Investigations on a geosynthetic reinforced bearing layer under static and cyclic loading

Etudes sur une couche de support renforcée géosynthétique sous charge statique et cyclique

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ABSTRACT: In order to utilize the heavy mobile construction machines like drilling rigs, pile driver and mobile cranes, temporary working platforms, which are partially reinforced with geotextiles, are often built, as the existing soil itself does not provide enough support. These working platforms and the underlying soft grounds or fillings have to guarantee a safe operation of the construction machines. Because one third of all accidents with chain driven construction machines are caused by inadequate dimensioned working platforms, an urgent need for their improvement and optimization is sensed. To clarify the bearing capacity of the reinforced and unreinforced two layered system (non-cohesive bearing layer over soft soil), model tests are carried out in a test pit of 4.82 x 2.72 m². The influence of the height of the bearing layer, the relevant mechanical parameters of the soft soil and different geotextiles are investigated in this research. This paper shows the results obtained from an unreinforced and a reinforced bearing layer and compares the two systems. The geosynthetic reinforcement increases the bearing capacity resistance by 22 %. It also decreases the settlement especially under higher loads.

RÉSUMÉ : Pour l'installation d'engins de chantier lourds et mobiles comme les plates-formes de forage, les plates-formes de battage de pieux et les grues mobiles, des plates-formes de travail temporaires, partiellement renforcées par des géotextiles, sont souvent créées car le sol existant n'offre pas assez de support. Ces plates-formes de travail et le sol mou ou remblayé sous-jacentes doivent garantir le fonctionnement des machines de construction. Dans ce contexte, il y a un besoin urgent d'amélioration et d'optimisation car un tiers des accidents avec des engins de chantier à chaîne sont causés par des plates-formes de travail mal dimensionnées. Pour clarifier la capacité portante du système à deux couches renforcé et non renforcé (couche de support minéral sur sol mou), des essais de modèle sont réalisés dans une fosse d'essai de 4,82 x 2,72 m². L'influence de la hauteur de la couche portante, les paramètres mécaniques du sol mou et les différents géotextiles sont étudiés dans le projet de recherche. Cet article présente les résultats d'une couche portante non renforcée et renforcée et compare les deux systèmes. Le renfort géosynthétique produit une capacité portante 22 % plus élevée et mène en particulier sous des charges plus élevées à des tassements inférieurs.

KEYWORDS: working platform, bearing capacity, cyclic loads, model test, geogrid, geosynthetic, reinforcement.

1 INTRODUCTION

For the purpose of installing heavy mobile construction machines like drilling rigs, pile driver and mobile cranes, temporary working platforms, which are partially reinforced with geotextiles, are often created, because the existing soil itself does not provide enough support. These working platforms and the underlying soft grounds or fillings have to guarantee a safe operation of the construction machines. In this context, there is an urgent need for improvement and optimization because one third of all accidents with chain driven construction machines are caused by inadequate dimensioned working platforms (BRE/FPS, 2004/2007). At the moment there are no guidelines avalilable for the calculation of such temporary working platforms in Germany. Available calculation approaches, e.g. Giroud and Noiray, (1981), Meyerhof (1974), Okamura et al. (1998), DIN 4017 or EBGEO (2011), lead to huge differences in the required height of the bearing layer and the tensile strength of the geogrid reinforcement.

The research project intends to improve the different calculation approaches for two layer systems. Therefore filed measurements and scaled model tests are carried out to validate numerical models. By means of numerical simulations a calculation approach will be developed and a recommendation for working platforms will be published. This paper will show the result of two model tests and compares the bearing capacity and the deformation behavior of an unreinforced and a reinforced bearing layer.

2 MODEL TESTS

Model tests in scale 1:3 are carried out to investigate the bearing and deformation beahaviour of the two layered system. The influence of the height of the gravel bearing layer, the undrained shear strength of the soft soil and the geosynthetic reinforcement are investigated in the experiments.

2 .1 *Design and measurement concept*

Fig. 1 shows the dimensions and the measurement concept of the model test. The test pit has a dimension of 4.82 m to 2.72 m. The load plate has a dimension of 0.25 m to 0.35 m. The load is applied with an eccentricity of 0.01 m to ensure the direction of failure. The settlement is measured at nine points with displacement transducers. In the case with reinforcement in the bearing layer, seven strain gauges measure the strains in the geogrid.

The base layer consists of gravel with grain sizes from 0 to 16 mm. The height of the bearing layer is 0.20 m and its density is 100 % standard proctor density. The soft soil is a loess loam with undrained shear strength of 20 kN/m². The height of the soft soil is 0.80 m. A geotextile is used between the soft soil and the bearing layer in the unreinforced test (only for separation). The reinforcement in the second test is a composite of a geogrid with maximum tensile strengths of 30 kN/m (bidirectional) and a geotextile. This layer lies between the soft soil and the gravel as well (reinforcement and separation).

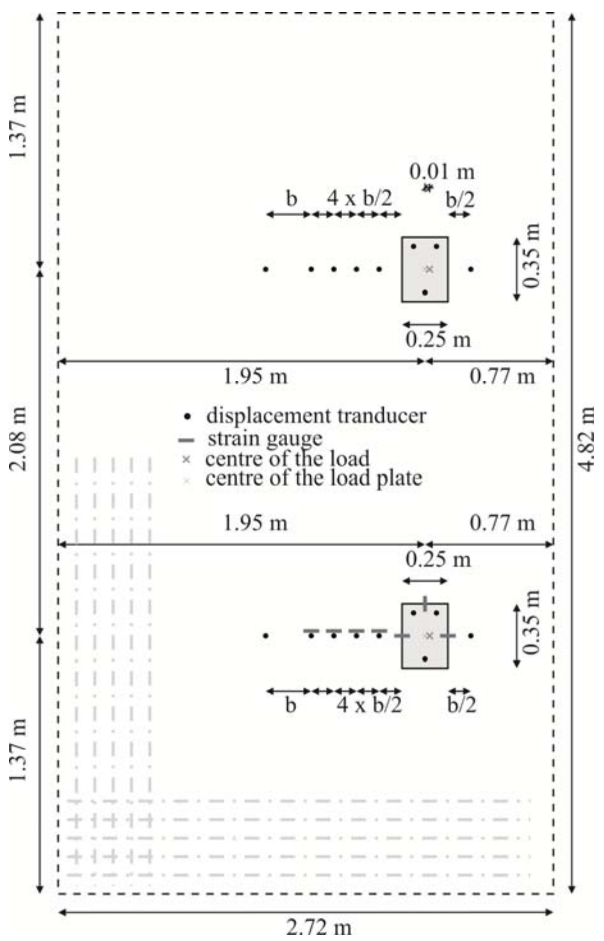

Figure 1. Dimension of the model test and measurement concept.

Fig. 2 shows the load scheme of the model tests. At the beginning, a static load of 8 kN is applied with a velocity of 0.1 kN/s. Afterwards a cyclic load with 1,000 load cycles and a frequency of 0.1 Hz is applied. Next the system is loaded to failure with a velocity of 0.1 kN/s.

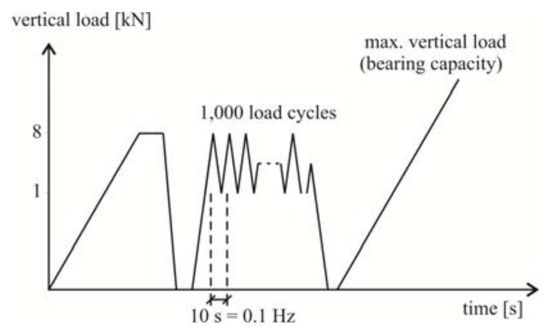

Figure 2. Load scheme of the model test.

Fig. 3 shows the position and denotation of the displacement transducers (D) and the strain gauges (S).

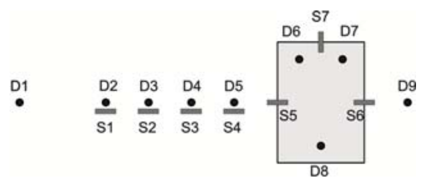

Figure 3. Layout of the measurement and title for the graphs (D: displacement; S: strain gauges).

2 1 *Results and discussion*

2.1.1 *Cyclic loading*

Fig. 4 shows the deformation at the top of the bearing layer at the points D7 (plate) and D1 (3b) over the cyclic loading of the unreinforced and the reinforced bearing layer. In both systems in a distance of three times the plate width, nearly no settlement due to cyclic loading can be seen. The deformation is locally restricted and the steel plate punches into the gravel bearing layer. Obviously the unreinforced bearing layer deforms higher at the beginning, but during the cyclic loading no apparent difference in the accumulation of permanent deformations is seen. The settlement of the plate is almost doubled in both systems after 1,000 load cycles.

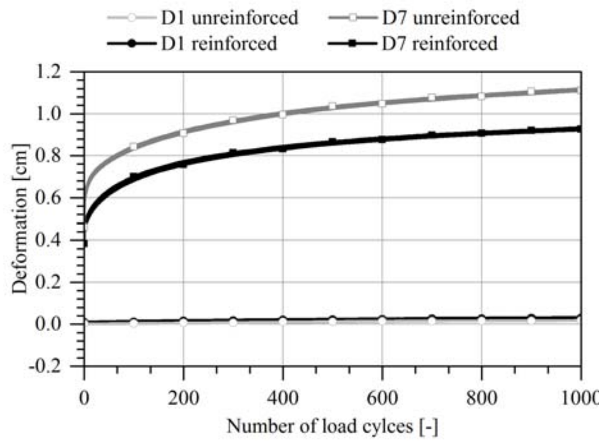

Figure 4. Settlement of the unreinforced and the unreinforced system at point D1 and D7 over the cyclic loading.

2.1.2 *Bearing capacity and deformation behavior*

Fig. 5 shows the load-displacement curve of the plate for the static loading applied after 1,000 load cycles for both systems. Until nearly 16 kN the stiffness of the two layer system is comparatively high and there is almost no increase in settlement. Certainly, the main reason is the compaction and consolidation through the cyclic loading with a maximum load of 8 kN. At about 56 kN, the load plate is unloaded in the unreinforced system due to the maximum press stroke. The unloading shows high plastic deformations of 15 cm. Afterwards the plate is reloaded and the maximum load is reached at 67.6 kN. The settlement of the plate increases from 24 cm to nearly 30 cm, although the load decreases. The reinforced system has at the beginning nearly the same stiffness. The reinforcement needs deformation and settlement to absorb tensile forces. Starting at about 30 kN the stiffness of the reinforced bearing layer is much higher compared to the unreinforced system. The unloading due to the maximum press stroke is at a load of around 80 kN. The plastic deformation of the soil under the plate is nearly 15 cm, equivalent to the unreinforced system, although the load is about 45 % higher. The maximum load is reached at 82.5 kN. The settlement of the plate increases from 27 cm to 30 cm, although the load decreases. The maximum settlement of both systems is the same. The bearing capacity of the reinforced system is 22 % higher compared to the system with an unreinforced bearing layer.

Fig. 6 shows the load-displacement curves of the unreinforced system at measurement points D1 (3b), D2 (2b) and D3 (1.5b). Positive deformation means settlement and negative deformation heave. At the beginning of final static loading, small settlements at point D1 already exist due to the first static and cyclic loading. After a small load the soil starts to heave. The heave at the stage of unloading is 0.2 cm. During reloading the heave grows till the maximum bearing capacity of 67.6 kN. After the bearing capacity reached, heaving continues although the load decreases. Point D2 shows until the maximum load nearly no deformation. After the bearing capacity is reached, the soil heaves 0.2 cm. On the other hand the soil at point D3 settles from the beginning till the maximum vertical load. Small heave after failure is apparent in Fig. 6 which cannot be clarified clearly if it is due to the elastic unloading response of the soil or heaving due to bearing failure as point D3 may be located on the failure surface.

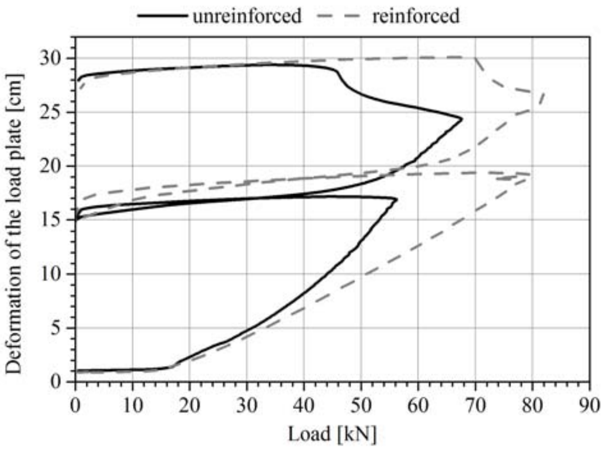

Figure 5. Load-Displacement curve at the load plate of the unreinforced and the reinforced system (displacement at point D7)

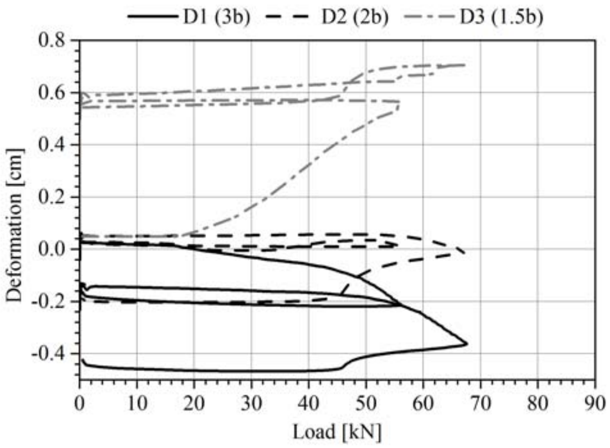

Figure 6. Load-Displacement curve of the unreinforced system at the points D1 (3b = 75 cm) and D2 (2b = 50 cm).

Fig. 7 shows the load-displacement curves of the reinforced system at the measurement points D1 (3b), D2 (2b) and D3 (1.5b). The load-displacement curve for the point D1 looks similar to the unreinforced system but the heaves are much higher. At the beginning of the vertical loading the soil settles at point D2 and once the maximum bearing capacity has been achieved the bearing layer heaves with a small value. At a distance of 1.5 b (point D3) settlements are much higher. The heave after the bearing capacity is reached cannot be clarified clearly as well.

Fig. 8 shows the deformations of the unreinforced bearing layer over the width of the load plate at different load steps. Fig. 9 depicts the deformations for the reinforced system. The plate is illustrated with a grey rectangle to visualize its width and location. After the cyclic loading and in the case of a vertical load of 20 kN the settlement for both systems is nearly the same. Under higher loads the deformations of the reinforced bearing layer are lower. The deformation behavior under the maximum vertical load is nearly the same, although the reinforced system has a 22 % higher bearing capacity.

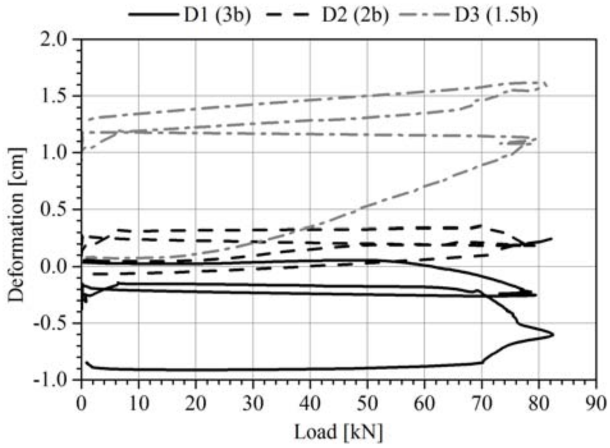

Figure 7. Load-Displacement curve of the reinforced system at the points D1 (3b = 75 cm), D2 (2b = 50 cm) and D3 (1.5b = 37.5 cm).

Fig. 10 shows the geogrid strains over the width of the plate for different loading steps. The plate is again illustrated with a grey rectangle to visualize its width and location. The strains prove the results of the deformation measurement. The higher the vertical loads and consequently the deformations are, the larger the geogrid strains. Especially the strains within a larger distance to the plate increase with higher loads. The geogrid strains during the loading steps point out, that the reinforcement needs a certain deformation to absorb tensile forces. This leads to an improved deformation behavior under higher loads and to an increased bearing capacity.

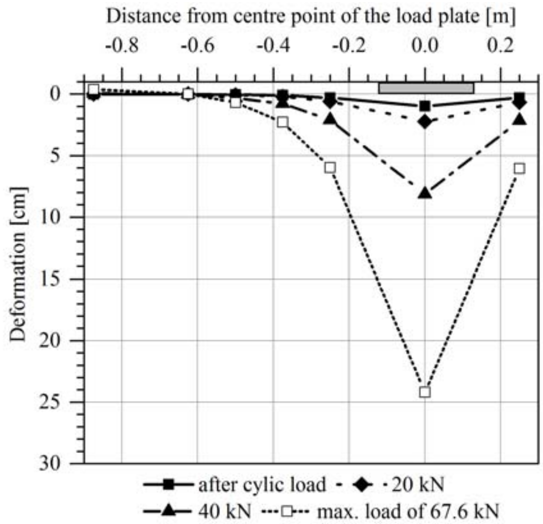

Figure 8. Deformations of the unreinforced bearing layer over the width of the load plate at different load steps.

3 CONCLUSION AND OUTLOOK

In order to clarify the deformation behavior of a non-cohesive bearing layer over a soft soil layer under static and cyclic loading, model tests, field measurements and numerical investigations will be carried out at the Institute for Geotechnical Engineering (IGS) of the University of Stuttgart.

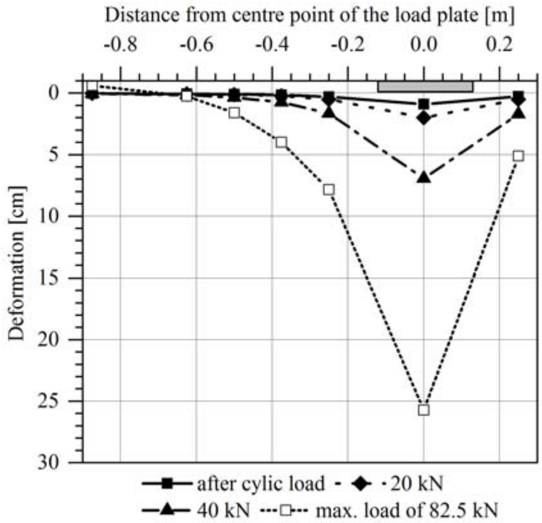

Figure 9. Deformations of the reinforced bearing layer over the width of the load plate at different load steps.

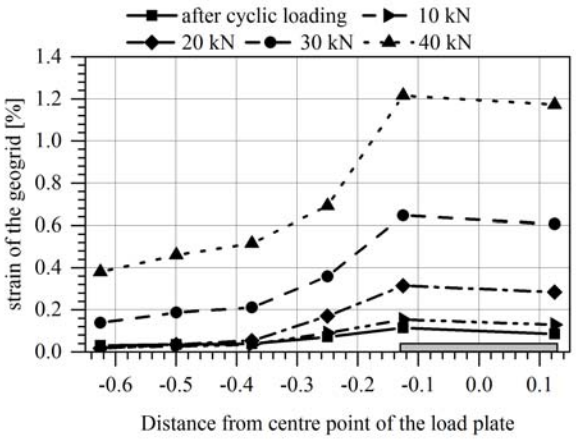

Figure 10. Strains of the geogrid over the width of the load plate at different load steps.

This paper shows the results of two model tests and compares an unreinforced and a reinforced bearing layer. The bearing capacity resistance with a geogrid reinforcement increases by 22 %. The reinforcement improves the deformation behavior especially under higher loads. The strain measurements show that the geogrid is more effective under higher loads and deformations.

The influence of the height of the bearing layer, the soft soil conditions and the reinforcement will be investigated in further model tests.

Field measurements under mobile cranes and construction machines are conducted in the research project as well to reach a better understanding of the bearing and deformation behavior of working platforms.

The results of the model tests and the filed measurements will be used for a comparison with calculation approaches in literature and to validate numerical models. Afterwards parametric studies will be done to work out an applicable and uniform calculation approach for unreinforced and reinforced working platforms including different input parameters like the soft soil conditions, the angele of internal friction of the bearing layer and the maximum tensile strength and the axial stiffness of the geosynthetic.

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