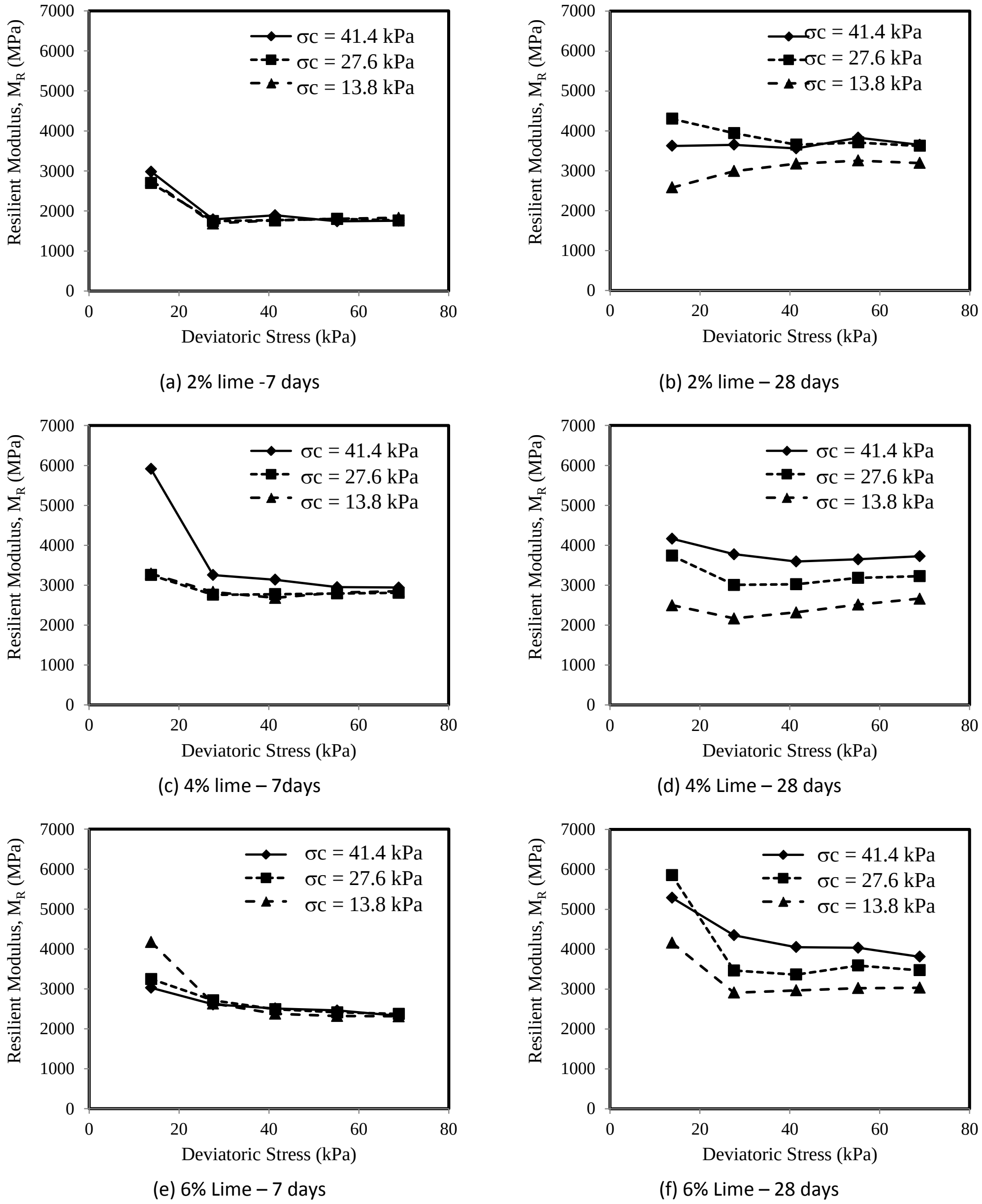

Figure 3. The variation of M_R of lime treated expansive soils with deviatoric stress as a function of lime content and curing period

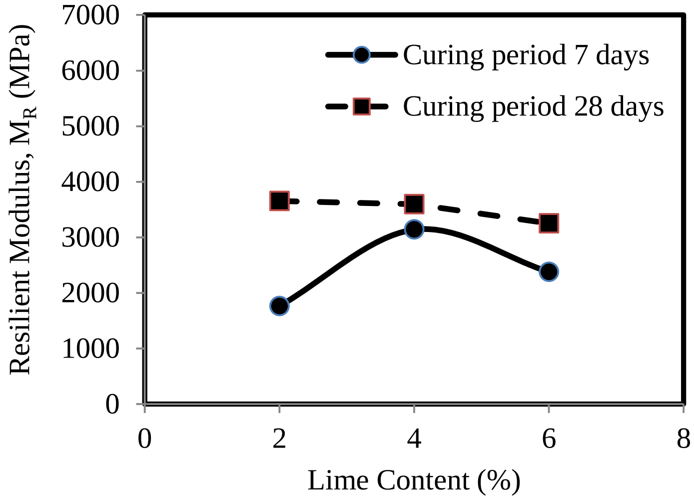

Figure 4. Values of M_R of lime treated expansive soils as a function of lime content and curing period

4.3. Predictive Model for M_R of lime treated subgrade

The results of the experimental resilient modulus were fitted using the three-parameter (k_1, k_2, k_3) model proposed by NCHRP1-28A. The proposed equation for the model is as follows:

$$\frac{M_R}{P_a} = k_1 \left(\frac{\theta}{p_a}\right)^{k_2} \left(1 + \frac{\tau_{oct}}{p_a}\right)^{k_3}$$

Where θ is the bulk stress, τ_{oct} is the octahedral shear stress, and p_a is atmospheric pressure (101.4 kPa). In this study, a series of multiple regression analyses were conducted to evaluate the regression coefficients for untreated and lime-treated expansive clay corresponding to the optimum lime content (i.e., 4% lime content and 28 day curing period). The results were summarized in Table 2.

Sample	k_1	k_2	k_3	R^2
Untreated expansive subgrade	36473.44	0.598	-1.565	0.8938
Lime treated expansive subgrade	17.17	0.354	-5.291	0.7716

5. Summary and Conclusions

The study summarizes the results of an experimental program devised to evaluate the resilient modulus of untreated and lime-treated expansive clayey soil from a site in Tabuk, KSA. Main conclusions driven from this study are as follows:

- The resilient modulus of lime-treated expansive clay was significantly higher than that for untreated soils. The percentage increase in M_R value ranged from 360% to 370% after 28 days curing.

- There is a shift in behavior of expansive soils in regards to trends for the variation of M_R with deviatoric stress as a result of lime addition Untreated soils exhibted strain softening behavior where the M_R decreases with increase in deviatoric stress. For lime-treated samples, a strain hardening behavior was observed suggest that samples has transformed to a non-plastic material.
- Based on varation of M_R with lime content it is recommended to use 4% as optimum dosage for lime treatment.
- The regression analysis used to fit NC-HRP1-28A three-paramteer yielded moderate fit to experimental data (regression coefficients 0.77 and 0.89 for untreated and lime-treated samples; respectively). This can be attributed to structural changes that the sample may undergo during resilient modulus test which are not considered in the model.

Acknowledgement

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