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Bearing Capacity Improvement of Gravel Base Layers in Road Constructions using Geocells

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ABSTRACT: Geocells consist of a series of interconnected single cells which are connected at their joints and forming a honeycomb structure. The geocells are expanded at the construction site and filled with soil. The cell walls completely encase the infill material and provide an all-around confinement to the soil. During vertical loading hoop stresses within the cell walls and earth resistance in the adjacent cells are mobilized which increase the stiffness and the load-deformation behavior of the soil. 1g model tests on a scale of 1:1 were carried out to evaluate the influence of a geocell layer on the load-deformation behavior of the soil. Geocells made from different materials, with different cell heights and different cell diameters were tested in a test box with inside dimensions of 2m length, 2m height and 2m width. To simulate soft subgrade material an artificial mixed soil called "Glyben" was used. The test results show that a geocell layer increases the bearing capacity of the soil and reduces the vertical stresses on the soft subgrade. To verify these results geocell reinforced and unreinforced in-situ test fields were carried out within different asphalt paved road constructions. Vehicle crossing tests and falling weight deflectometer measurements show that the stresses beneath the geocell layer were reduced about 30 percent, the deflections on asphalt surface were reduced about 15 percent and the back calculated layer modulus were increased about 10 percent compared to the unreinforced test section.

1 Introduction

Geocells are honeycomb interconnected cells that completely encase the soil and provide an all-around confinement, thus preventing the lateral spreading of the infill material. If vertical loads are applied hoop stresses within the geocell walls and earth resistance in the adjacent cells are mobilized. The hoop stresses and earth resistance reduce the lateral deformation of the infill material. As a result the stiffness and the load-deformation behavior of the soil are increased. Due to an increase in stiffness, the soil-geocell layer acts as a stiff mat and distributes the vertical traffic loads over a much larger area of the subgrade soil.

Several model tests (e.g. Dash et al. 2001, 2003, Sitharam and Sireesh 2005) have shown the positive effect of geocells, made from different geogrids, on the load bearing capacity of soils. The geogrids are placed vertical and the longitudinal and diagonal members are connected e.g. by plastic strips. The results of these tests have shown that grid-cells increase the bearing capacity of soils up to six times and reduce the stress distribution on the subgrade material.

Meyer and Emersleben (2005a, 2005b, 2005c, 2006a, 2006b) and Mhaiskar et al. (1992) have evaluated the influence of industrially manufactured geocells on the load-deformation behavior of soils. In contrast to the grid- cells these geocells are industrially manufactured from strips of polymer sheets, which are welded together. The use of geocells to stabilize unpaved road constructions is continuously increasing in certain regions, especially if qualified soils are not available near the construction site (Ben Kurari 2000, Forsman et al. 1998, Leytland et al. 2006).

The stabilization of gravel base layers of asphalt paved road constructions over soft soils with geocells is an alternative technique to reduce the deformations of the asphalt surface and to increase the stiffness of the main construction. Al Quadi et al. (2000) reported an increase of the resilient moduli of aggregate layers about 2 times due to the installation of geocells within an asphalt paved road construction. The resilient moduli were back calculated from results of falling weight deflectometer measurements based on known thickness and assumed resilient moduli of pavement layers based on material testing and field experience.

This paper presents the results of static load and in in-situ field tests. By means of vertical stress measurements beneath the geocell layers and by means of falling weight deflectometer (FWD) measurements in geocell reinforced test fields the positive influence of geocells could be evaluated.

2 Model tests

2.1 Materials

To simulate a soft subgrade material an artificial mixed soil called “Glyben” was used. The soil consists of glycerin and bentonite and contains no water. The main advantage of Glyben compared to other cohesive soils is that the soil parameters are constant for a long time. The glycerine is neither pressed out during loading nor evaporated at laboratory temperature. The soil parameters of the Glyben are primarily depending on the rate of mixture. The mixed portion of Glyben got an undrained cohesion of c_u = 15 kPa and a friction angle of f_u = 8°. The back calculated elastic modulus from uniaxial compression tests for a stress range 10 kN/m² to 150 kN/m² is about 5 MN/m².

Dry sand with a maximum particle size of 2 mm was used as infill material of the geocells and also for the unreinforced tests. The coefficient of uniformity (C_u) was 3.2 the coefficient of curvature (C_c) was 1.03. The void ratio at infill density was 0.39; the friction angle was 38.9°.

Two different types of geocells were used for the tests. Geocell “type A” was made form thermally solidified nonwoven with a tensile strength of 20.7 kN/m. The peel strength of the junction points is 10 kN/m the shear strength is 13 kN/m. The length and width of a single cell is 264 mm and 218 mm. Three different cell diameters of 16 cm, 23 cm and 30 cm were tested at constant cell height of 20 cm.

Geocell “type B” was made from high density polyethylene (HDPE). Single cells with a cell area of 262 cm² are 210 mm long and 250 mm wide. The geocells have seam strength, depending on there height, of 1150 N (10 cm height), 1725 N (15 cm height) und 2290 N (20 cm height). The cell walls are perforated with 10 mm diameter holes and the surface of the cell walls is textured. Three different cell heights (h) of 10 cm, 15 cm and 20 cm were tested in the model tests while the cell diameter (d = 23 cm) was constant in all tests.

2.2 Test Preparation

To evaluate the influence of a geocell layer on the load-deformation behavior and the stress distribution on the subgrade, static load tests were carried out in a test box with inside dimension of 2m length, 2m height and 2m width (figure 1).

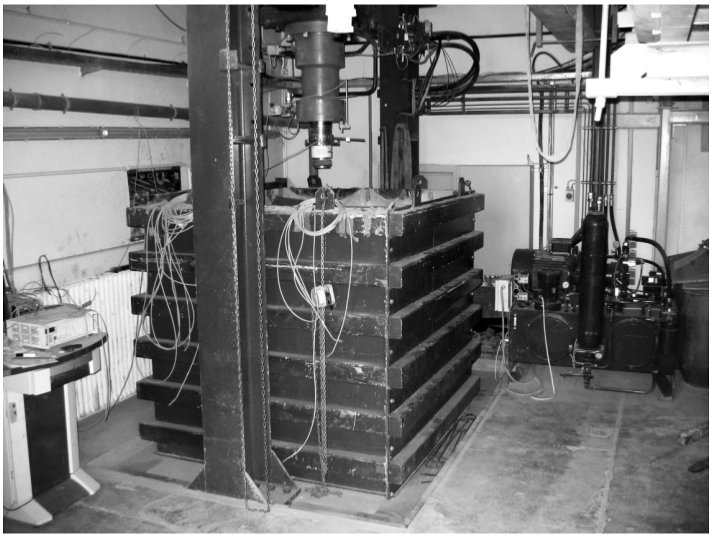


Figure 1: Test device for static load tests

The walls of the test box were coated with oil and plastic foil to minimize the friction between the infill material and the sidewalls of the test box. Glyben was filled in the test box in 10 cm layers up to a height of 1 m and compacted by vibrating plate compactor to a target density of 16 kN/m³. A nonwoven was placed on the Glyben to separate subgrade and infill material.

Eight earth pressure cells with a diameter of 5 cm were used to measure the vertical earth pressure on the subgrade. To minimize the influence of hard-inclusion effects on the measurement results the pressure cells were placed within a sand bed. The pressure cells were calibrated for the sand before using them in the model tests. The pressure cells were placed in different distances to the load device (figure 2). In order to avoid a mutual influence of the earth pressure cells, they were placed in different directions to the load plate. The distance between single earth pressure cells was at least two times the diameter.

After the pressure cells were installed, the geocells were placed on a nonwoven, stretched, adjusted with steel bars, filled with dry sand and compacted by a vibrating plate compactor. The surface of the geocell layer was covered with 2 cm sand. The layer thickness above pressure cells was selected to be equal in all tests. Distance between pressure cells and load plate was chosen to 35 cm. After installation of geocells a load plate with a diameter of 30 cm was installed on the geocell layer. Static loads are applied by a hydraulic jack and are transferred by the steel plate to the soil. The load was applied continuously until a contact pressure of 500 kN/m² was reached. To measure the heave and settlement on the soil surface six inductive displacement gauges (Dg) were installed in different distances of to the center of the load plate (figure 2).

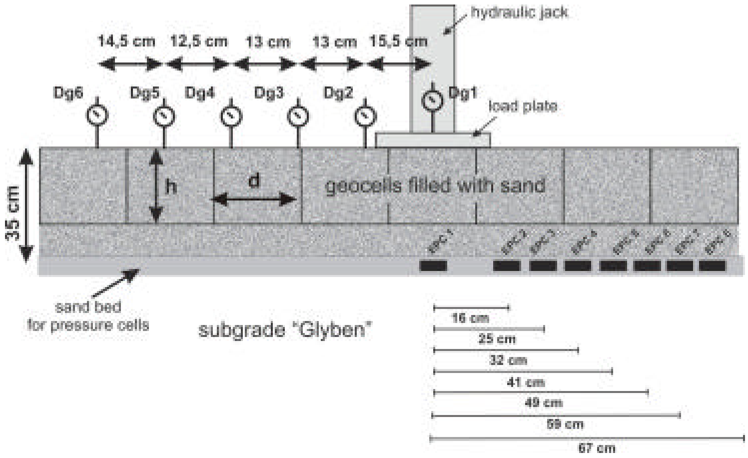


Figure 2: Schematic test setup

2.3 Test variables

Two different test series were carried out. Test series A was conducted with geocell "type A" to evaluate the influence of different cell diameters on the load-deformation behavior. The influence of different cell heights on the bearing capacity of the soil was evaluated with geocell "type B" in test series B. Two different geocell products were needed because the geocells are mechanical manufactured and the standard geometries could not be changed. In addition an unreinforced test with same layer configuration was carried out as a reference tests (test series C). Details of laboratory model tests are represented in table 1.

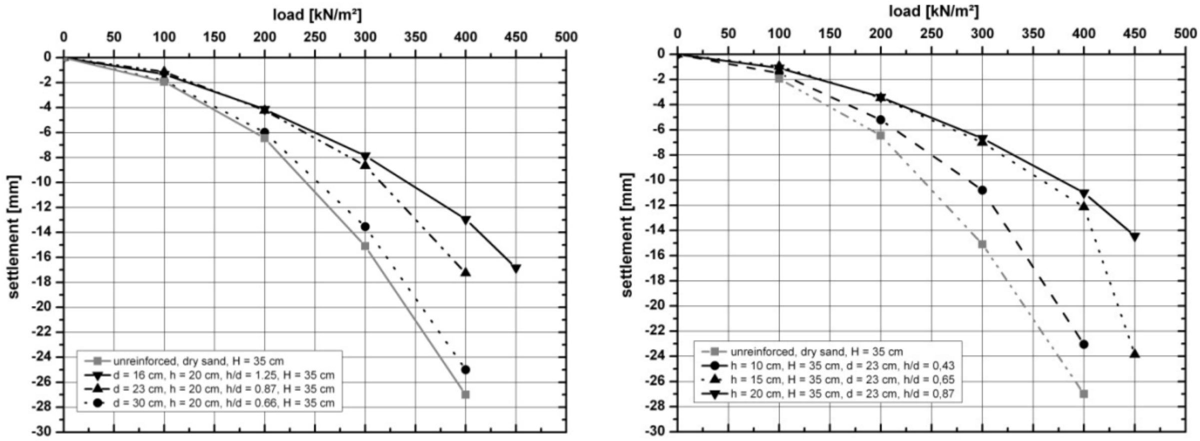
Table 1: Details of model tests

Test series	Geocell type [°]	Variables	Constant parameters	Infill material
A	A (nonwoven)	d = 16 cm; 23 cm and 30 cm	h = 20 cm, b = 110 cm	dry sand
B	B (HDPE)	h = 10 cm, 15 cm and 20 cm	d = 23 cm, b = 110 cm	dry sand
C	Unreinforced	---	H = 35 cm	dry sand

3 Results of model tests

3.1 Settlements

The measured settlements for test series A are shown in figure 3a. The highest settlements were measured for the unconfined dry sand. If the sand is reinforced by a geocell layer the settlement was reduced depending on the geocell diameter. With decreasing cell diameter the settlements also decrease. The smallest settlements were measured for a cell diameter of 16 cm. The difference between the geocell diameter of 16 cm and 23 cm was marginal up to a load of 300 kN/m². At higher loads the measured settlements were higher for the geocell layer with a diameter of 23 cm. The highest settlements were measured for a cell diameter of 30 cm. In this case the settlements were similar to the unreinforced sand and no significant benefit due to the geocell layer was observed.



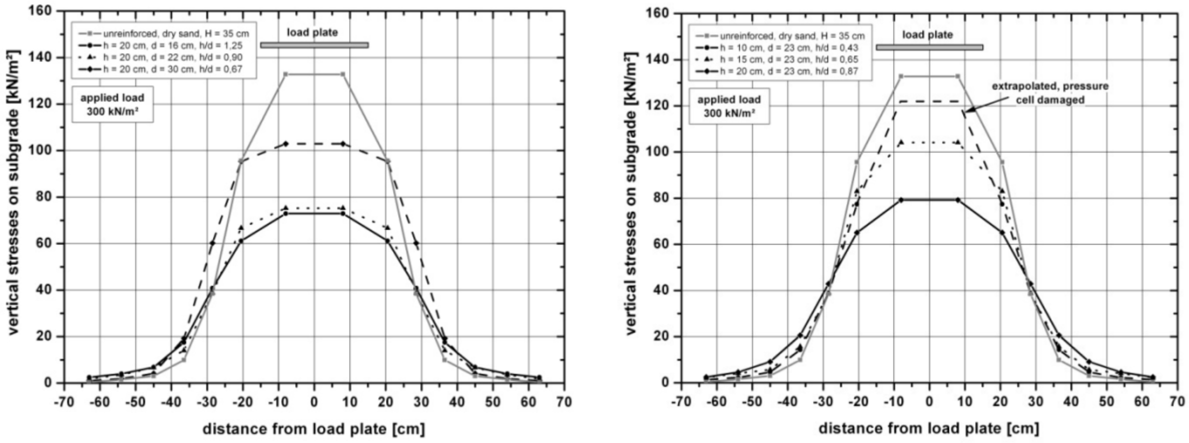
(a) (b)

Figure 3: Influence of geocell diameter (a) and geocell height (b) on load settlement response

The influence of the geocell height on the load-settlement behavior (test series B) is represented in figure 3b. Independent of the geocell height larger settlements were measured for the unreinforced sand compared to the geocell reinforced sand. The measured settlements are decreasing with increasing cell height. The smallest settlements were measured for a cell height of 20 cm. The improvement of load settlement response due to an increase of the cell height from 15 cm to 20 cm is negligible. Similar results were observed by Dash et al. (2001) and Sitharam and Sireesh (2005).

3.2 Vertical stresses

The influence of different cell diameters on the vertical stress distribution on the subgrade at a vertical load of 300 kN/m² is shown in figure 4a. The highest vertical stresses were measured for the unreinforced sand. With decreasing cell diameter the vertical stresses on the subgrade were reduced. Compared to the unreinforced sand a stress reduction on the subgrade of about 25 percent was measured due to an installation of a geocell mattress with a cell diameter of d = 30 cm. For a cell diameter of d = 16 cm a stress reduction of 45 percent was measured compared to the unreinforced sand. The difference between a cell height of 16 cm and 23 cm was negligible.



(a) (b)

Figure 4: Influence of geocell diameter (a) and geocell height (b) on vertical stress distribution

The influence of different cell heights on the vertical stress distribution is represented in figure 4b. It has to be observed that during the test with 10 cm height geocells the earth pressure cell directly beneath the load plate (EPC 1) was damaged and the vertical stresses could not be measured. Therefore the vertical stresses of EPC 1 were extrapolated from the results of the pressure cells (EPC 2-8) for this test.

The measured vertical stresses on the subgrade in the area beneath the load plate were decreasing with increasing cell height. Compared to the unreinforced test a stress reduction of 10 percent was measured for a cell height of 10 cm. With increasing cell diameter the stress reduction also increased up to 40 percent at a cell height of 20 cm. If figure 4a and 4b are compared it can be observed that for a similar aspect ratio h/d = 0.87 respectively 0.90 the measured vertical stresses on the subgrade are similar for both geocell materials.

4 Reconstruction of road K-23

In addition to the conducted model tests, an in-situ test field was carried out during the reconstruction of the road K-23. The road K-23 is located in the middle of Germany, near the cities of Braunschweig and Hannover. During the reconstruction geocells were placed within the gravel base layers of the asphalt paved road construction. To evaluate the influence of geocells on the bearing capacity of the road construction vehicle crossing tests and falling weight deflectometer (FWD) measurements were conducted.

The existing road construction consisted of a 20 cm asphalt layer, a 15 cm gravel base layer and a subgrade with low bearing capacity. Static plate load tests on the subgrade gave an E_{v2}-value of about 20 MN/m². The road had to be reconstructed since a large number of cracks have appeared on the road surface and lane grooves in the outer areas of the pavement have developed due to high traffic.

The main reconstruction concept of the existing road consisted in a stabilization of the road foundations. In addition a new bituminous asphalt pavement should be placed on the existing road surface. After the existing asphalt layers were removed at the road sides on a width between one and two meters the gravel and the soil beneath the asphalt layers were removed until a depth of 70 cm was reached. After compaction of the subgrade material a new 70 cm thick gravel layer with a maximum particle size of 32 mm was placed in layers of 15 to 25 cm thickness. Approximately a 1 m wide band in the middle of the road was not built up newly. In this part of the road only the existing cracks were filled. When the gravel layers at the road sides were build up completely a 17.5 cm thick new asphalt pavement was applied over the whole width of the road.

In one part of the road 20 cm high geocells of “type B” with a diameter of 23 cm were installed on a length of approximately 500 m directly below the asphalt layer. After the existing 20 cm thick asphalt course and the 40 cm thick gravel base layer had been removed, earth pressure cells with a diameter of 20 cm were installed on the soft subgrade. After the installation of earth pressure cells a new 15 cm thick gravel layer 0/22 mm was build up and compacted with a vibrating roller. The geocells were then installed on a nonwoven and mounted. After the installation of the geocells they were filled with gravel with a maximum particle size of 22 mm until the old road surface was reached, then the infill material was compacted with a vibrating roller. Another section was build up without geocells in the same way.

When the installation of the geocell mattress had been finished the new 17.5 cm asphalt course was applied. The asphalt course consists of a 10 cm thick base course 0/32 mm, a 4 cm thick binder layer 0/16 mm and a 3.5 cm thick wearing layer of SMA 0/8 mm. A comparison of the three different rehabilitation sections can be seen in figure 5. Only test section one and two were instrumented with earth pressure cells.

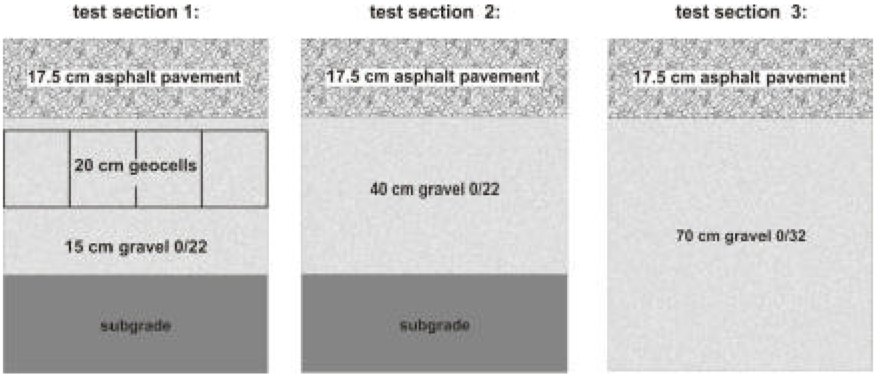


Figure 5: In-situ test sections K-23

After installation of the gravel base course and before the installation of the asphalt pavement plate load tests were carried out while the stresses on the subgrade were measured. In addition initial vehicle crossing tests with a grader were performed on the gravel base course. The plate load tests have shown that the vertical stresses on the subgrade were reduced about 50 percent due to the installation of a geocell layer. During crossing of the grader vertical stresses of 120 kN/m² were measured on the subgrade in the unreinforced test section 2 while only 75 kN/m² were be measured on the subgrade in geocell reinforced test section 1. This equates to a stress reduction of about 40 percent. For the same geocell material and geometry a stress reduction of 45 percent was measured in the model tests. However, it has to be noted that different soils and layer thicknesses were tested in the model tests.

4.1 Vehicle crossing tests

After the road surface course was reconstituted further measurement was conducted after the asphalt layers and the underground was more compacted because of the increasing traffic load. In this case controlled vehicle crossing tests were carried out. A heavy truck with five axes and a weight of approximately 41 tons crossed the road at different speeds while the stresses on the subgrade were measured by the installed earth pressure cells. The stresses measured at a crossing speed of 40 km/h are presented in figure 6.

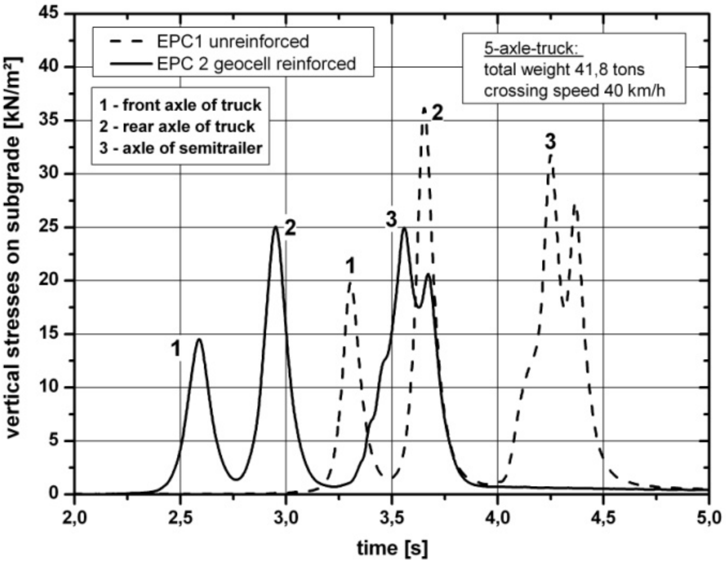


Figure 6: Results of vehicle crossing tests

The measured peak values (1) and (2) result from the crossing of the single axles of the truck, the double peak values (3) result from crossing of semi trailer. The results clearly confirm the results of previous tests. The stresses which are measured in the geocell reinforced tests section are significantly lower than the stresses which are measured in the unreinforced section. The average stress reduction on the subgrade due to the installation of geocell layer in the gravel base layer is approximately 30 percent. Similar results were also measured at other crossing speeds. Both the stresses in the reinforced and also in the unreinforced section decreased with increasing crossing speed.

4.2 Falling Weight deflectometer measurements

In addition to vertical stress measurements falling weight deflectometer measurements were carried out after the road construction was loaded by traffic for a longer time. Falling weight deflectometer (FWD) is a dynamic measuring instrument, which punctually notes the reaction of the pavement structure at a defined load impulse. To measure the pavement reaction a falling weight falls from a defined height on a rubber-puffer-system. The dynamic load impulse of 50 kN is transferred into the pavement structure by a load plate with a diameter of 30 cm. The size and duration of the load impulse are corresponding with a truck passage. The pavement reaction is measured on the road surface by nine geophones in form of deflections. The deflections and the form of the deflection hutch are the base for the evaluation of the bearing capacity and the stiffness of individual base layers and also for the total pavement structure. The linear-elastic moduli of the material layers were back calculated on basis of the theory of the linear-elastic half-space and multi-layer models [Ullitz, 1998]. The evaluation of the elastic layer moduli rely upon varying the linear-elastic moduli of the component material layers until a satisfactory match to the observed surface deflection is achieved.

To evaluate the influence of geocell layer within the mineral base course falling weight deflectometer measurements were carried out both in geocell reinforced section (test section 1, figure 5) as well as in the unreinforced section (test section 2, figure 5). Additional measurements were conducted in a test section with standard reconstruction of 70 cm gravel base course (test section 3, figure 5).

The average values of measured deflections and back calculated layer moduli are presented in figure 7. The results show, that the highest deflections and lowest layer moduli were measured in the unreinforced test section with a base layer of 40 cm gravel. Both the deflections and the layer modulus of the unreinforced test section with 70 cm thick gravel base layer and the geocell reinforced test section were very similar. The deflections of these test fields were about 15 percent lower, the layer modulus were about 10 percent larger than those of unreinforced test field with a 40 cm gravel base layer.

Therefore a stabilization of 40 cm mineral base course with 20 cm height geocells, placed in the upper part of the base layer, has a comparable effect like a 70 cm thick unreinforced gravel base layer with similar boundary conditions.

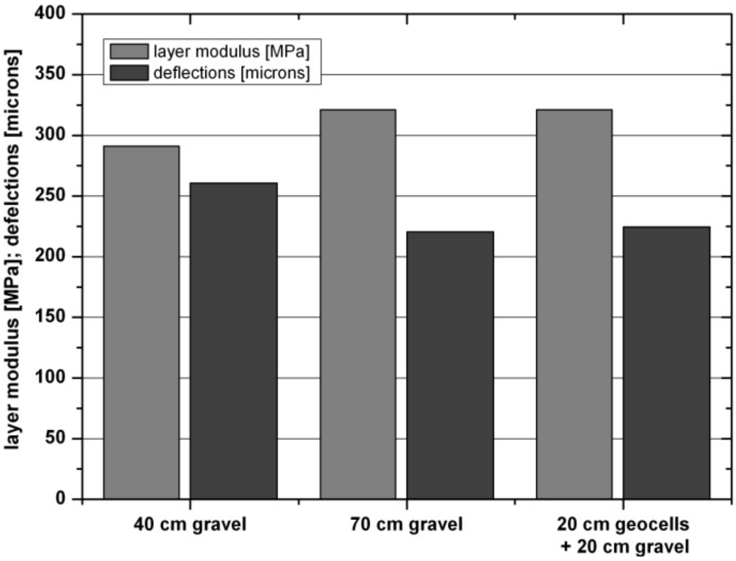


Figure 7: Results of FWD-measurements

5 Conclusion

To determine the influence of a geocell layer on the load-settlement behavior and the vertical stresses on the subgrade 1g model tests were conducted in a test box with inside dimension of 2m length, 2m width and 2m height. The results have shown that a dry sand filled geocell layer placed over a soft subgrade material reduced the vertical deformation compared to an unreinforced sand layer with same thickness. During loading the vertical stresses on the subgrade material were measured with eight earth pressure cells. The results of stress measurement have shown, that depending on the aspect ratio of the geocell layer, the vertical stresses on the subgrade were reduced up to 45 percent.

In addition to the model tests an in-situ test field was constructed during the reconstruction of the road K-23. In one test section a 20 cm height geocell layer was placed within a 40 cm thick gravel layer, another test section was build up without geocell in the same thickness. Earth pressure cells were installed on the subgrade material to measure the vertical stresses on the subgrade. Vehicle crossing tests after finishing the reconstruction of the road have shown that in the geocell reinforced test sections the vertical stresses on the subgrade were reduced about 30% compared to the unreinforced section. In addition to the vertical stress measurements FWD measurements were also carried out. The results have shown that the geocell layer increased the layer modulus of the gravel base layer and decreased the deflections on the asphalt surface course.

The conducted measurements have shown that a geocell layer placed within the gravel base layer of an asphalt paved road construction reduced the vertical stresses on the subgrade during vehicle crossing about 30 percent and increased the layer modulus of the gravel base layers compared to an unreinforced layer. As a result the measured deflections on the asphalt surface were also reduced. Geocells can be used as an alternative to common methods e.g. cut and cover, lime stabilization to stabilize road base courses over soft soils and to increase the long-term behavior of road constructions. To verify the results of the measurements, further tests are necessary.

6 References

Al-Quadi I.L. and Hughes J.J. (2000). Field evaluation of geocell use in flexible pavements. Transportation Research Record (TRB) H. 1709, S. 26 - 35

Ben Kurari K. (2000). Implementation of geocells in low bearing capacity roads. Proceedings of the 2nd European Geosynthetics Conference, Session7A , S. 365 -368, Bologna

Dash S.K., Krishnaswamy N.R. and Rajagopal, K. (2001). Bearing capacity of strip footings supported on geocell-reinforced sand. Geotextiles and Geomembranes, Volume: 19, Issue: 4, S. 235-256, June, 2001

Dash S.K., Sireesh S. and Sitharam T.G (2003). Model studies on circular footing supported on geocell reinforced sand underlain by soft clay. Geotextiles and Geomembranes, Volume: 21, Issue: 4, S. 197-219

Forschungsgesellschaft für Straßen- und Verkehrswesen, FGSV Arbeitspapier "Tragfähigkeit" Teil C2 "FWD, Auswertung und

Bewertung", AK 4.8.2, Entwurf Stand Februar 2004

Forsman J., Slunga E. and Lahtinen P. (1998). Geogrid and Geocell Reinforced Secondary Road over Deep Peat Deposit. Proceedings of the 6th International Conference on Geosynthetics, Vol. 2, S. 773-778, Atlanta

Leytland I.V., Aliver Y.A. and Bubnovsky V.V (2006). Experience on using plastic geocells in the construction of roads under conditions of the arctic of Russia. Proceedings of the 8th international Geosynthetic Conference, S. 705 – 708, Yokohama

Meyer N. and Emersleben A. (2005a). Mechanisches Verhalten von bewehrten Böden mit Geozellen. 9. Informations- und Vortragstagung über "Geokunststoffe in der Geotechnik", Sonderheft der Geotechnik, S. 49 - 55.

Meyer, N. and Emersleben A. (2005b). Mechanisches Verhalten von bewehrten Böden mit Geozellen. Symposium Geotechnik – Verkehrswegebau und Tiefgründungen, Schriftenreihe Geotechnik, Universität Kassel Heft 18, S. 93 – 112

Meyer, N. and Emersleben A. (2005c). Einsatz von Geozellen im Verkehrswegebau. Tiefbau – Ingenieurbau – Straßenbau (TIS) Heft 11, S. 32 – 37

Meyer, N. and Emersleben A. (2006a). Bodenstabilisierung mit Geozellen im Straßenbau. 21. Christian Veder Kolloquium (CVK) – Neue Entwicklungen der Baugrundverbesserung, Heft 28, S. 85-101 Technische Universität Graz (TUG)

Meyer, N. and Emersleben A. (2006b). Stabilisierung von mineralischen Tragschichten mit Geozellen. Tiefbau Heft 11, S. 634 – 640

Mhaiskar S. Y. and Mandal, J. N. (1992). Soft Clay Subgrade stabilisation using Geocells. Geotechnical special publications, Vol. 30, S. 1092 – 1103, New York, American Society of civil engineer ASCE

Ullidtz, Per: Modelling Flexible Pavement Response and Performance. Polyteknisk Forlag, Lyngby, 1998

Sitharam T.G., Siressh S. (2005). Behavior of embedded footings supported on geogrid cell reinforced foundation beds. Geotechnical testing journal Vol. 28, No. 5, S. 1-12