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Enhancement of pavement sections on soft clay soils to sustain overloading

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ABSTRACT

The weight of goods transported on Egyptian roads has increased rapidly, which requires infrastructure improvements. However, designing highways on soft clay soil remains a challenging issue, resulting in unstable roadbeds and excessive settlement. Thus, treating soft-soil roadbeds has become crucial. To support the appropriate pavement portion and its traffic loads, this study intends to improve the clay soil using various techniques. In this study, quicklime is used to stabilize soft clay soil. geogrid layers are also used to strengthen the base and subbase layers which increases the overall strength of the pavement section. A finite element program (PLAXIS 2D) was used to simulate these improvement techniques to identify the best solutions for the problem. Results showed that improving a 60 cm layer of subgrade soil with quicklime combined with adding a geogrid layer in the middle of the subbase layer gives the best results.

Keywords: Soft clay, Overloading, Quicklime, Geogrid, PLAXIS 2D

1 INTRODUCTION

It has always been considered to be difficult to build roads on soft clay soil. This kind of subgrade is frequently water-sensitive and is unable to withstand sufficient traffic loads when wet. Soft clay soils have high compression, secondary compression, and creep behavior values. It frequently results in issues like excessive settlement or a roadbed that is unstable. [1]

As a result, treating soft soil roadbeds has gained much importance. One of the most time-consuming and expensive parts of road building is subgrade preparation for pavement sections.

In Egypt, the problem gets bigger as the weights of trucks mostly exceed the allowable limits announced by the government on roads due to the growing volumes of transported goods and the need to reduce the cost of transportation through the roads network

As the main component of the road's pavement layers, soil or gravelly material is employed in road building projects. The soil used to build pavement should meet particular requirements that may be achieved by soil stabilization in order to have sufficient strength against tensile stresses and strain spectrum. [2]

There are many different ways to stabilize soil, including mechanical stabilization, which involves changing the gradation of the soils by mixing them with other soils, densifying the soils through compaction, or replacing the existing soils with granular material. In some cases, dewatering is also used. [3]

Soil stabilization can also carried out via employing binding materials like cement, lime, fly ash, bitumen, or a mixture of these, and combining them in a certain percentage with weak subgrade soil. In comparison to the original soil, the stabilized soil components are stronger, less permeable, and less compressible [1]

Geosynthetics are another option witch is described as "a planar product manufactured from polymeric material used with soil, rock, earth, or other geotechnical engineering related materials as an integral part of a man-made project structure or system" [4]. In the road pavement section, geosynthetics are inserted into the subgrade or subbase layers to produce pavement sections which can sustain heavy loads. [5]

In Egypt, the first of two common ways for enhancing the pavement section on a soft clay soil layer is quicklime. When quicklime is mixed with moist soil, it may quickly absorb up to 32% of its own weight in water to create hydrated lime. Moreover, the heat produced by this chemical reaction leads to additional water loss through evaporation, increasing the soil's strength. [6]

The second method involves employing geogrid layers to support the road pavement section so that it can withstand heavy loads. The performance of the road is improved in many ways by the addition of geogrids to the road layers. By minimizing lateral strain value and cracks in the asphalt layer, geogrid reinforcement of granular layers over soft soils can avoid shear failure of the subgrade and enhance soil bearing capacity [reference].

In this research, high traffic loads that exceed the maximum weights allowed by the Egyptian government are simulated, and then the best combination of using quicklime and geogrid layers to achieve the best results to enhance pavement sections constructed on soft clay subgrade soil were investigated.

2 METHODOLOGY

Using finite element software (PLAXIS 2D), the study was divided into two main parts. The following methodology was used to meet the aim of the research:

- By first checking earlier laboratory work and validating results, simulating the pavement section using finite element software (PLAXIS 2D).
- After that, creating a simulation model using PLAXIS 2D to show the effects of heavy loads on pavements constructed on soft clay subgrade soil., Afterwards, specifying the best combination of geogrid and subgrade soils improved by quicklime.

2.1 Validation Model

A model was developed by using PLAXIS 2D to validate a laboratory work that was done to investigate the effect of improving a soft clay soil which was classified as MH soil according to the unified soil classification system (USCS), which means that the soil materials are a mix of silt and clay with high plasticity. with a 7% quicklime added to the top layer of subgrade. In previous study, it was found that 7% was the optimum quicklime percentage to be added to subgrade soil, the soil was collected from east port said zone in Egypt. [1]

The laboratory model scale was taken into consideration to calculate validation model dimensions. the thicknesses of the layers were obtained from laboratory model for asphalt, base and subgrade layers as shown in table (1).

Table 1. Thicknesses of validation model layers

Layer	Thickness
Asphalt	**12 cm**
Base	**60 cm**
Subgrade with 7% lime	**1 m**
subgrade	**8.28 m**

The total depth of model is 10 meters to assure that the boundaries will not affect the results, the model is a 15 node model which provides high accuracy, and the mesh is defined as a very fine mesh

The boundary conditions of the model were selected to reduce the impact of the stress distribution. The horizontal base for our model was chosen to be a fixed support. horizontal displacement was prevented for both vertical sides of the model .

The parameters for FEM model layers are displayed in Table 2:

Table 2. Properties of validation model layers

Layer	Asphalt	Base	Subgrade soil with 7% lime	Natural subgrade soil
E (KN/m^2)	**2000000**	**120000**	**64345**	**5263**
υ	**0.4**	**0.35**	**0.3**	**0.3**
γ (KN/m^3)	**23.3**	**21.8**	**18**	**18**
C (KN/m^2)	**-**	**1**	**60**	**11**
φ	**-**	**48**	**22**	**21.3**
Material Model Type	**Linear elastic**	**Mohr columb**	**Mohr columb**	**Mohr columb**

(E = Modulus of elasticity, υ = Poisson ratio, C = cohesion, and φ = angle of internal friction) [7]

Modulus of elasticity for subgrade soils was calculated by using the following equation:
E = 1500 CBR [8], [9]
This equation is valid for all CBR values less than 10 % . The CBR value for natural subgrade soil and subgrade soil improved by 7% quicklime were 0.509 % and 6.223 % respectively

A load that is equal to an equivalent single axle load (1 ESAL = 82 KN) was placed on top of asphalt layer considering a wheel width of 25 cm, then the resulting settlement was calculated and compared to the outputs of the laboratory test.

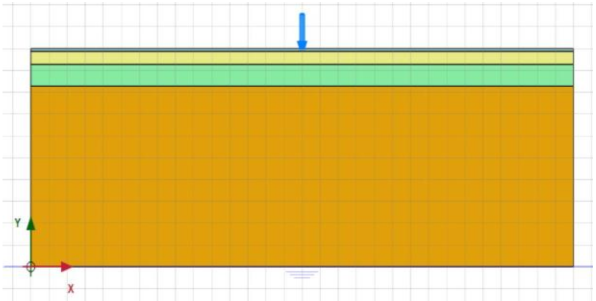

Figure 1: PLAXIS 2D validation model

The calculated settlement was 1.246 cm compared to laboratory test results which was 1.2 cm

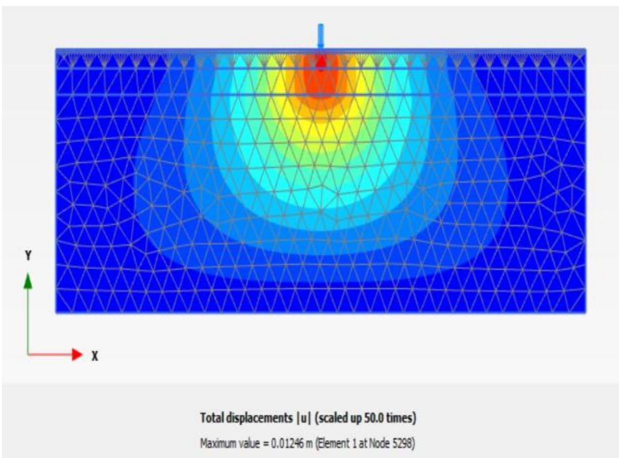

Figure 2: settlement distribution for validation model

The next step was to enhance the model to better represent the extreme loads experienced on Egyptian roads - particularly those constructed on soft clay subgrade soil- and to determine the most effective solutions to withstand these loads.

2.2 Research Model

The model chosen in this study was developed to simulate the extreme loads that exceed the limits announced by the Egyptian government and to find the optimum solution for the problem using quicklime and geogrid improvement techniques.

A subbase layer was added to the model and the limestone layer was reduced to 60 cm to improve the workability of our model.

The thicknesses of the model layers are as the following:

Table 3. Thicknesses of research model layers

Layer	Thickness
Asphalt	12 cm
Base	60 cm
Sub Base	60 cm
Subgrade with 7% lime	60 cm

The total depth of model-2 is 10 meters to assure that the boundaries will not affect the results, the model is a 15 node model which provides high accuracy, and the mesh is defined as a very fine mesh.

The boundary conditions of the model were selected to reduce the impact of the stress distribution. The horizontal base for model-2 was chosen to be a fixed support. Horizontal displacement was prevented for both vertical sides of the model.

The parameters for FEM model layers are as the following:

Table 4. Properties of research model layers

Layer	Asphalt	Base	Sub Base	Subgrade soil with 7% lime	Natural subgrade soil
E (KN/m^2)	2000000	120000	100000	64345	5263
υ	0.4	0.35	0.35	0.3	0.3
γ (KN/m^3)	23.3	21.8	21.4	18	18
C (KN/m^2)	-	1	1	60	11
φ	-	48	48	22	21.3
Material Model Type	Linear elastic	Mohr columb	Mohr columb	Mohr columb	Mohr columb

(E = Modulus of elasticity, υ = Poisson ratio, C = cohesion, and φ = angle of internal friction) [7]

Geogrids are thin, normally rigid structures that lack bending stiffness. They are only able to withstand tensile forces. They are frequently utilized to simulate ground reinforcements. Geogrid layers only have one (axial) degree of freedom at each node and are incapable of withstanding compression pressures. (EA = 100000 KN / m). [10]

The maximum weight allowed for a single axle load moving on the Egyptian roads is 13 tons with dual wheels. To simulate the extreme roads existing in reality, the maximum load was increased by 50 % so that the axle load is 19.5 tons.

The dual wheels are spaced by 60 cmand the width of the truck is modeled to be 2 meters between the axis of the wheels.

Figure (3) illustrate the research model carried out by using PLAXIS 2D software.

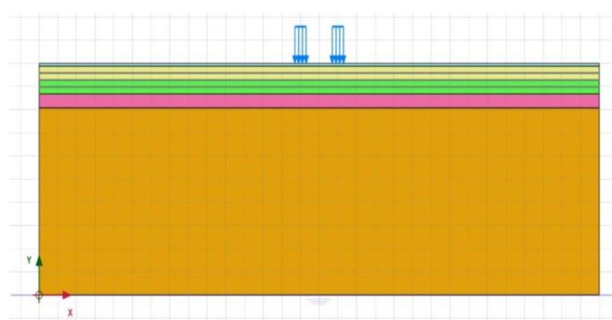

Figure 3: PLAXIS 2D research model

Ten scenarios were developed in order to specify the optimum combination of improvements using quicklime and geogrids as the following:

Table 5. Scenario details

Scenario number	Description
S1	No improvements
S2	A geogrid layer added in the middle of base
S3	A geogrid layer added between base and subbase layers
S4	A geogrid layer added in the middle of subbase
S5	Three geogrid layers added in all the previous three locations
S6	60 cm of soft clay soil is improved with 7% quicklime
S7	60 cm improved with lime + A geogrid layer added in the middle of base
S8	60 cm improved with lime + A geogrid layer added between base and subbase layers
S9	60 cm improved with lime + A geogrid layer added in the middle of subbase
S10	60 cm improved with lime + Three geogrid layers added in all the previous three locations

Three main parameters were calculated to compare between the ten scenario to determine the best solution for the problem; these parameters are [7]:

1. Maximum settlement value (U_y)
2. Lateral strain under wheels at the bottom of asphalt layer (ε_{xx})
3. Vertical stress under wheels at the top of natural subgrade layer (at 60 cm under the subbase layer) (δ_{yy})

2.2.1 Maximum Settlement Value (U_y)

Calculating settlement in road pavements is an important aspect of road design and construction.

Settlement can lead to a number of problems in road pavements, such as unevenness, cracking, and potholes. These problems can cause discomfort to road users, increase vehicle operating costs, and reduce the service life of the pavement.

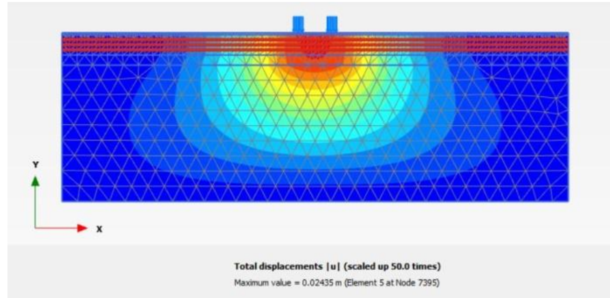

Figure 4: Settlement distribution for research model

The obtained results of maximum settlement are indicated in table 6.

Table 6. Maximum settlement values results

Scenario number	U_y	Percentage of improvement%
S1	**3.094 cm**	**0 %**
S2	**3.093 cm**	**0.03 %**
S3	**3.053 cm**	**1.33 %**
S4	**2.957 cm**	**4.43 %**
S5	**2.949 cm**	**4.69 %**
S6	**2.489 cm**	**19.55 %**
S7	**2.462 cm**	**20.43 %**
S8	**2.458 cm**	**20.56 %**
S9	**2.437 cm**	**21.23 %**
S10	**2.435 cm**	**21.30 %**

2.2.2 Lateral Strain Value (ε_{xx})

Lateral strain is the deformation of the pavement layer in a direction perpendicular to the direction of the applied load. When a vehicle passes over a pavement, it exerts a load on the pavement surface, which causes the pavement layers to deform laterally. This lateral deformation can cause cracking, rutting, and other forms of pavement distress, leading to decreased pavement performance and safety concerns for road users [11].

Figures 5 and 6 show the lateral strain distribution in the model in the S1 and S10 scenario cases.

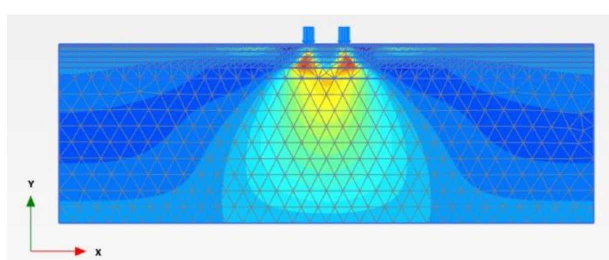

Figure 5: Lateral strain distribution for S1

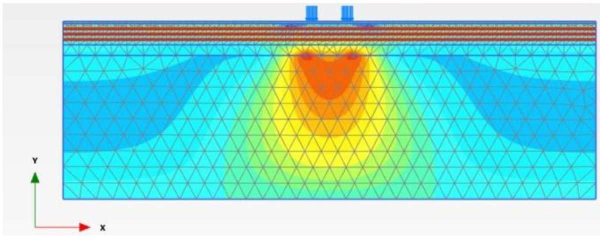

Figure 6: Lateral strain distribution for S10

The figures show a significant reduction in lateral strain in the S10 scenario case compared to the S1 scenario case.

Lateral strains were calculated at the bottom of asphalt layer under the wheels and the obtained results were as the following:

Table 7. Lateral strain values results

Scenario number	ε_{xx}	Percentage of improvement%
S1	$4.794*10^{-4}$	0 %
S2	$4.710*10^{-4}$	1.75 %
S3	$3.728*10^{-4}$	22.24 %
S4	$2.901*10^{-4}$	39.49 %
S5	$2.856*10^{-4}$	40.43 %
S6	$1.754*10^{-4}$	63.41 %
S7	$1.682*10^{-4}$	64.91 %
S8	$1.568*10^{-4}$	67.29 %
S9	$1.559*10^{-4}$	67.48 %
S10	$1.524*10^{-4}$	68.21 %

2.2.3 Vertical Stress Value (δ_{yy})

Calculating the vertical stress reaching the subgrade soil under roads pavement is important because it affects the stability and performance of the pavement structure. The pavement structure is designed to distribute the traffic loads from vehicles to the subgrade soil, which ultimately supports the pavement and prevents it from experiencing excessive deformation or failure.

If the vertical stress on the subgrade soil exceeds the allowable limit, it can cause the subgrade soil to deform, which may lead to pavement distress such as rutting, and settlement. These distresses can reduce the pavement's structural capacity, increase maintenance costs, and shorten its service life [11].

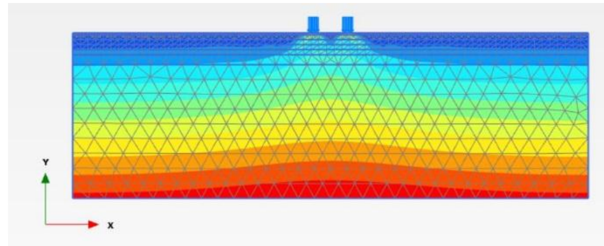

Figure 7: Vertical stress distribution for S1

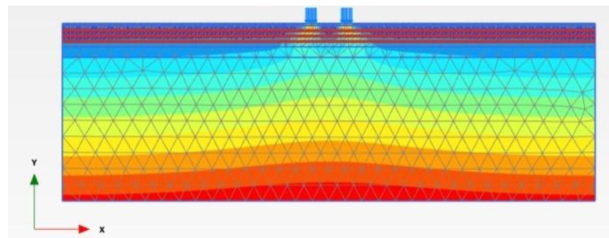

Figure 8: Vertical stress distribution for S10

The vertical stresses were calculated at the top of natural subgrade layer (at 60 cm under the subbase layer) under the wheels and the obtained results were as the following:

Table 8. Vertical Stress values results

Scenario number	δ_{yy} (KN/m^2)	Percentage of improvement%
S1	32.37	0 %
S2	32.28	0.28 %
S3	30.84	4.73 %
S4	28.72	11.28 %
S5	28.64	11.52 %
S6	25.49	21.25 %
S7	25.36	21.66 %
S8	25.02	22.71 %
S9	24.59	24.03 %
S10	24.56	24.13 %

3 RESULTS AND DISCUSSION

When maximum settlement were calculated for the 10 cases, as shown in table 1, it was found that installing a geogrid layer in the middle of the base layer improved settlement by 0.03% (S2), while when it was installed in the middle of the subbase layer, the improvement was 4.43%. Also, when geogrid was installed in three layers (S5), the improvement was 4.69%.

When a 7% quick lime was added to The 60 cm subgrade layer (S6), the improvement increased significantly to 19.55%, and when this case was combined with installing three layers of geogrid (S9), the improvement reached 21.3%.

When lateral strain value ($\mathcal{E}_{xx}$) wer calculated at the bottom of asphalt layer directly under the wheels for last scenarios, as shown in table 1, it was found that installing a geogrid layer in the middle of the base layer (S2) improved lateral strain by 1.75%, while installing geogrid mesh in the middle of the subbase layer (S4), the improvement increased significantly to 39.49%, and when installing three layers of geogrid (S5, the improvement was 40.43%.

But, if 7% quick lime was added to the 60 cm layer of subgrade (S6), the improvement increased even more to 63.41%, and installing three layers in addition to the 7% quicklime (S10), the improvement reached 68.21%.

The vertical stress values (δ_{yy}) were calculated at the top of natural subgrade layer (at 60 cm under the subbase layer) under the wheels for our 10 cases in table 1. It was revealed that S2 case improved vertical stress by 0.28%, while the improvement was 11.28% for case S4, and S5 gained 11.52% improvement.

However, adding 7% quick lime to a 60 cm layer of soil (S6), the improvement increased significantly to 21.25%, and S10 case acquired 24.13% improving.

Credit Authorship Contribution Statement:

Mohamed Badra: Methodology, Writing Original Draft, Software.
Ahmed Mohamady Abdallah: Conceptualization, Review and Editing, Supervision.
Ahmed Adel Turk: Supervision, Review and Editing.

Declaration of competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence.

4 CONCLUSIONS

1) Improving a 60 cm layer of soft clay soil using quicklime has a great effect in reducing settlement values, lateral strains, and vertical stresses.

2) Using geogrids to strengthen pavement sections has also proven to be a fair way in reducing settlement values, lateral strains, and vertical stresses.

3) The best location for using geogrids is in the middle of the subbase layer, Geogrids are used in reducing settlement, absorbing lateral strains, and reducing vertical stresses reaching subgrade soil.

4) There was not much improvement when three layers of geogrid were used when compared to using only one layer in the middle of the subbase layer.

5) For the best results, we recommend combining the improvement of a 60 cm layer of soil with using only one layer of geogrid in the middle of subbase soil as it has better results when compared to using quicklime improvement only.

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