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Constructing Highway Pavements over Soft Clay Soil Improved by Quicklime

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Abstract

The national network of highways has been monotonically increased over the last few years. The increasing need for infrastructure development has led engineers to find safe techniques to construct the infrastructure on soft soils. The design of highway pavement on soft clay soil still remains a very challenging issue. It often causes problems, such as roadbed instability or excessive settlement. As a result, soft soil roadbed treatment has become more and more important. The study aims at improving the clay soil by different methods to sustain the suitable pavement section and its traffic loads. In this paper, soft clay soil is stabilized with quicklime in order to determine the optimum percent of quicklime, which increases the CBR ratios to acceptable values. Results showed that adding quicklime to soft clay enhances its properties to a great extent. However, a 7% quicklime achieved the optimum enhance n properties at which the modulus of compressibility (Es) is improved by 2.87%, and the CBR by 11.2%. Using cyclic loading model device, the measured settlements under the pavement are 12, 7.21and 3.49 mm for soft clay improved by quicklime, using geotextile and using geotextile with geogrid together, respectively.

Key words: Soft clay , Pavement, Quicklime, Geotextile, Geogrid, Cyclic loading.

1. INTRODUCTION

Road constructions on soft clay soil have been considered a tough challenge. Complete failure or excessive settlement of soil can be improved by having appropriate foundation soil strength under the constructed roads. The purpose of a foundation ground improvement is to hold up together the structure and traffic loading above it. Therefore, it is important to ensure that the foundation is really in good condition to avoid the failure of structure or road construction. Subgrade preparation for pavement sections can be one of the most time consuming and costly aspects of roadway construction.

Mixing quicklime with wet soils; immediately reduce up to 32% of its own weight of water from the surrounding soil to form hydrated lime. In addition, the generated heat accompanied by this chemical reaction will further cause loss of water due to evaporation which in turn results in increased consistency of the soil [1], [2].

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The advantages of quicklime over hydrated lime are higher available free lime content per unit mass, being denser than hydrated lime (less storage space is required) and less dust, and generates heat which accelerates the strength gain accompanied by large reduction in the moisture content [3]. However, much care is needed when dealing with and using quicklime for its high affinity for water which may cause burns which touching human skin.

2. Testing Program Design

To achieve the study objectives quicklime was investigated as an improvement material when mixed with soft clay. The following paragraphs discuss in details the conducted tests which include California Bearing Ratio (CBR) test as well as consolidation tests, for different investigated ratios of quicklime.

Details of the natural soft clay properties which are used in this study were presented in reference [6].

In this study Calcium Oxide (CaO) was added with percentages of 3%, 5% and 7% by dry weight. Mixing of the stabilizer continued for three minutes until the mixture achieved uniform color and consistency, as shown in Figure (1). The mixed soil was sealed with plastic wrap to minimize evaporation losses while placing the mixture into specimen molds.

Figure (1): Mixing Soft Clay Soil and Quicklime.

Untreated soft clay and quicklime-treated clay after initial mixing with different percentages of quick lime 3%, 5% and 7 % are illustrated in Figure (2).

Figure (2): Comparing Untreated Soft Clay to Quicklime-Treated Clay after Initial Mixing with Different Percentage of Quicklime.

Samples of natural soft clay soil and soft clay mixed with different dosage of calcium oxide underwent the CBR tests. The tests included varying the dosage of CaO from 3% to 5% and 7% by dry weight of the treated soft clay soil. The CBR test is outlined in references [4] and [5]. The test involves a simple penetration test using a load frame and a standard, compacted CBR test mold of the material to be tested.

Consolidation test is performed on the soft clay improved by 7% quicklime. This test was performed to determine the magnitude and rate of volume decrease that a laterally confined soil specimen undergoes when subjected to different vertical pressures.

3. Pavement Modeling and Testing

Details of the pavement model test and the reference test RT (natural soft clay without improvement) were presented in reference [6].

In case C1, the quicklime was used to improve the subgrade soil. By adding 7% calcium oxide to the soft clay and a depth of 1 meter improvement which is equivalent to 5 cm improvement in the tank model, the preparation of soil improvement and the pavement are shown in Figure (3).

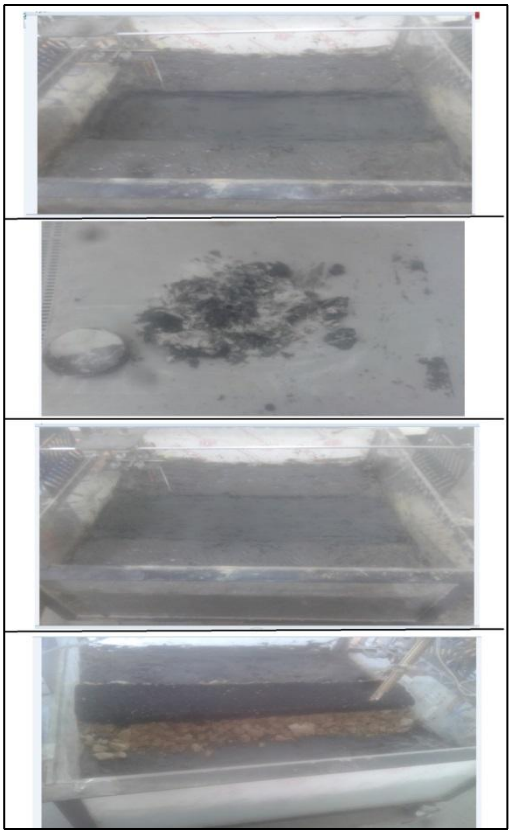

Figure (3): Soil Improvement by Quicklime under the Pavement.

In case C2, quicklime was used to improve subgrade soil. At the same time geotextile layer is also used to improve the pavement. The pavement preparation and soil improvement with quicklime and geotextile are shown in Figure (4).

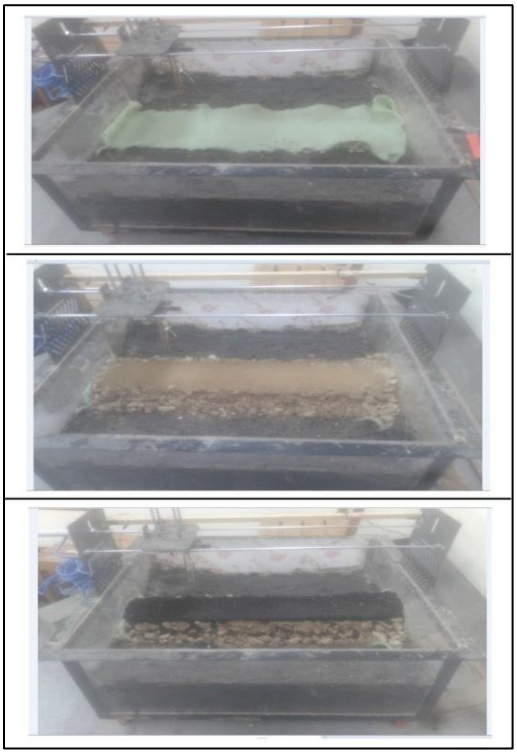

Figure (4): Soil Improvement by Quicklime and Geotextile under the Pavement.

In case C3, quicklime, geotextile and geogrid were used to improve the subgrade soil and the pavement sections. The pavement preparation and soil improvement with quicklime, geotextile and geogrid are shown in Figure (5).

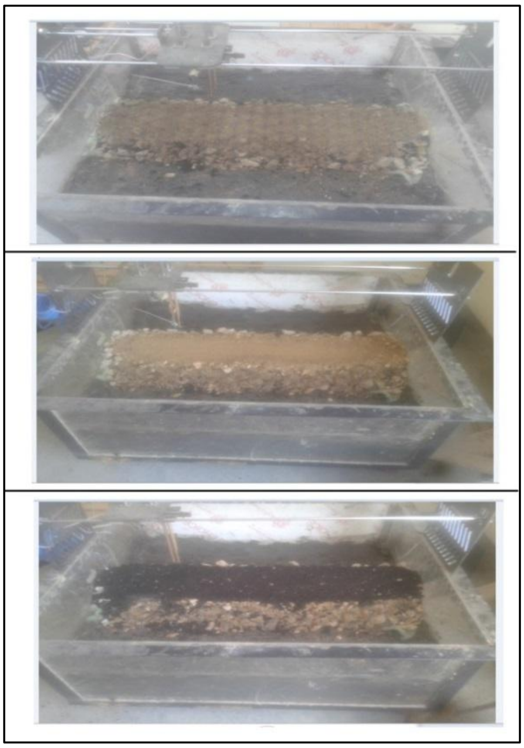

Figure (5): Soil Improvement with Quicklime under the Pavement, Geotextile and Geogrid.

4. ANALYSIS OF THE RESULTS

Samples of soft clay soil mixed with different dosage of calcium oxide underwent the CBR test. Tests included varying the dosage of CaO with percentages of 3%, 5% and 7% by dry weight. The CBR test results for the soil improved by 3%, 5% and 7% are shown in Figure (6).

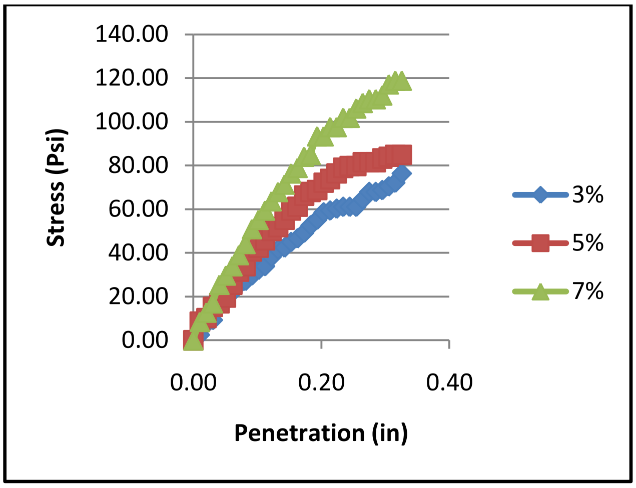

Figure (6): The Variation of CBR Test Results with the Different Quicklime Percentages Added to the Soft Clay Soil Samples.

Soft clay soil was stabilized with quicklime in order to determine the optimum percent of quicklime which increases the CBR ratios in this study. Figure (9) shows that it is preferable to add approximately 7% quicklime to bring the sample to the best value of CBR (CBR = 6.223 %).

The above test results reveal that the soil with quicklime improvement is more stable than the original soil. Mixing the soil with quicklime is very important and takes place immediately after the quicklime is spread on site. This is noticed in the laboratory tests in which the moisture content decreased immediately as soon as the quicklime reacted with the soil.

The consolidation test was performed to study the compressibility of the soft clay improved by 7% quicklime used in this study and to determine the magnitude and rate of volume decrease that a laterally confined soil specimen undergoes when subjected to different vertical pressures. The test was conducted to a maximum stress of 355.28 kN/m^2. The parameters obtained from the consolidation test results for natural soft clay [6], and soft clay improved by quicklime are presented in Table (1).

Table (1): Consolidation Test Results for Natural Soft Clay and Soft Clay Improved by Quicklime.

	Natural Soft Clay	Soft Clay Improved by Quicklime
Water Content (Wc)	49.6%	29.7%
Compression index (Cc)	0.46	0.35
Swelling index (Cs)	0.115	0.050
Coefficient of volume change (mv)	7.7×10^{-3} (m^2/kN)	1.99×10^{-3} (m^2/kN)
Modulus of Compressibility (Es)	129.84 (kN/m^2)	502.37 (kN/m^2)

The recorded measurements include the settlement measured at different elapsed times under different loads. The relation between stress and void ratio in loading and unloading stages are presented in Figure (7) for soft clay improved by quicklime.

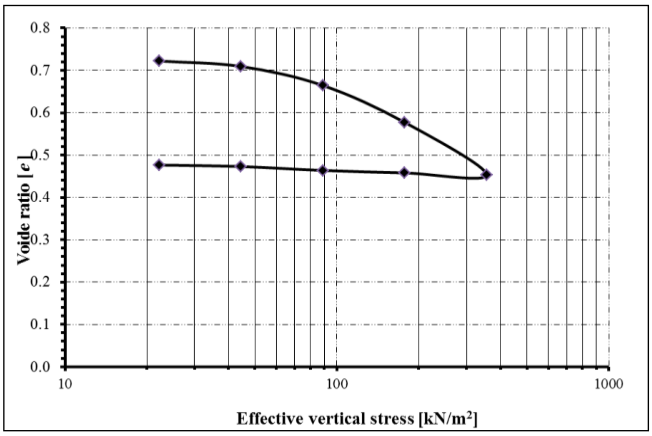

Figure (7): Consolidation Test Results for Soft Clay Improved by Quicklime.

The roadbed soil (subgrade soil) behavior depends on the settlement-time behavior of the repeated loading. The load applied by the wheel was 16.5 kg. The following experiments present results of applying cyclic loading on soft clay improved by quicklime C1, quicklime with geotextile C2 and quicklime with geotextile & geogrid C3. The reference test results (natural soft clay without improvement RT) are presented in reference [6].

Improving the soft clay using quicklime, case C1 was prepared and tested. Figure (8) shows the relationship between settlement and time curve for soft clay improved by quicklime. Results show that the rate of settlement increase with time at a lower rate than that recorded in the reference test RT over time, and reaching the maximum settlement after 120 minutes with the value of 12 mm, as shown in Figure (9).

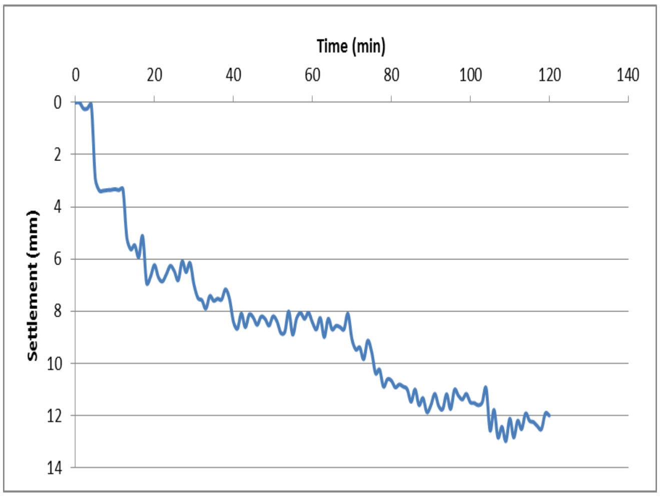

Figure (8): Settlement –Time Curve, C1.


Figure (9): The Deflection Shape, C1.

The relationship between settlement and time for soft clay improved by quicklime and geotextile, experiment C2 is shown in Figure (10). It is noticed that the rate of settlement increase is much lower than that in RT and C1 over time and reaching the maximum settlement after 120 minutes with a value of 7.21 mm, as shown in Figure (11).

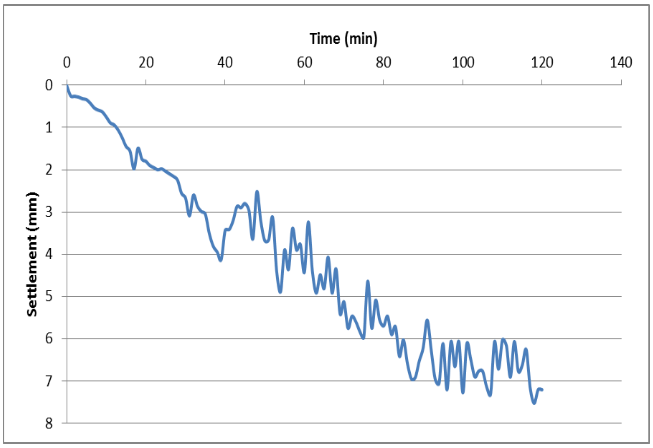

Figure (10): Settlement –Time Curve, C2.

Figure (11): The Deflection Shape, C2.

Figure (12) shows the relationship between settlement and time curve for soft clay improved by quicklime, geotextile and geogrid, experiment C3. It is noticed that the rate of settlement increase is increasing by a much lower rate than that in RT, C1 and C2 over time, and reaching the maximum settlement after 120 minutes with the value of 3.49 mm, as shown in Figure (13).

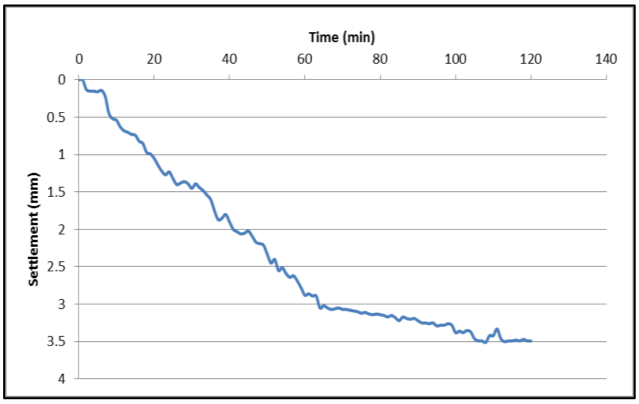

Figure (12): Settlement –Time Curve, C3.

Figure (13): The Deflection Shape, C3.

5. Summary of Time–Settlement Values for the Investigated Cases

The following table summarizes the settlement with time values for each case.

Table (2): Time – Settlement Values for the Investigated Experiments.

Experiments	Time (min)	Settlement (mm)	% Settlement*
RT	38	120.05	100%
C1	120	12.00	9.99%
C2	120	7.21	6.00%
C3	120	3.49	2.91%

* The percent obtained compared to the percent of reference test RT (natural soft clay without improvement) [6].

6. CONCLUSIONS

1- Adding an optimum percent of 7% quicklime by weight to soft clay enhances its properties.
2- The soil properties are improved by 2.87 % for the modulus of compressibility (Es), and 11.2% for the CBR.
3- The measured settlement are 120.05, 12, 7.21 and 3.49 mm for natural soft clay without improvement, using quicklime, using quicklime with geotextile and using quicklime with geotextile & geogrid together, respectively.
4- The measured settlement are 10.00%, 6.00% and 2.91% of the original soft clay case when using quicklime, quicklime with geotextile and quicklime with geotextile & geogrid together
5- The geogrid greatly enhances the pavement to sustain the traffic load. Also the quicklime enhances the soft clay under the pavement.
6- Using multiple enhancements with quicklime and geogrid achieves a vital enhancement.

7. References

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انشاء أرصفة الطرق على التربة الطينية الضعيفة المحسنة بإستخدام الجير الحى

تشهد شبكة الطرق القومية تطور ملحوظ خلال السنوات القليلة الماضية. أدت الحاجة المتزايدة لتطوير البنية التحتية المهندسين إلى إيجاد تقنيات آمنة لبناء البنية التحتية على التربة الطينية الضعيفة . لا يزال تصميم الرصف للطرق على تربة الطينية الضعيفة يمثل مشكلة صعبة للغاية. غالبًا ما يسبب مشاكل ، مثل عدم ثبات الطريق أو الهبوط المتزايد. نتيجة لذلك ، أصبحت معالجة التربة الطينية الضعيفة تحت الطرق أكثر أهمية. تهدف هذه الدراسة إلى تحسين التربة الطينية بطرق مختلفة للحفاظ على قطاعات الرصف وتحمل الأحمال المرورية عليها. في هذا البحث ، يتم تثبيت التربة الطينية ال ضعيفة بالجير الحى وتحديد النسبة المثالية المضافة لتحسين الطين الضعيف ، والتي تزيد من قيمة نسبة تحميل كاليفورنيا CBR.

أوضحت النتائج أن إضافة ال جير الحى إلى الطين الضعيف يعزز خصائصه إلى حد كبير . وقد حققت النسبة 7 ٪ من الجير الحى المضافة للطين القيم المثلى لتعزيز خصائص هذ التربة، حيث تم تحسين معامل الانضغاط (Es) بنسبة 2.87 ٪ ، و نسبة تحميل كاليفورنيا CBR بنسبة 11.2 ٪.

باستخدام جهاز نموذج التحميل الدوري ، يبلغ الهبوط تحت الرصف 12 و 7.21 و 3.49 مم للطين الضعيف الذي تم تحسينه بالجير الحى ، باستخدام الجيوتكستيل واستخدام الجيوتكستيل و الجيوجريد معًا ، بالترتيب.