# Prestressed geosynthetic reinforced soil by compaction

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ABSTRACT: Prestressed reinforced concrete is a state of the art construction method. In this paper prestressed geotextile reinforced soil is presented. It is already known that the building up process of a geogrid reinforced embankment is an important factor of the building's long time performance. Deformations in the soil need to occur to activate tensile forces in the geogrid by soil-grid interaction. The more deformation in the soil and the better interaction between soil and geogrid the higher are the forces in the reinforcement. To avoid high deformations after the building up process of the embankment it is important to activate the tensile forces in the geogrid during the compaction respectively construction process. Prestressing the geogrid reinforcement with the help and as a result of compaction is therefore researched and demonstrated by using a mesoscopic discrete element method (DEM) analysis with the Particle Flow Code in three dimensions. Qualitatively prestressed respectively prestrained reinforcing as a result of compaction is numerically analyzed and validated by a small scale laboratory test. In this paper the method of prestressing the geogrid by compaction is presented and the performance of a specific compaction advice is qualitatively confirmed.

## 1 INTRODUCTION

Since more than forty years reinforced soil is an important engineering tool for geotechnical problems. Since nearly twenty years geosynthetics as reinforcement are used and these materials are further developed.

The idea for taking a step forward and prestressing the reinforcement, generally geogrids, is based on the theory of prestressed concrete. The use for pre-stressing the reinforcement is on the one hand defining a special stress level and on the other hand reducing displacements. Defined stress-conditions can be constituted by constructively prestressing the reinforcement. Therefore several options are possible. For example tensioning the geogrid with the shovel of an excavator leads to a defined stress level in the geogrid (Detert et al 2004).

The current idea at the Institute of Soil Mechanics and Foundation Engineering at Graz University of Technology for prestressing the geotextile reinforcement is compacting the soil-layers filled on the geogrid in a specific way. Therefore it is important to understand the interaction of soil and geogrid during compacting the reinforced soil layer with a compaction roller (Chapter 3).

## 2 COMPACTION ADVICE

A defined prestressing in the geogrid because of compacting the overfilled granular soil layer can be achieved by using the spreading stresses occurring between soil and geogrid. During compaction loads affect on the reinforced soil. These loads lead to deformation of the loosely dumped soil and thereby to a change of the vertical and horizontal stresses.

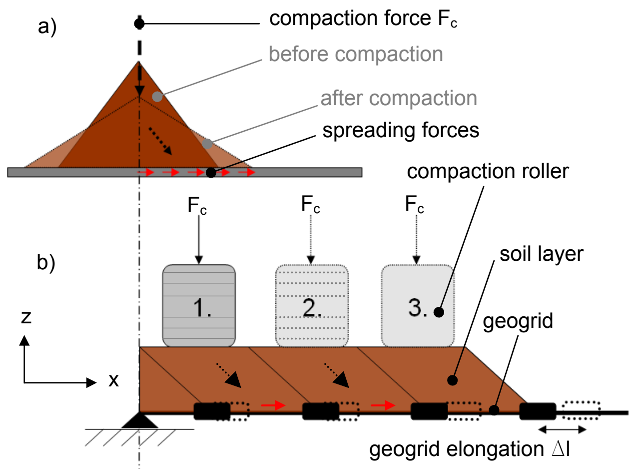


Figure 1. a) Principle to constitute spreading stresses during compaction b) Compaction advice to prestress the geogrid

At the bottom of a soil-layer where the geogrid is applied, spreading forces reach their maximum and because of interaction between soil and reinforcement a tensile force in the geogrid occurs.

Figure 1 shows the schematic behavior of the prestressing as a result of compaction.

## 3 NUMERICAL MODEL

Before dealing with tensile forces in the geogrid due to prestressing by compaction, the understanding for the interactive behavior between the reinforcing geogrid and the surrounding soil has to be approved.

Therefore a numerical model is applied to show the soil-geogrid interaction. For this mesoscopic scale problem a three dimensional discrete element analysis (DEM) with the Particle Flow Code (Itasca Consulting Group 2005) is performed. The model is generated by spherical discrete elements so called particles which move independently of one another and interact at contacts of the particles.

The system's mechanical behavior is described by the movement of each particle. Newton's law of motion provides the fundamental relationship between particle motion and forces causing motion. $F_j$ is the resultant force, $m_j$ the particle's mass and $g_j$ is the body force acceleration vector.

$$F_j = m_j \cdot (\ddot{x}_j - g_j) \tag{1}$$

The rotational motion can be defined with (2) where the $M_j$ is the resultant moment acting on a particle, $I_j$ the moment of inertia of the particle, $\omega_j$ is the angular acceleration and $R_j$ is the particle's radius.

$$M_j = I_j \cdot \dot{\omega}_j = \left(\frac{2}{5} \cdot m_j \cdot R_j^2\right) \cdot \dot{\omega}_j \tag{2}$$

The numerical model simulates a test where a geogrid is laid on a stiff plane layer and covered with a layer of soil. To demonstrate the system's behavior a biaxial geogrid 2.0 m * 1.0 m is generated with discrete elements.

The radius of the geogrid-particles is 0.5 cm. The soil is also generated with particles. The radius of the soil-particles amounts 2.0 cm. Figure 2 shows the discrete generated model with the three dimensional Particle Flow Code.

In a first step a box to define the model's boundaries is created. Inside this created box the geogrid modeled with particles is laid. The next step includes covering 30 cm of the geogrid in x-direction and 1.0 m in y-direction with soil-particles (Figure 2). The height of the soil layer amounts related to a defined porosity of the soil approximately 35 cm. Subsequently the Particle Flow Code calculates all the particles in equilibrium. After reached equilibrium the compaction roller - modeled as a cylinder - rolls over the in filled granular soil particles. The cylinder moves with a continuous velocity in y direction and a defined spin around the x-axes. The z-position of the compaction roller is related to the in advance defined compaction ratio and is calibrated and controlled on the basis of the soil's porosity after compaction. The soil's porosity is calculated and recalibrated by three Particle Flow Code intern called measure balls.

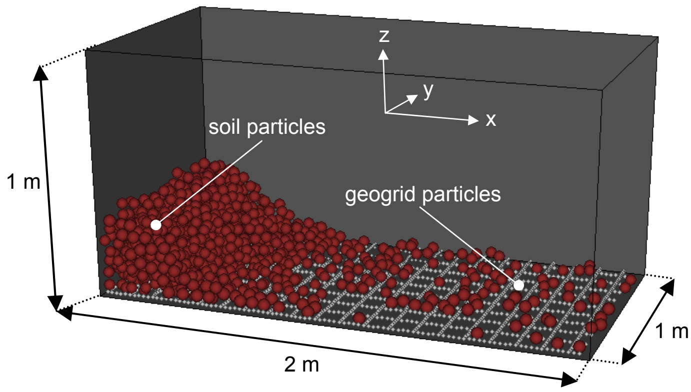


Figure 2. Generated model with the Particle Flow Code.

The material parameters of geogrid and soil differ from the input set of an finite element analysis. The Particle Flow Code is based on microscopic parameters. Normal- and shear contact stiffness, $k_n$ and $k_s$, are used to model the rigidity-properties of the material. The normal- and shear contact forces are covert by using so called bonds. Parallel bonds with a defined bonding radius are used to model a defined bending capability of a material. The normal and shear contact forces can be expressed as:

$$\begin{aligned} F_n &= k_n U_n \\ \Delta F_s &= -k_s \Delta U_s \end{aligned} \tag{3}$$

In (3) the value of $U_n$ is the relative normal displacement of two separate elements. $\Delta U_s$ is the increment of the relative shear displacement between two particles.

To define the microscopic parameters of the modeled materials several calibration calculations need to be done. For a qualitatively demonstration of the interactive behavior of soil and reinforcement previous researches related to geosynthetics and to granular assemblies were adducted to calibrate the model and to run the simulation (Cundall et al 1979). In future research work a detailed calibration of each material and the combined system will be performed. Therefore in-situ tests with specific geogrids, granular soils and a defined compaction roller are possibilities to calibrate respectively verify the results out of the discrete element analysis.

By modeling the sequence of compaction a detailed insight in the interactive behavior of the geogrid and the overfilled soil can be gained and the general behavior, described in Figure 3, can be confirmed. This general understanding helps to develop the concept of prestressing the reinforcement as a result of compaction.

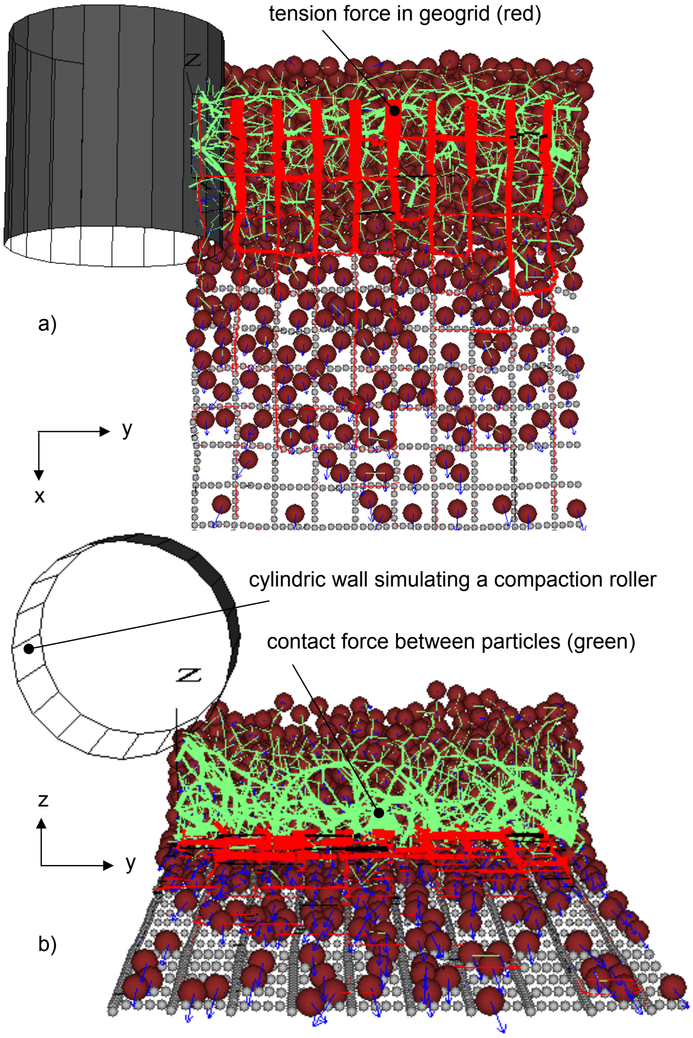


Figure 3. Discrete model of granular soil, geogrid and compaction roller (the thickness of the red lines represents the tensile force in the geogrid string. a) Topview b) Frontview

The results of the DEM analysis show that the interaction between soil and geogrid can be defined as a composition between friction- and interlocking effects.

On the one hand the soil's spreading stresses occurring during compaction can be transferred into the grid by friction between surrounding soil and geogrid. An important factor for this interaction is the soil particle's surface roughness and the surface roughness of the geogrid.

On the other hand an interlocking effect between the geogrid and the granular soil particles does occur. Depending on the soil's grain size and the mesh size of the geogrid these interlocking effects differ.

With the help of the described simulation parameter studies referring to the grain size and mesh distance respectively surface roughnesses of the geogrid can be performed to quantitatively describe these effects.

For granular materials such as gravel it is furthermore interesting how the grain's shapes influence the interaction effects between geogrid and soil.

Recently those shape effects can be numerically simulated by clumping spherical particles together. So called computer aided designed clumps are produced. At the moment the described discrete numerical simulation is running with different shaped clumps to check the influence on the interaction effects.

Meanwhile it seams like the more interlocking between the clumps occurs the more resistant the granular material itself is. That furthermore means that till to a specific stress level the geogrid hardly takes any resistant work.

The compaction force for an ideal prestressing by compaction is influenced by the granular material's shape and its soil-grid interaction effects.

## 4 SMALL SCALE LAB TEST

In order to qualitatively validate the system of prestressed geogrid reinforced soil a small scale lab test was performed. Because of the small scale test stresses that would have occurred in situ could not be applied. Therefore a usual geogrid for insitu projects could not be used.

Many materials such as a plastergrid, a bird-protection grid or a carpet underlay had been evaluated (Figure 4). The best results in pretests were performed with a coarse carpet underlay that is shown in figure 4d.

After the pretest for validating the materials compaction following the concept described in Chapter 2 was performed. Layer by layer, loose sand was filled on top of the geogrid that was fixed at one end of the glass box (Figure 5). After one sand layer had been dumped it got compacted with a specific static load.

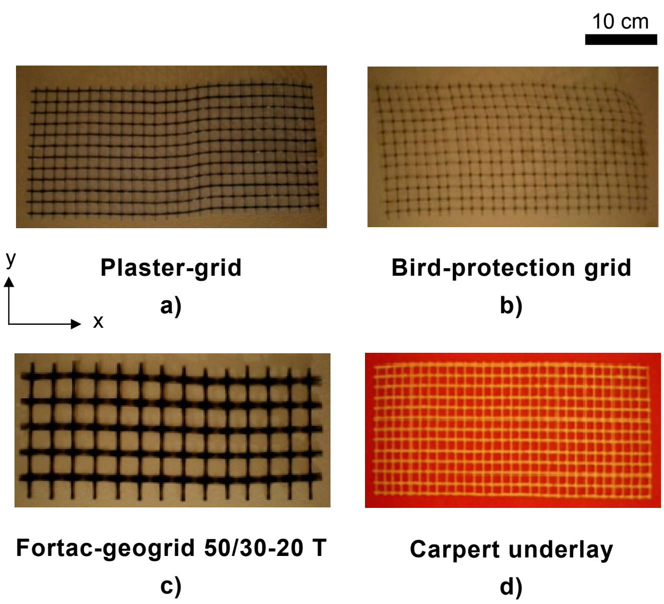


Figure 4. Soft material validation for small scale labtest.

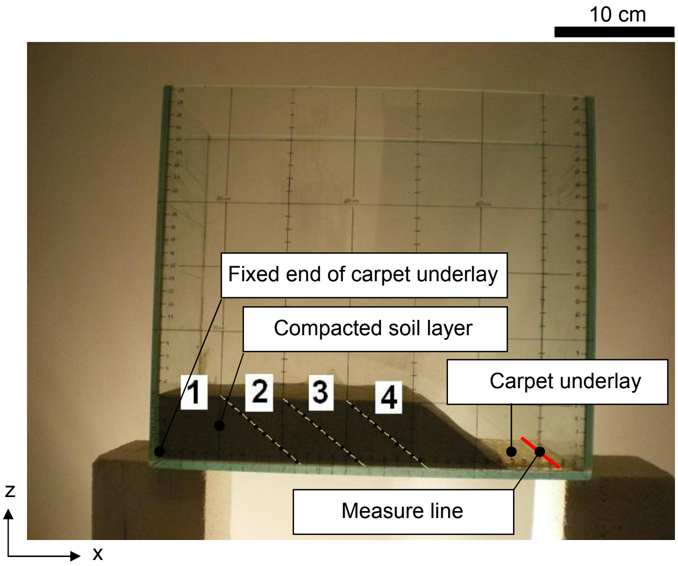


Figure 5. Frontview of the small scale prestressing test during filling and compaction process

In order to measure the prestressing in the grid during the compaction process a measure line at the end of the glass box was drawn. The grid's elongation could be metered visually (figure 6) and plotted in a compaction – elongation curve (figure 7).

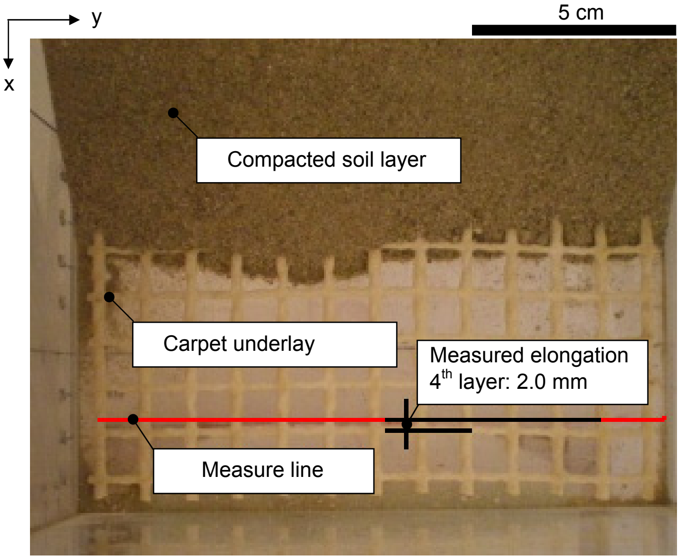


Figure 6. Topview of the small scale prestressing test after filling and compaction to measure the grids elongation

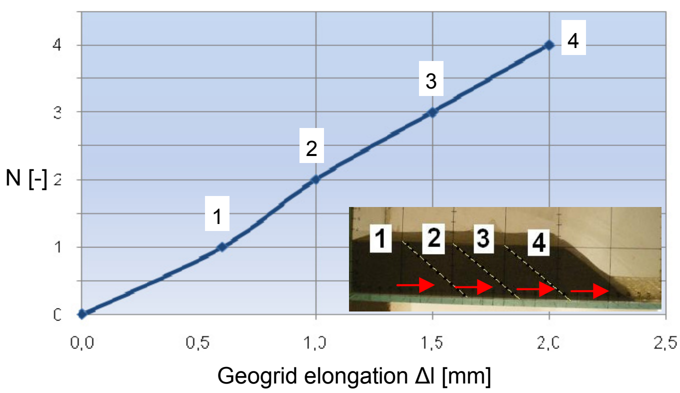


Figure 7. Geogrids elongation after filling and compacting with the compaction advice (Chapter 2)

## 5 CONCLUSIONS

In this paper a short overview on prestressed reinforced soil was given. Prestressing the geogrid as a result of compaction was presented.

A numerical simulation was presented where prestressing in the geogrid had been implemented as a result of compaction an overfilled soil layer on the reinforcement. Therefore a three dimensional discrete element analysis (DEM) with the Particle Flow Code was performed to generally understand the interactive behavior between the reinforcing geogrid and the surrounding soil.

Furthermore a qualitatively confirmation of the system's function had been given by performing a small scale lab test. The test was carried out by using different geogrid alternatives such as a carpet underlay. Qualitatively the information won out of the discrete numerical simulation was confirmed by the small scale test's results.

## 6 OUTLOOK

In order to quantitatively confirm the compaction advice of Chapter 2 more calibration work for the numerical simulation has to be done. Therefore a large scale lab test will be performed to show the positive effects of prestressing the geogrid during compaction to minimize deformation after the building up process.

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