The influence of hoop stresses and earth resistance on the reinforcement mechanism of single and multiple geocells

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ABSTRACT: Geocell structures consist of a series of interconnected single cells, made from different polymer materials. The cell walls completely encase the infill material and provide an all-around confinement to the soil. The confinement effect is based on three main mechanisms: active earth pressure within loaded cell, earth resistance in the adjacent cells and hoop stresses in the cell walls. To evaluate the influence of different parameters e.g. geocell stiffness, number of interconnected cells, geocell height and soil cover height on the interaction mechanism between hoop stresses and earth resistance static radial load tests were carried out. The test results have shown that the stiffness of the geocell material and the number of adjacent cells are the most important parameters. The test concept and the test results are presented in the paper.

1 INTRODUCTION

Different authors have carried out triaxial tests on single and multiple geocells to evaluate the influence of the mobilized hoop stresses in the cell walls on the shear strength of the infill material (Bathurst & Karpurapu 1993; Madhavi Latha & Murphy 2007; Rajagopal et al. 1999). They reported that the geocells mobilized an apparent cohesion to the soil while the friction angle of the confined and unconfined was the same. The value of the cohesion was depending on the geocell material stiffness and the number of adjacent geocells. The cohesion was increasing both with increasing stiffness of the geocell material and the number of adjacent cells. Nevertheless no attempt was made to quantify the influence of the geocells other than its influence on the peak strength. To evaluate the strain-dependent influence of different parameters on the mobilization of hoop stresses within the geocell walls and the earth resistance in the surrounding soil/adjacent geocells radial load tests were carried out. A horizontal load is applied on the cell walls of a single or multiple geocell structure, while the strains in the cell wall and the horizontal stresses within the surrounding soil were measured in different distances to the loaded cell. Due to the application of a horizontal load influences e.g. of the soil beneath the geocells can be disregarded and the interaction between hoop stresses and earth resistance can be evaluated without the influence of other factors.

2 MATERIALS

2.1 *Soil*

An uniform dry sand with a maximum grain size of 2 mm was used as confinement material of single geocells and infill material of multiple geocells. The soil is classified as SP according to the Unified Soil Classification System (USCS). The sand was filled in the geocells by hand and was compacted afterwards by a hand tamper to a relative density of at least 80 percent. The relevant soil parameters of the sand are shown in table 1.

Table 1. Characteristics of soil

characteristics	sand (SP)
coefficient of uniformity U	2.10
coefficient of curvature C_c	1.00
porosity in loosest state	0.45
porosity in densest state	0.34
angle of friction φ	38.9°

2.2 *Geocells*

Three different types of geocells were used in model tests. Geocell "Type 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 width. Single cells with a cell area of 262 cm² were welded together to form a uniform geocell mattress. The cell walls are perforated with 10 mm diameter holes. The total open area is 16 % of the cell wall area. The surface of cell walls is textured. Geocell “Type 2” was made from the same material but was manufactured without perforations. Geocell “Type 3” was made form thermally solidified non-woven (PES). The height of all geocells was 15 cm.

Table 2. Characteristics of geocell material

characteristics	type 1	type 2	type 3
wall thickness (mm)	1.70	1.70	1.50
secant modulus at 2 % strain [N/cm]	1.59 x 10^5	3.68 x 10^5	1.85 x 10^5
secant modulus at 5 % strain [N/cm]	1.50 x 10^5	6.95 x 10^5	1.42 x 10^5

3 RADIAL LOAD TESTS

3.1 *Test Device and Measurement Equipment*

The radial load tests were conducted in a test device in the soil mechanical laboratory of Institute of Geotechnical Engineering and Mine Surveying, Clausthal University of Technology. The test device consists of a test box with inside dimensions of 1.27 m in width, 1.27 m in length and 0.30 m in depth. Radial load is applied over an air pressure bag with a diameter of 210 mm and a height of 300 mm which is placed in the centre of the test box (figure 1). Maximum static loads ranging up to 600 kN can be applied. The air pressure bag is placed directly within a single geocell and the load is applied radial symmetrically to the geocell wall.

The deformations of cell walls were measured by an electrical potentiometer which is placed outside the test box. The potentiometer is connected to the geocells by a wire and the wire is passed through a trench into the test box. The strains within the cell walls are back calculated from the measured deformation on basis of mathematical coherences. The horizontal pressure in the surrounding soil is measured by four earth pressure cells in distances of 10 cm, 20 cm, 30 cm and 40 cm to the air pressure bag (Figure 1). The earth pressure cells (EPC) have a diameter of 5 cm and a maximum pressure capacity of 500 kN/m² (figure 1). Deformation of the surface is measured by six inductive settlement transducers which are placed in different distances to the air pressure bag (figure 1).

3.2 *Test Preparation*

The air pressure bag was placed in the centre of the test box. The centre geocell of the geocell structure was placed on the air pressure bag and the strain measurement system was connected to the centre geocell. To simulate in-situ field conditions an initial pressure was applied until the opening of the junctions of the loaded geocell was the same as in field construction. For the type 1 and type 2 geocells the opening angle was chosen to be 90 degree. Because of less stiffness of geocell material the opening angle of the type 3 geocell was 130 degree. After preparation of the geocells the earth pressure cells were installed in different distances to the air pressure bag (figure 1).

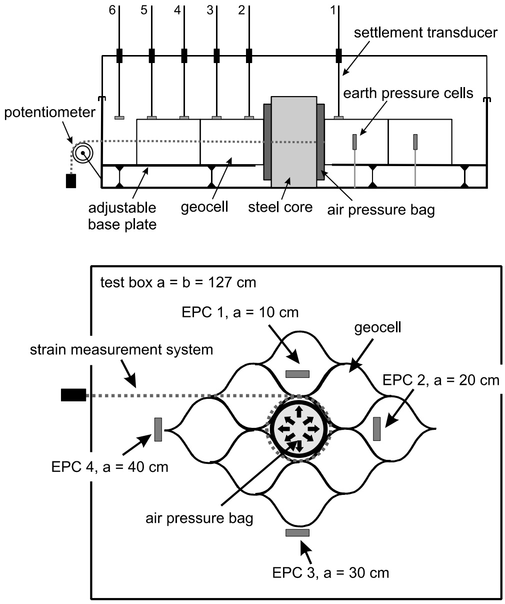

Figure 1. Radial load test device

After installation of earth pressure cells dry sand was poured into the tests box by hand in different layers and compacted by a tamper afterwards. The infill density was controlled by the infill weight of the sand and the volume of the test box. After the test preparation was finished the tests were started. Static tests were carried out deformation controlled until a failure of the tests samples was observed.

3.3 *Test Program*

Five different test series were carried out to evaluate the influence of the number of adjacent cells, opening of junctions, material stiffness, geocell height and cover thickness on the stress-strain behaviour of geocells and the horizontal pressure distribution in the surrounding soil. Each test series was carried out with three different numbers of adjacent geocells (one, nine and twenty-five). Each single test was carried out at least three times to control the reproducibility of the test results. Because of the excellent reproducibility the average values of three test results were taken for further analysis.

4 TEST RESULTS

4.1 *Influence of number of adjacent cells*

Because the restraint of infill material and the earth resistance increases also the horizontal pressure increases with increasing number adjacent cells independent of the geocell type (figure 2). Large scale model tests (Emersleben & Meyer 2008a, 2008b) have shown no further increase of load-settlement behaviour if the number of geocells was increased to more than twenty-five.

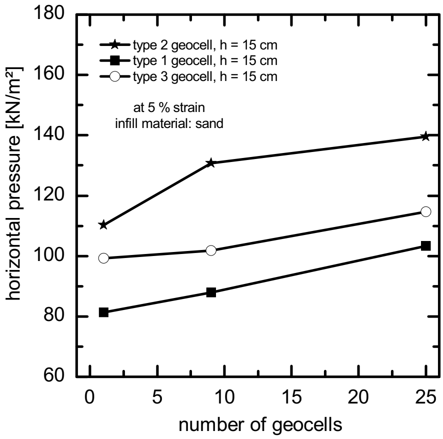

Figure 2. Influence of number of geocells on the horizontal pressure at 5 % percent strain

Because of the increasing soil restraint with increasing number of geocells within the cell walls the measured horizontal pressure within the surrounding soil also increase with increasing number of geocells (figure 3).

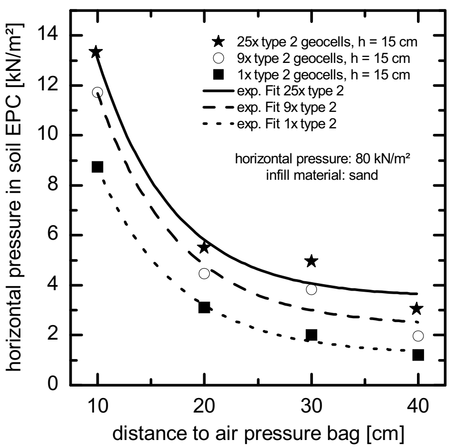

Figure 3. Influence of number of geocells on the horizontal pressure distribution in the surrounding soil at 80 kN/m²

4.2 *Influence of the opening angle of the junctions*

Expanding of geocells during installation at the construction site leads to an opening of the junctions. Index tests have show that the opening angle of the junctions is dependent on the stiffness of the geocell material. With increasing stiffness of the geocell material the opening angle of junction is decreasing.
The opening angle has got a large influence on the stress-strain behaviour of soil confined and unconfined geocells (figure 4). With increasing opening angle smaller horizontal pressure can be applied at the same strain level.

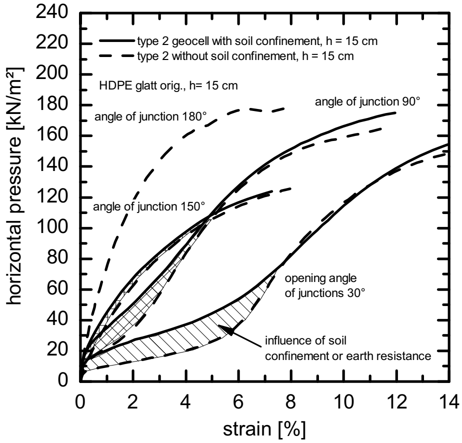

Figure 4. Influence of junction opening angle on the stress-strain behavior

At the same time the influence of the soil confinement/earth resistance is decreasing with increasing opening angle. If a horizontal load is applied and the opening angle is small first of all the junctions are opened. Due to the opening no strains and because of that no hoop stresses are mobilized within the geocell walls. But because of the large deformations large amount of earth resistance is mobilized. With larger opening angles hoop stresses are mobilized within the geocell walls and the applied pressure is completely taken by the geocell material. Only small earth resistance is mobilized within the surrounding soil.

4.3 *Influence of geocell stiffness*

The influence of the material stiffness on the opening angle of the junctions is described above. The material stiffness also has got a large influence on the horizontal pressure. Independent of the number of interconnected geocells the horizontal pressure which can be applied to the system is increasing with increasing geocell stiffness (figure 5).

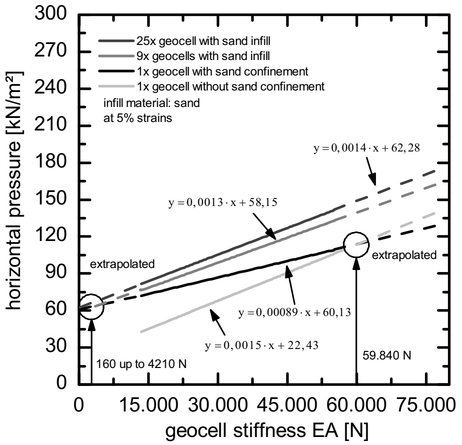

Figure 5. Influence of geocell stiffness on the horizontal pressure at 5 percent strain, linear regression for all tests

The regression analysis of all tests at 5 percent strain has shown that the influence of the soil confinement/earth resistance on the horizontal pressure is decreasing with increasing geocell stiffness. If the geocell material has got stiffness (at 5% strain) of more than 59.840 N the soil confinement of a single cell has no influence on the horizontal pressure. At a calculated stiffness of 223.000 N and 498.000 N nine and twenty-five interconnected geocells have no influence on the horizontal pressure. At these stiffness values the horizontal pressure is taken by the large mobilized hoop stresses within the geocell walls. Because of that the soil confinement/adjacent cells leads to no further increase of horizontal pressure. Same analysis can be done for all strain levels.

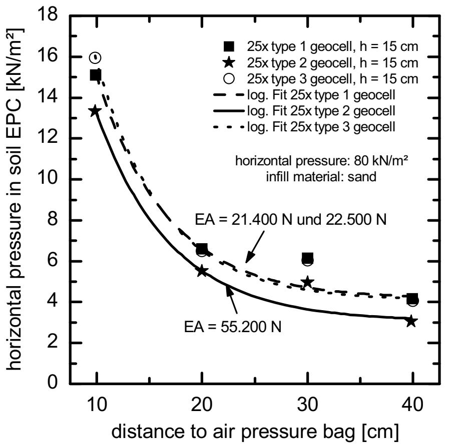

Figure 6. Influence of geocell stiffness on the horizontal pressure distribution in the surrounding soil at horizontal pressure of 80 kN/m²

The horizontal stress distribution in the surrounding soil/geocell system is also influenced by the material stiffness (figure 6). With increasing material stiffness the measured horizontal pressure in different distances to the air pressure bag is decreasing. The stresses are transferred over a larger area in fact of lower material stiffness. Because the geocells with higher material stiffness carry more loads by hoop stresses than geocell with smaller stiffness at the same load or strain level, smaller amount of pressure is transferred into the adjacent cells. Because of that the restraint of the soil within the adjacent cells is higher at a smaller material stiffness.

4.4 *Influence of geocell height and cover thickness*

With increasing geocell height and cover thickness of the adjacent cells the horizontal pressure increase independent of the number of adjacent cells and stains. At the same time the horizontal pressure distribution in the surrounding soil also increases with increasing geocell height and cover thickness because of an increase of the restraint of soil.

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