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Soil Improvement Technique for Pilot Section as New Railway Project in Libya

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Abstract— **The construction of embankments on soft saturated soils can be a challenge due to the low shear strength and high compressibility of these soils. The application of reinforced and pile-supported embankments to sustain the imposed dead and traffic loads for train speeds of up to 250 km/h is recently growing in Libya. The aim of this study examine the performance of Geogrid-reinforced embankments with Vibro- stone columns as a ground improvement method adopted in "Pilot Section Al Khoms" subject to cyclic loadings that are applied over a specific area of the embankment to improve strength and provide a safe and economical design for the whole coastal railway. The main result from the load plate test indicates that the stringent performance requirements of the new railway project were met. Furthermore, it was observed that with an increasing number of reinforcement Geogrid layers, enormous cycles of loading could be applied without experiencing excessive deformation and an important reduction in the stress and settlement on the subgrade. The results from field experience, show the project was completed on time and the ground improvement method adopted was employed successfully to reduce the costs of construction maintenance of embankments in the high-speed railway project.**

Index Terms: **Geogrid, Settlement, Embankments, Stone Column, Consolidation.**

I. INTRODUCTION

The construction of a high-speed railway double-track line project (Tripoli – Sirt) of the railway network is recently started in Libya with a design speed of 250 km/h, over a total length of 450 km. Figure. 1 indicates the location of the start section of the project described here as the “Pilot Section Al Khoms”.

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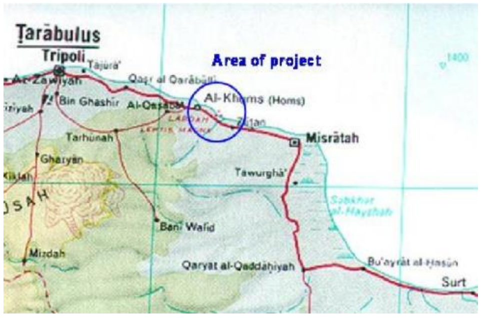

Figure 1. Location of pilot section al khoms

The global rail industry during the last decades is facing an uphill Challenges to meet the increasing demand for freight and passenger transportation. Soil improvement techniques have undergone significant development, especially as a result of the increasing need to construct on the soft ground providing economical solutions. The purpose of the track components is to convert the wheel load to relatively uniform stresses on the sub-grade. The track sub-structure layers have a significant influence on the railway’s performance, all the stresses occur in these layers and may be due to several different causes including short and long-term settlements due to static and dynamic loadings. Designing embankments related to bearing capacity failures and intolerable settlements raises several concerns. In recent years, due to the increase in traffic speed and train axle loads, several existing railway lines are showing signs of distress, instability, and settlements. These phenomena have a serious influence on the safety and efficiency of train operations. The solution of improving the top layer of the railway track by providing a suitable designed sub-ballast layer is essential to withstand higher stresses. However, installing a thick sub-ballast under running traffic is extremely difficult and expensive. A variety of techniques may be used to address the above concerns. A new kind of foundation called “Geosynthetic-reinforced and pile-supported embankment” was established as shown in Figure. 2.

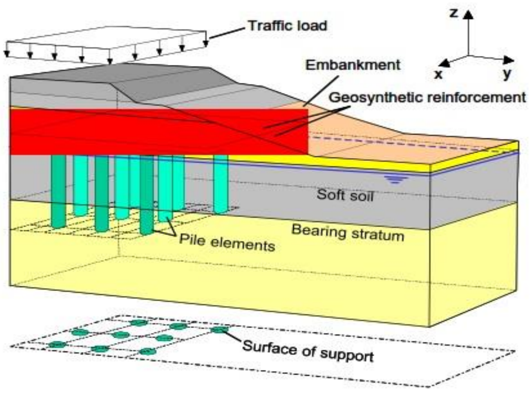

Figure 2. Geosynthetic-reinforced pile-supported embankment

The type of ground improvement method adopted in the project is dependent on various factors such as the type of soil, the height of the embankment, and the thickness of loose deposits. In areas with soft subsoil embankments supported by columns and a horizontal Geogrid reinforcement on top have important advantages compared to "conventional" embankment foundation from the technical, ecological and financial point of view the application of such solutions is recently growing in Libya. In this study, detailed investigations have been performed using an experimental program to improve our understanding and evaluate the behavior of the ground improvement method adopted in "Pilot Section Al Khoms".

II. LITERATURE REVIEW

The impetus for ground improvement has been both the increasing need to use marginal sites for new construction purposes and to mitigate the risk of failure or potential poor performance. Ground improvement is now recognized as a major sub-discipline of Geotechnical Engineering. It is expected that the high-speed train will transmit cyclic load to the sleepers that will induce permanent settlement of the railroad tracks primarily due to the compression of the subbase and the compacted in situ soil [1]. Geosynthetic reinforced and pile-supported embankments (GPE) are often used to transfer traffic loads into a bearing layer through a soft soil layer. The effect of GPE on the mechanical behavior of the load transfer from the Geogrid to the piles has not been yet fully investigated. In the last years, many researchers have dedicated themselves to this topic with different types of model concepts. A summarised overview of the different models can be found in [Heitz 2006] the load transfer mechanism of a GPE system is based on soil arching developed in the embankment as shown in Figure. 3 [2]. A part of the load is carried directly by the pile-like elements due to the soil arching, another part of it by the Geosynthetic, often Geogrid, and the rest by the soil reaction in the soft layer [3].

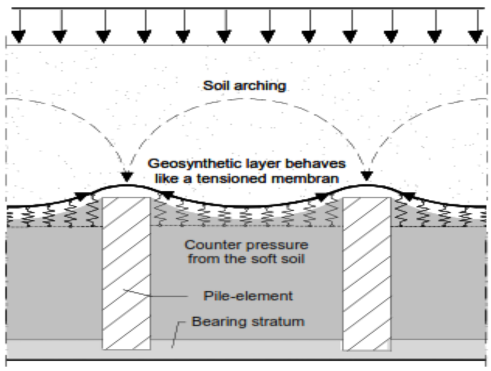

Figure 3. Mechanisms of load transfers

Throughout the history of geosynthetics, monitored full-scale field studies have been extensively utilized to study the performance of Geogrid stabilized sections. Full-scale research by [Tingle 2003] has provided guidance for the use of Geogrid in roadway design. Subgrade bearing capacity factors of the unsterilized and stabilized sections were determined using empirical data from full-scale testing, the calculated bearing capacity factor of the Geogrid stabilized section was more than double that of the unsterilized section [4]. The most beneficial effect of reinforcement is derived when one layer of geotextile and one layer of Geogrid are placed at the interface of the subgrade soil and subbase course [5]. The shear stress-strain relationship developed at the soil-reinforcement interface can be tested in both direct shear and pull-out boxes. In the direct shear box, tests are usually conducted in accordance with the conventional procedure of tests on un-reinforced soil samples. In the pull-out tests, the rear end of the specimen is free while the front end is clamped to the pull-out loading machine. The variation of testing parameters (soil density, displacement rate, confining pressure, and boundary conditions) on the pull-out response of the Geogrid were affected [6]. More recently results of several studies have been published which related to different aspects of ground improvement [7-8]. Lee et al. (2007) examined the load-carrying capacity and failure mechanism of Geogrid encased stone columns by model tests. The reinforcement of the sub-ballast by means of a Geogrid allows the reduction of the depth of the excavated soil and at the same time assures higher long-term performances [9]. Hereby is presented the design for the rehabilitation of the "Pilot Section Al Khoms" railway line, founded on an old embankment subject to continuous and differential settlements. The solution required the reinforcement of the sub-ballast by means of a double Geogrid-geotextile layer and the excavation and replacement of the first 0.70 m of sub-ballast with free-drainage granular fill soil to avoid swelling and desiccation within the silty embankment as shown in Figure. (4) [10].

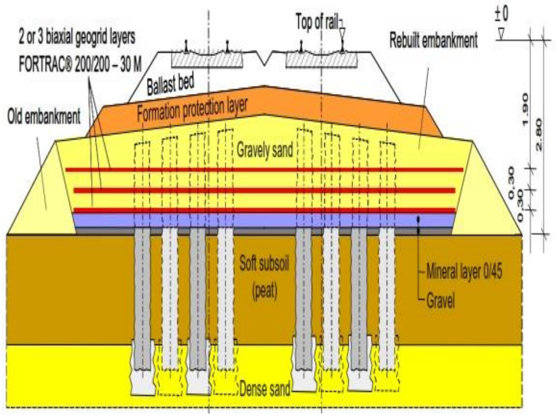

Figure 4. Railway cross section in pilot section

III. EXPERIMENTAL PROCEDUR

In this study, the test procedure was based on the application of the load and determination of load-displacement behavior of the Geogrid-reinforced embankments with Vibro- stone columns as a ground improvement method.

Geotechnical investigations have been undertaken to supplement existing information for the current phase of design development. The cross-sections highlight the interbedded nature and lateral variation of materials is underlain by a thick layer of brown and dark brown of soft to firm alluvial clayey silt/silty clay is present Figure. 5. The upper alluvial layers are generally under-consolidated and occasionally thinly interbedded with peat and sand layers. Typical vane shear strengths of 20 kPa to 35 kPa were measured in the clayey silt/silty clay layer. Cone penetration tests indicated the cone tip resistance is generally below 0.6 MPa in this material. The groundwater level is close to the ground surface during the winter.

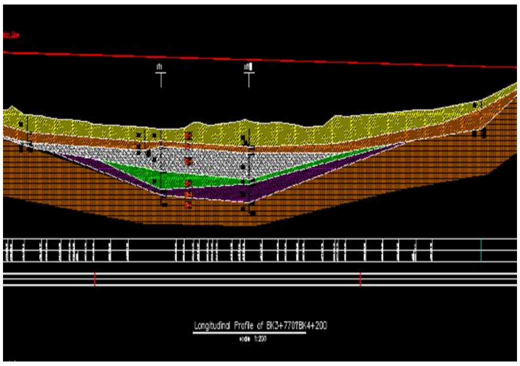

Figure 5. Railway cross section in pilot section

The geogrid type 40/40 Q 1 is composed of an integral biaxial polypropylene geogrid heat-bonded to a non-woven whose properties are reported in Table 1. This geogrid has exceptional confining and reinforcing properties due to its high tensile modulus and junction strength. The unrolling direction of the geogrids always takes place thereby in the embankment longitudinal axis. Experiences show that the triangular arrangement can favorably influence the load transfer mechanism of a GEP-system. The non-woven geotextile is heat-bonded on the lower side of the geogrid layer to assure a filtration function.

Table 1: Material Properties of Geogrid

Technical Data	Test Method	unit	40*40 Q1
Raw Material	Polypropylene (P.P White)		
Mass per unit area	EN 965	G/M^3	230
Max. Tensile strength	EN ISO 10319	KN/M	>40/>40
Elongation at nominal strength	EN ISO 10319	%	<8 /<8
Tensile strength at 2%Elongation	EN ISO 10319	KN/M	16*/16*
Tensile strength at 5%Elongation	EN ISO 10319	KN/M	32*/32*
UV – resistance	ENV 12224	%	95
Weather resistance	FGSV	CLASS	HIGH

Pile elements are placed in a regular pattern through the soft soil down to a lower load-bearing stratum, above the pile heads the reinforcement of one or more layers of geogrids is placed and then embankment is built up. The embankment makes use of the following techniques (i) five rows of stone columns around the perimeter of the embankment to strengthen the ground, (ii) lightweight sand fill to reduce the imposed load and hence ground settlement, (iii) reinforcement of the 1:4 slopes with geogrids (iv) geotextile basal reinforcement to increase the short term stability and the seismic resistance of the embankment and (v) wick drains within the central unreinforced zone of the embankment to increase the consolidation rate as shown in Figure. 6.

Figure 6. Crushed stone pile and geogrid in pilot section

IV. RESULTS AND DISCUSSION

Plate bearing tests with up to 250 KN of axial loads were carried out on 20 stone columns. Measured stone column settlements under the test load were generally less than 15mm. No indication of failure of the stone column was observed. Back analyzed Young's modulus values of the stone columns were in the order of 160 MPa. This is about 100 times that of the surrounding clay and is significantly higher than the published values of 20 to 40 times. Measurements of settlement gauges installed in the unreinforced zone of the embankment indicated ground settlements of 100 mm under 2 m of the lightweight fill. This was in good agreement with the predicted settlement. The embankment settlement rate became very small 6 months after construction. Within the stone column reinforced zone, ground settlements of 40 mm to 70 mm were measured under the 4m high embankment load. At a distance of about 2m outside the embankment area, no detectible ground deformation was recorded in the deformation surveys. Pull-out tests were used to provide the load-displacement relationship at the facing of the Geogrid specimen and its pull-out resistance.

Figure.7 shows the load-displacement relationships from a series of pull-out tests on Geogrid samples tested under the standard testing conditions. The result shows that a decrease in displacement rate results in an increase in the peak pull-out resistance of the Geogrid. The change of expansion occurs around 50, 43, and 35 mm of horizontal displacement for 10, 15, and 25 kPa respectively.

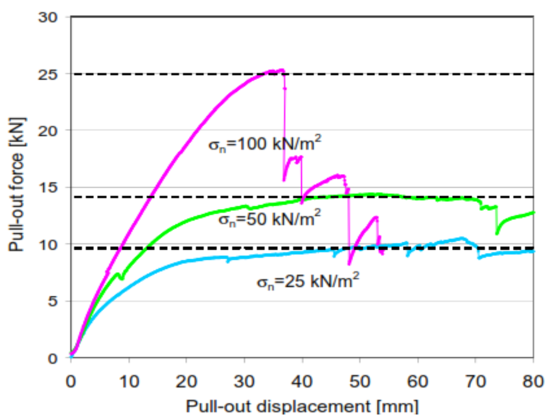

Figure 7. The load-displacement relationships

Fig. 8 shows plots of the variations of the settlements measured with time subjected to a number of load cycles at the top of the column heads, top of the upper Geogrid layer, and top of the rail. For all tests several observations can be made, the permanent settlements increased with time thin the settlement remained practically constant at load cycle greater than about 1 x 10s cycles.

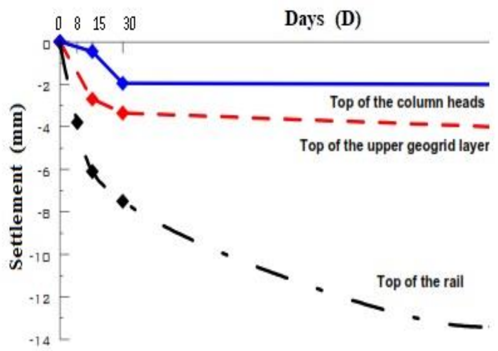

Figure 8. Settlements with time relationships

For the rectangular arrangement of the pile elements, the model test results showed that the largest strains, hence the largest tensile stress, are transferred to the piles through the shortest direction between the piles. On the other hand, a very small strain was measured at the center. The strain in the triangular pattern showed quite another trend. The largest strains were recorded by strain gauges in the diagonal direction between the piles. Whereas those strain gauges arranged in the direction of the shortest distance between the piles had been subjected to less strain. However, there exists a higher local stress concentration in the middle of the Geogrid. Similar to the rectangular grid system can be found in Ref [3], the soil pressure and its distribution on the top surface of the Geogrid were estimated based on the calibrated nodal forces and the influence as shown in Figure. 9.

It can be observed that the stress concentration on the top of the pile is higher compared to the rectangular grid system, which indicates a stronger soil arching. The soil pressures on the Geogrid are relatively uniformly distributed and are smaller compared to the rectangular grids.

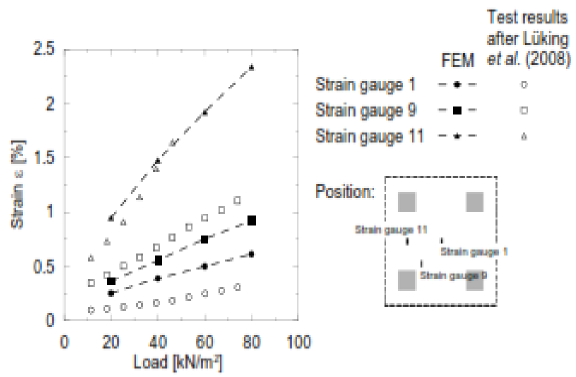

Figure 9. Comparison of measured and calculated strains

Table 2 shows how the presence of one Geogrid layer reduces the dynamic loads between 40 to 20% while two geogrid layers reduce the dynamic loads between 60 to 30% at a depth of 0.90 m.

Table 2: Influence of the reinforcement layers

Axle Load [t]	Layer Without Reinforcement		Single Layer of Geogrid Reinforcement		Double Layer of Geogrid Reinforcement	
	Dynamic Stress		Dynamic Stress		Dynamic Stress	
	[kPa]	%	[kPa]	%	[kPa]	%
16.00	18.79	100%	10.94	58%	7.51	40%
20.32	24.84	100%	16.99	68%	13.07	53%
22.10	27.34	100%	19.49	71%	15.56	57%
25.00	31.40	100%	23.55	75%	19.63	63%
30.00	38.41	100%	30.56	80%	26.64	69%

The determination of the shear stresses and the horizontal deformations at the embankment base as well as the tensile forces in the geosynthetics reinforcement. Plane strain FE-models were used to analyze the model tests of un/reinforced embankments on soft underground without pile elements, whereas three-dimensional FE-models had been employed in the case of a piled soft underground. Details of the model tests can be referred to in the works which have been done by [Fahmy 2009] [11]. Figure. 10a and 10b show selective results of the FE-computation and comparison with measured values. The calculated and measured strains in the Geogrid agree very well in the case of underground without pile elements. Whereas, the calculated strains in the base reinforcement on top of pile elements show a large difference. This may be attributed to the simulation of the Geogrid as a membrane. The Geogrid seem to behave differently as a membrane, especially when it is laid on a point support system. This phenomenon has also been reported by [Heitz 2006].

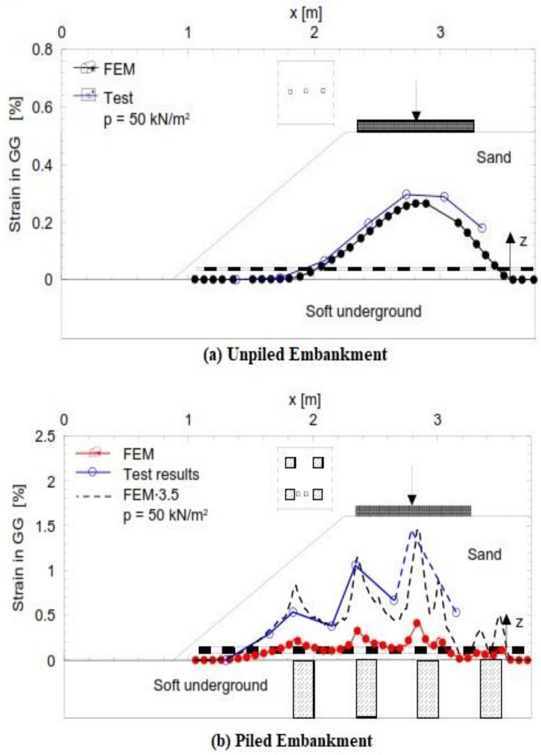

Figure 10. Strain in reinforcement

V. CONCLUSIONS

The results from numerous load tests and settlement plates indicate that the stringent performance requirements of the new railway project were met, and have proven to be a cost-effective solution. Furthermore, it was observed that increasing the number of reinforcement Geogrid layers, improves the stress-strain behavior and reduced the horizontal force around the stone pile head. As a result, the shear strength and bearing capacity of the reinforced soil is increased significantly while total settlements are reduced and can reduce the deformations on the stone pile elements. The results, from field experience, show the project was completed on time and the ground improvement method adopted was employed successfully to reduce the costs of construction and maintenance of embankments in the high-speed railway project. There remains scope for research that needs to be further developed to realize even greater efficiencies and savings.

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