THE USE OF GEOCELLS IN ROAD CONSTRUCTIONS OVER SOFT SOIL: VERTICAL STRESS AND FALLING WEIGHT DEFLECTOMETER MEASUREMENTS

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Abstract: Geocells consist of a series of interconnected single cells that are manufactured from different types of polymers. The geocells are expanded at the construction site and filled with soil. The cell walls completely encase the infill material and provide all-round confinement to the soil. During vertical loading, hoop stresses within the cell walls and earth resistance in the adjacent cells are mobilized which increases the stiffness and the load-deformation behaviour of the soil. Thus the soil-geocell layers acts as a stiff mat and distribute the vertical traffic loads over a much larger area of the subgrade soil. Large scale static load tests were carried out to evaluate the influence of a geocell layer on the load-deformation behaviour of the soil. The test results show that a geocell layer increases the bearing capacity of the infill materials up to three times compared to an unreinforced soil. The vertical stresses on the soft subgrade, measured by eight earth pressure cells, where also reduced about 30 percent. To verify the results of model tests in-situ field test where carried out within different road constructions. Earth pressure cells where installed on the subgrade to measure the influence of the geocell layers on the stress distribution. After finishing the road construction vehicle crossing tests with a 40-ton truck were carried out while the stresses on the subgrade where measured. Compared to an unreinforced test section the stresses beneath the geocell layer were reduced by about 30 percent. In addition to vertical stress measurements, falling weight deflectometer (FWD) measurements were conducted in reinforced and unreinforced test sections. The results show that the deflections measured in geocell reinforced test section were significantly smaller than in the unreinforced section. Back calculated layer modules were significantly higher in the geocell reinforced section compared to an unreinforced section.

Keywords: geocell, cellular system, earth reinforcement, field measurement, soil improvement, load tests

INTRODUCTION

Geocells are honeycomb interconnected cells that completely encase the soil and provide all-around confinement, thus preventing the lateral spreading of the infill material. Due to the confinement of the soil the geocells increase the stiffness and the load-deformation behaviour of gravel base layers and thereby reduce the deformation of the soil. The soil-geocell layers act as a stiff mat, thus distributing the vertical traffic loads over a much larger area of the subgrade soil.

Several model tests (e.g. Dash *et al.* 2001, 2003, Sitharam &Siressh 2005) have shown the positive effect of geocells, made from different geogrids, on the load bearing capacity of soils. Meyer & Emersleben (2005a, 2005b, 2005c, 2006a, 2006b) and Mhaiskar & Mandal (1992) have evaluated the influence of industrially manufactured geocells on the load-deformation behaviour of soils.

The use of geocells to stabilize unpaved road constructions is far from common, especially if suitable 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 deformation of the asphalt surface and to increase the stiffness of the main construction. Al Quadi & Hughes (2000) reported an increase of the resilient modules of aggregate layers about two times due to the installation of geocells within an asphalt paved road construction.

This paper reports the results of static load tests 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 was evaluated.

LARGE SCALE MODEL TESTS

Test Device

To evaluate the influence of geocells on the load bearing capacity of soil and the stress distribution large scale model tests were carried out in a test box with internal dimensions of 2m length, 2m width and 2m height. Static load is applied over a loading frame, and vertical loads up to 150 kN can be applied. The loads are applied by a hydraulic jack and are transferred by a steel plate with a diameter of 30 cm to the soil.

To measure the heave and settlement on the soil surface five inductive displacement gauges were installed at different distances from the centre of the load plate. For the determination of the stress distribution below the geocells, eight earth pressure cells were installed at a depth of 35 cm. The earth pressure cells (EPC) with a diameter of 5 cm and a maximum pressure capacity of 500 kN/m² were aligned at different distances to the load plate.

Materials

Soils

An artificial mixed soil called "Glyben" was used to simulate soft subgrade material. The soil consists of glycerine and bentonite. The soil parameters depend on the rate of mixture. The soil was mixed in small portions, placed in the test box and compacted. The main advantage of Glyben compared to other cohesive soils is that the soil parameters are constant for a long time because the water or glycerine content is not changing. The mixed Glyben is not saturated and has an undrained cohesion of c_u = 15 kPa and a friction angle of φ_u = 8°. The stiffness modulus from axial compression tests at relevant loads is about 5 MN/m².

Dry sand with a maximum particle size of 2 mm was used as infill material for the geocells as well as for the unreinforced tests. The coefficient of uniformity (C_u) was 3.2 the coefficient of curvature (C_c) was 1.03. The maximum and minimum void ratio of the sand is 0.45 and 0.34. The void ratio at infill density was 0.39. The friction angle at infill density was 38.9°. The sand was poured into the test box and compacted with a vibration plate compactor.

Geocells

Two different types of geocells were used in the model tests. Geocell "Typ 1" was made from high density polyethylene (HDPE) with a density of 0.95 g/cm³. Single cells are 210 mm long and 250 mm wide. Single cells with a cell area of 262 cm² were welded together to form a uniform geocell mattress. The geocells have seam strength, depending on the height: 1150 N (10 cm height), 1725 N (15 cm height) and 2290 N (20 cm height). The cell walls are perforated with 10 mm diameter holes. The total open area is 16 % of the cell wall area. 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 equivalent cell diameter (d_0 = 23 cm) was constant in all tests.

Geocell "Typ 2" was made from a thermally solidified non-woven geosynthetic with a tensile strength of 20.7 kN/m. The peel strength of the junction points is 10 kN/m and the shear strength is 13 kN/m. Three different cell diameters (d_0) of 16 cm, 22 cm and 30 cm were tested in the model tests at a constant cell height of h = 20 cm.

Test installation

After the walls of the test box were covered with foil and lubricant to minimize the friction between the soil and the infill material, the subgrade layer was installed. Glyben was placed in the test box in 10 cm layers up to a height of 1 m. Afterwards the installation and adjustment of eight earth pressure cells took place. They were laid in a thin sand bed at different distances to the load device, aligned and covered with sand. The layer thickness above the pressure cells was selected to be equal in all tests. The distance between the pressure cells and the load plate was chosen to be 35 cm. Extensive preliminary tests indicate that a minimum distance of 15 cm between the pressure cells and the lower edge of the geocells is necessary in order to measure a representative stress distribution in the ground. On the subgrade material a non-woven with low tensile strength at high strains was placed over the soil to separate the subgrade and infill material. The geocells were then placed on the non-woven. The geocells were stretched, adjusted with steel bars, filled with dry sand and compacted by a vibrating plate compactor. The load plate and displacement gauges were installed on the sand surface. The schematic experimental setup is shown in Figure 1.

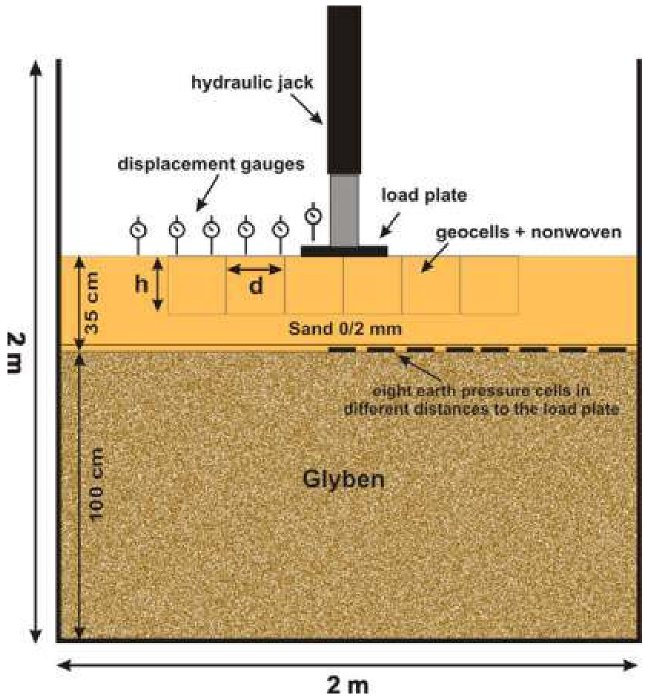

Figure 1: Schematic diagram of test device.

Static load was applied in steps. The number of applied load steps depended on the maximum bearing capacity of the soil. Every load step was applied until no further settlement was observed.

TEST RESULTS

Load carrying capacity

The increase in load carrying capacity due to the provision of geocell layer is represented using a non-dimensional load carrying factor (LCF).

$$\mathrm{LCF} = \frac{\sigma_{r,(s)}}{\sigma_{u,(s)}} \, [-]$$

The LCF is defined as the ratio of the footing pressure with geocells at a given settlement $\sigma_{r,(s)}$ to the corresponding pressure of the unreinforced soil at the same settlement $\sigma_{u,(s)}$. The calculated load carrying factors for two different test series are presented in Figure 2. Test series A was conducted with geocell "typ 1" to measure the influence of the geocell height on the load-deformation behaviour and test series B was carried out with geocell "typ 2" to measure the influence of different cell diameters on the load-deformation behaviour.

The load carrying factors were calculated up to load a of 400 kN/m² respectively up to a settlement of 16 mm. At this settlement the ultimate bearing capacity of the unreinforced sand was reached.

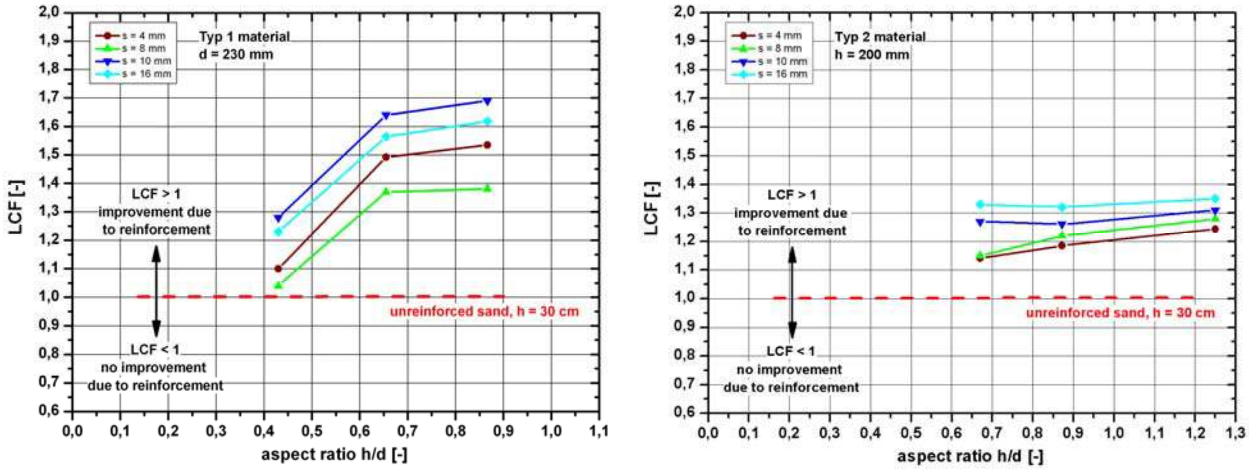

Figure 2: Load carrying factors for test series A (typ 1, d = 230 mm) and test series B (typ 2, h = 200 mm).

The load carrying capacity increases with increasing cell height and decreasing cell diameter. Depending on geocell height and diameter, the load carrying capacity could be improved up to 1.5 times due to the reinforcement of dry sand with geocells. Further improvement will occur at higher settlement and loads because the ultimate bearing capacity of unreinforced sand could not be increased while the ultimate bearing capacity of the reinforced sand was not reached at a load of 400 kN/m².

Vertical stresses

During static load tests vertical stresses on the subgrade were measured with eight pressure cells at different distances from the load plate. To avoid influences on the stress distribution resulting from measured peak stresses in single pressure cells the stresses of two pressure cells, which are lying next to each other, were averaged according to the following equation.

$$\overline{\sigma}_{epc,i} = \frac{\sigma_{epc,i} + \sigma_{epc,i+1}}{2}$$

Vertical stresses were measured in every test. Exemplary the results of tests with 20 cm height and 23 cm in diameter geocells "typ 1" are presented in Figure 3b for different loads. Vertical stresses measured in the corresponding unreinforced test are presented in Figure 3a.

The stresses that are measured in the unreinforced soil are significantly higher than those measured in the geocell reinforced soil at the same load. A stress reduction between 30% and 36% can be observed depending of the applied load. Similar results were observed for different cell heights and cell diameters.

In the unreinforced soil the stresses are more concentrated in the area of the load plate while the stresses in the geocell reinforced soil are distributed over a larger area. These results indicate that the geocell layer acts like a stiff matt and distributes the footing load over a larger area thus reducing the vertical stresses directly beneath the load plate. This effect increases with increasing load. Similar results were observed by Dash *et al.* (2003). The influence of different cell heights and cell diameters on the magnitude of vertical stresses was marginal.

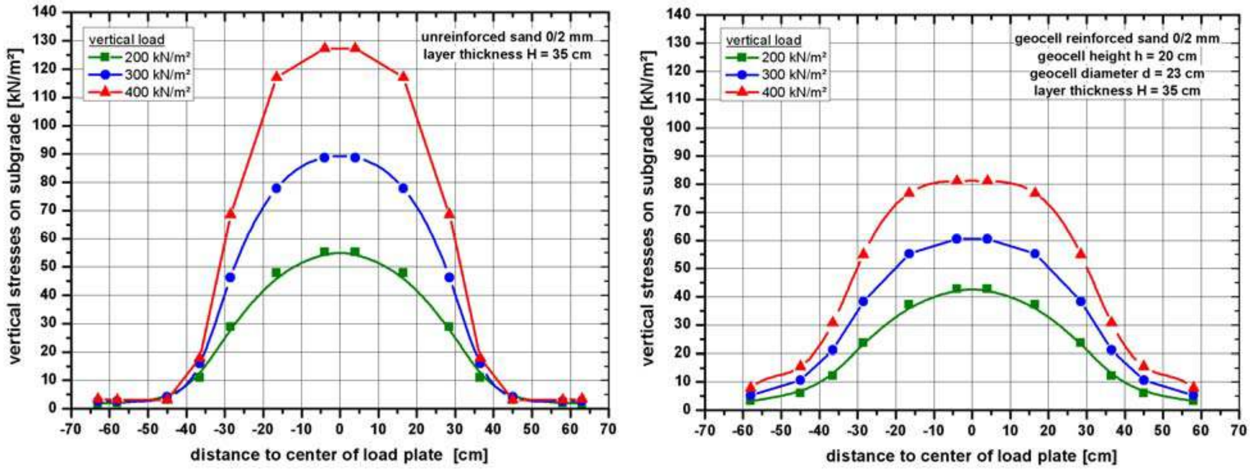

Figure 3: Measured vertical stresses on subgrade, unreinforced sand (l) and geocell "typ1" reinforced sand (r).

IN-SITU TEST FIELDS

To verify the results of large scale model tests, two different in-situ tests fields were carried out. Geocells were placed within the gravel base layers of two different asphalt paved road constructions. To measure the vertical stresses on the subgrade the test sections were instrumented with earth pressure cells. After the road constructions were finished vehicle crossing tests were carried out while the stresses on the subgrade were measured. In addition falling weight deflectometer (FWD) measurements were conducted.

Reconstruction of the road K-23

The existing road K-23 consisted in the upper part of an approximately 20 cm thick asphalt layer. Below the asphalt layer there was a 15 cm gravel base layer. The underlying ground consisted of sandy clay with low bearing capacity. At both sides of the street a drainage channel was located a small distance from the pavement over the whole length of the road to drain the adjacent agricultural areas. The existing road had to be reconstructed since a large number of cracks have appeared on the road and lane grooves in the outer areas of the pavement have developed. Because of the close proximity of the drainage channels to the road the lateral support of the pavement was insufficient, deformations of the outer road areas have taken place and rutting has occurred due to traffic.

The main reconstruction concept of the existing road consists of stabilization of the road foundations. In addition a new bituminous asphalt pavement is placed on the existing road surface.

First of all the existing asphalt layers were removed at the sides of the road to a width of between one and two meters. After that, the gravel and the soil beneath the asphalt layers were removed to a depth of 70 cm. 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. An approximately 1 m wide band in the middle of the road was not rebuilt at all. In this part of the road only the existing cracks were filled. When the gravel layers at the road sides were built up completely a 17.5 cm thick new asphalt pavement was applied over the whole width of the road (Figure 4).

In one part of the road an alternative road reconstruction was used, using "typ 1" geocells. 20 cm high geocells with a diameter of 23 cm were installed on a length of approximately 500 m directly below the asphalt layer (Figure 4).

Figure 4: Different reconstruction section, road K-23.

In this section, first of all the existing 20 cm thick asphalt course was removed. After that the base course, consisting of a 40 cm gravel layer, was also removed until the subgrade was reached. Load plate tests on the subgrade gave an E_{v2}-value of 20 MN/m². After the Subgrade was compacted, earth pressure cells were installed on the subgrade. After the installation of earth pressure cells a new 15 cm thick gravel layer 0/22 mm was built up and compacted. In one section a non-woven was installed on the surface of the gravel layer. The geocells were placed on top of the non-woven. 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 (Figure 5). Another section was built up without geocells in the same way.

Figure 5: Installation of geocell layer directly beneath the asphalt surface.

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.

After installation of the gravel base course on the earth pressure cells, plate load tests were carried out while the stresses on the subgrade were measured. The measured stresses in the geocell stabilized test section 1 were about 50 % percent smaller than in the unreinforced test section 3.

In addition to plate load tests initial vehicle crossing tests were performed on the 25 cm thick gravel layer. During crossing of a grader vertical stresses of 120 kN/m² were measured on the subgrade in the unreinforced test section 3 while only 75 kN/m² could be measured on the subgrade in geocell reinforced test section 1.

Vehicle Crossing tests and vertical stress measurements

After the asphalt surface course was reconstituted further measurements were conducted to take account of any further compaction of the asphalt layers and the underlying soil due to the increased traffic load. In this case controlled vehicle crossing tests were carried out. A heavy truck with five axles and a weight of approximately 41 tons crossed the road at different speeds. During truck crossing the stresses in the underground were measured by the installed earth pressure cells. The stresses measured at a crossing speed of 40 km/h are presented in Figure 6.

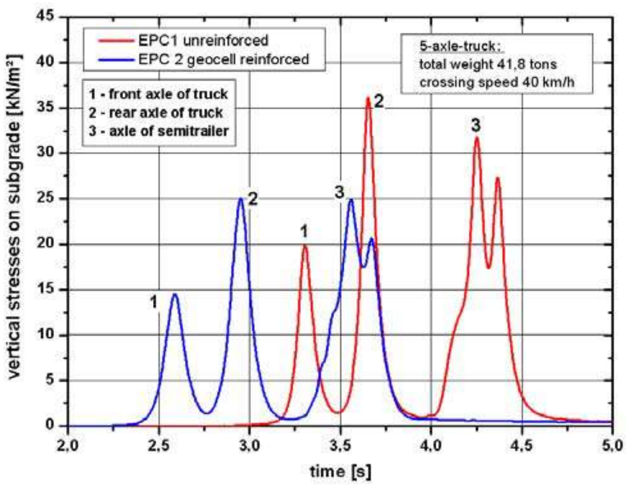

Figure 6: Results of truck crossing tests, crossing speed 40 km/h.

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 that are measured in the geocell reinforced tests section are significantly lower than those which are measured in the unreinforced section. The average stress reduction on the subgrade due to the installation of the geocell layer in the gravel base layer is approximately 30%.

Similar results could also be observed at other crossing speeds. Both the stresses in the reinforced and also in the unreinforced section decrease with increasing crossing speed.

Falling weight measurements (FWD)

In addition to vertical stress measurements falling weight deflectometer (FWD) measurements were carried out after the road construction was loaded by traffic for a longer time.

The FWD is a dynamic measuring instrument, which measures the reaction of the pavement structure to 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 broadly correspond with those due to the passage of a truck.

The pavement reaction is measured at the road surface, in the form of deflections, by nine geophones. The geophones are aligned at different distances from the load plate. The deflections and the form of the deflection bowl are the base for the evaluation of the bearing capacity and the stiffness of individual base layers and also for the total pavement structure (Figure 7).

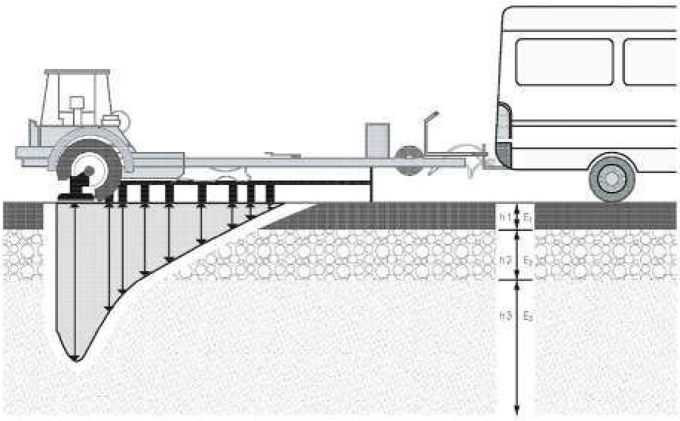

Figure 7: Schematic diagram of falling-weight-deflectometer (FWD) measurements (FGSV, 2004).

To evaluate the influence of the geocell layer within the mineral base course, falling weight deflectometer measurements were carried out on both the geocell reinforced section (test section 1, Figure 4) as well as on the unreinforced section (test section 2, Figure 4). 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 modulus are presented in Figure 8. The calculation of the layer modulus was based upon the theory of the elastic half space and on multi-layer models (Ullitz, 1998). The results show that the highest deflections and lowest layer modulus 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 and the layer modulus about 10 percent higher than those of the unreinforced test section with a 40 cm gravel base layer.

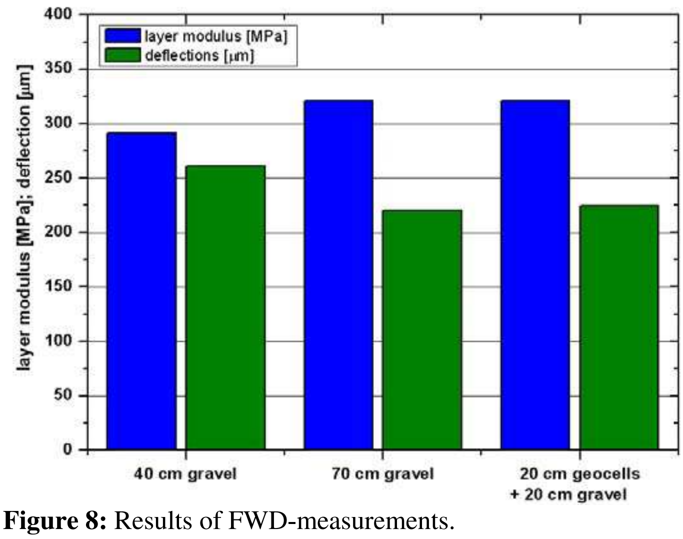

Figure 8: Results of FWD-measurements.

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 to a 70 cm thick unreinforced gravel base layer with similar boundary conditions.

The FWD measurements conducted confirm the results of the vertical stress measurements.

Reconstruction of the road K-637

To verify the results of large scale model tests and the results of in-situ field measurements during the reconstruction of the road K-23 a further test field was carried out. The road K-637 had to be widened and stabilized, since the road was to be used as an access road during construction of a highway.

The main reconstruction concept of the existing road comprised a widening of the road shoulders of approximately two meters. In addition a new bituminous asphalt pavement was placed on the existing road surface. First of all the existing soil at the sides of the road was removed to a width between one and two meters until a depth of 50 cm was reached. After compaction of the subgrade material a new 40 cm thick hydraulic bound base layer (HBB) was placed in layers of 20 cm thickness. Every HBB-layer was compacted with a vibrating plate compactor. The middle of the existing road was not rebuilt. In this part of the road only the existing cracks were filled. When the HBB-layers at the road sides were completed an 18 cm thick layer of new asphalt pavement was applied over the whole width of the road.

In one part of the road an alternative road reconstruction was carried out, using three different stabilization methods. Four test fields, each 5 m long, were carried out. In one test section geocells were built in within the mineral base layer (test section 1, Figure 9). A further road section (test section 3, Figure 9) is stabilized with a 20 cm thick hydraulic bonded base layer. As a reference, test section (test section 2, Figure 9) remains unreinforced. In this section a 40 cm thick mineral base layer is build in beneath the asphalt pavement. An overview of the test fields and their construction is shown in Figure 9.

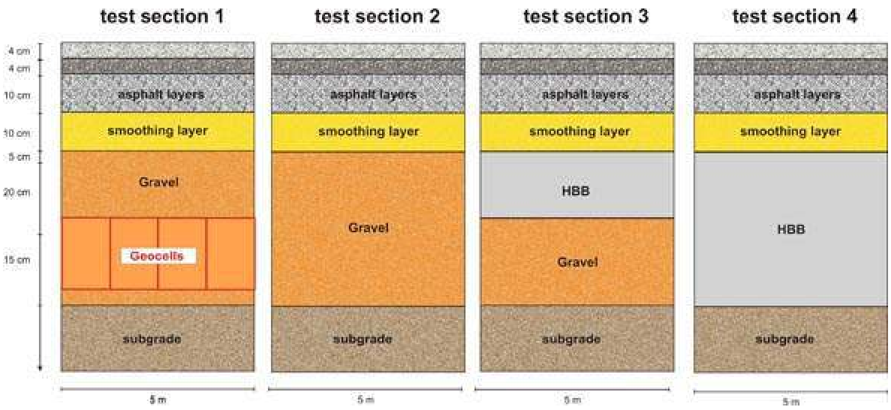

Figure 9: Test section K-637.

In test sections 1, 2 and 3 dynamic earth pressure cells were installed directly on the subgrade material. During and after the road construction vehicle crossing tests were carried out. The stress measurements during crossing tests verify the results of in-situ field tests during construction of the road K-23. The vertical stresses in the geocell reinforced section were about 30 % lower than the stresses which were measured in the unreinforced test section. Because of its higher stiffness the 20 cm hydraulic bonded base layer could reduce the vertical stresses about 22 % compared to the geocell reinforced test section. No stresses were measured in test section 4.

Falling weight deflectometer measurements were also carried out. The measured deflections in the geocell reinforced section were smaller than those measured in the unreinforced section. A further reduction could be observed in test sections 3 and 4, were 20 cm and 40 cm thick hydraulic bonded base layers were placed beneath the asphalt pavement. With increasing height of HBB-layer the deflections were decreasing.

The highest back calculated layer modulus could be observed in the HBB-layers while the modulus of the unreinforced test section was the smallest. The modulus of the geocell reinforced section is smaller than those of the HBB-layers but higher than the modulus of the unreinforced section.

If the vertical stress measurements and the FWD measurements are summarized, a very good agreement between the vertical stresses and deformations can be observed. With increasing layer modules the deformation and the vertical stresses are decreasing (Figure 10).

The investigations conducted confirm the results of large scale model tests as well as the test results of in-situ test fields of road K 23.

CONCLUSIONS

To determine the influence of a geocell layer on the load-settlement behavior and the vertical stresses on the subgrade, large scale model tests were conducted. The results have shown that the geocell layer reduced the vertical stresses on the subgrade about 30 %, distributed the vertical loads over a larger area and improved the bearing capacity of the infill material between 1.1 and 1.7 times.

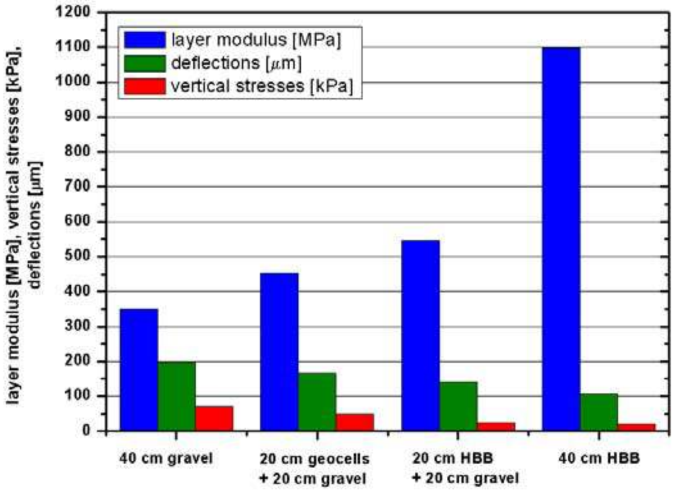

Figure 10: Results of FWD measurements K 637.

In addition to the model tests, two different in-situ test fields were constructed during the reconstruction of the roads K-23 and K-637. Vehicle crossing tests have shown that in the geocell reinforced test sections the vertical stresses on the subgrade were reduced about 30% compared to the unreinforced section. FWD measurements have shown that the geocell layer increased the layer modulus of the gravel base layer and decreased the deflections on the surface. The results of the in-situ tests confirmed the results of the large scale model tests. With increasing soil stiffness, e.g. due to installation of geocells or a hydraulic bonded base layer, the vertical stresses on the subgrade and the deflections on the surface were reduced and the layer modulus were increased.

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