GEOGRID WRAPPED VIBRO STONE COLUMNS

U. Trunk
Keller Grundbau GmbH, Bereich Nord, Germendorf, Germany

G. Heerten
Naue Fasertechnik GmbH & Co. KG, Lübbecke, Germany

A. Paul
Hochschule Anhalt, Anhalt University, Dessau, Germany

E. Reuter
iwb Ingenieurgesellschaft mbH, Braunschweig, Germany

ABSTRACT: Incompatible, harmful or unacceptable large deformations and settlements can occur in the case where foundations of buildings are constructed on cohesive or organic soils with high levels of deformability. In order to limit the settlements to a permissible degree, methods exist for building ground improvement, aside from placing the foundation on rigid elements. In the case of the geogrid columns presented here, the geogrid column is inserted with the bottom feed vibrator into the low load-bearing ground and the suitable and necessary soil, mineral material or concrete is inserted and compacted in a controlled way. In laboratory experiments, the load-strain and support characteristic behavior of geogrid ground columns was examined under static and dynamic loads. The system indicates low lateral strains and high load-bearing capacities. Material, cohesion and insertion technologies were tested and optimized in field trials. The lateral strains with load application were low. This means that economical and high capacity foundation elements and ground improvement elements can be constructed in case of low, undrained shear resistance of the existing ground.

1 INTRODUCTION

If buildings (building construction, engineering or excavation works) are placed on cohesive or organic soils with high levels of deformability, without additional measures, incompatible, harmful or unacceptable large deformations and settlements may occur, assuming sufficient load-bearing capacity and ground-failure security. In order to limit the settlements to within acceptable parameters, methods for ground improvement are available, as well as the foundation on rigid elements.

A large number of techniques are available as ground improvements, with which the load-bearing capacity of the underground subsoil can be increased and the deformability reduced. In the past decades, column-like, ground improvement and foundation elements have been increasingly designed and built for this purpose, which are inserted in raster layouts into the ground. Vibro stone columns, ready-mix mortar stone columns or vibro concrete columns as pile-type support sections, reinforced cast-in-place concrete piles, geotextile coated sand columns, as well as geogrid-wrapped mineral-material or soil columns are used in this application. Geogrid- wrapped mineral-material or soil columns are presented in the following text in more detail.

The ground improvement or foundation process, which is optimal for the respective building, results from technical and economical aspects.

All column-like ground improvement and foundation elements indicate a higher level of stiffness with respect to the surrounding ground than the surrounding low-load-bearing ground. In the case of ground improvement elements, the loads are taken up by the ground and improvement elements.

The geogrid- wrapped mineral-material or soil columns to be presented here indicate in weak soils or ground a higher level of stiffness with respect to non-wrapped columns, as well as smaller lateral strains due to load application. The stiffness of the columns lies between that of pure vibro stone columns and pile-like support sections such as ready-mix mortar stone columns.

The geogrid-wrapping mineral-material columns consist of a combination of outside or covering geogrid reinforcement and the applied and compacted mineral materials, such as sand, gravel or ballast. In many cases of application these mineral-material columns offer a series of technical and economic advantages.

2 PRODUCTION TECHNOLOGY AND PRODUCTTION PROPERTIES OF THE GEOGRID

For the column manufacture, Secugrid R geogrid or a composite from Secugrid R geogrid and a mechanically bonded nonwoven material are used. In the case geogrids manufactured from extruded, stretched, monolithic and structured flat bars with welded junctions are used. They form rectangular grid openings with different tensile strengths in the longitudinal and transverse directions.

In an initial production step, polyester granulate is melted and manufactured into flat bars (strength according to requirement). After the extrusion, the flat bars are stretched by application of a stretching mechanism up to the optimal extension limit. In a further work operation, the stretched flat bars are laid over each other in a special cross-shaped system and welded at the junctions, so that surface-stable and fixed-node geogrids result.

For applications where a separating and/or filtering-material is additionally necessary, a Combigrid® geogrid is recommended. R-Products are also involved here, combined with a mechanically bonded nonwoven, inserted between the flat bars, before the welding process. After the welding, a surface compound results of flat bars with the nonwoven at every junction. Secugrid® and Combigrid® geogrids are characterized by outstanding stress-strain behavior in the utilization load area, with up to 2% strain.

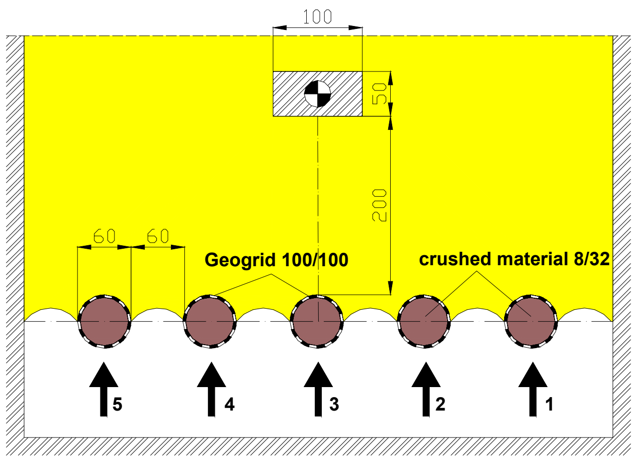
In a second work operation, these geogrids are fabricated and connected to reinforcement columns with the required diameter. The special advantage of these elements consists in their not being subject to any construction strain, so that a direct force transfer is ensured. The main tensile forces are thus applied in the column grid without activation strain.

3 SUITABILITY TESTS IN THE LABORATORY

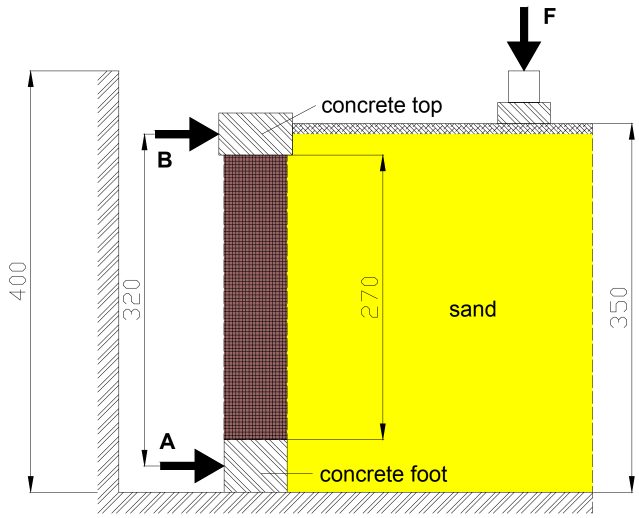
3.1 *Orientation tests*

3.1.1 *Experimental setup*

A test program was prepared in the year 2002 in cooperation with the Gropius Institute of the Anhalt University, Dessau, their specialist field being geotechnics. The objektive being the testing of the product properties of mineral-material columns wrapped with Secugrid geogrids in which the extensive positive experiences of the Gropius Institute from numerous Secugrid geogrid tests were applied for temporary earth sinking protection [PAUL, 2002; SCHWERDT, 2003]. In an initial experimental phase, orientation tests were carried out for the general support characteristic of differently filled Secugrid mineral-material columns.



Plan layout of test equipment



Cross section of test equipment

Figure 1 Full-scale field trial by Stuttgart University [SMOLTCYK, 1999]

Although SMOLTCZYK [1986, 1999] reported more than 15 years ago about the positive properties of mineral-material columns, reinforced with stiff geogrids, such a system had not been the subject of corresponding basic principle tests. In this case, it could be verified even then with few loading tests (see Figure 1), that the combination of a stiff "geosynthetic reinforcement column" with pressure-stable, low-deformation, mineral-filler material, for the take-up and distribution of stresses from bending moments and lateral forces through e.g. sloping, layered building ground or through flow pressure in the case of soft soil layers, is better suited than woven-structure-wrapped sand columns, which indicate a different support characteristic with these stresses. In the case of the latter, relatively large lateral strains are necessary for the activation of the ring-tensile forces, which can have as a consequence relatively large settlements of the overall system [SCHUESSLER, 2002].

In an initial experimental phase, static loading experiments were carried out in a full-scale field-trial pit of the Anhalt University,Dessau on freestanding columns, 1.88 m high, 0,6 m diameter and filled with different mineral materials. A gravel sand of grain size 0/8 mm and a crushed stone ballast mixture 0/32 mm were employed. In accordance with DIN 4022, a closely-graded, fine-gravel, weak middle-sized-core gravel natural sand was used (Soil group SE in accordance with DIN 18196) and a quartz-porphyry crushed, rough-sand, fine to middle-core-size sandy gravel (Soil group GI in accordance with DIN 18196). A product of the strength class 40/200 R6 with 200 kN ring-tensile, short-term strength was selected as geogrid.

The column-shaped reinforcement column was initially set up on a square backplate of steel, with edge lengths 1.35 m and a thickness of 2 cm. This plate formed a defined support surface. Under this was located cohesive soil of stiff consistence (Figure 2).

On the top of the Secugrid columns (Figure 3), a circular steel loading plate (d = 0.6 m) was installed. The loading was applied only statically, in loading stages, with a servo-hydraulic loading equipment, having a maximum load of 400 kN.

The Secugrid columns were equipped with pressure pads at different heights for the take-up of the vertical stresses within the columns. Steel measuring tapes for the recording of the ring-tensile strains were used and a great number of measuring marks on the external body surface, for the determination of the vertical displacements of the system under load.

Figure 2 Grid column without mineral-material filling on the back plate

Figure 3 Head area of the geogrid- wrapped mineral-material column

In total, four Secugrid mineral-material columns were tested in this experimental phase. In the case of one of the sand-filled and gravel-filled columns, the sand gravel material was not compacted. In the case of other columns, the installed soil was compacted in layers with a concrete vibrator with water addition.

Figure 4 Secugrid-wrapped ballast column at the beginning of the rial

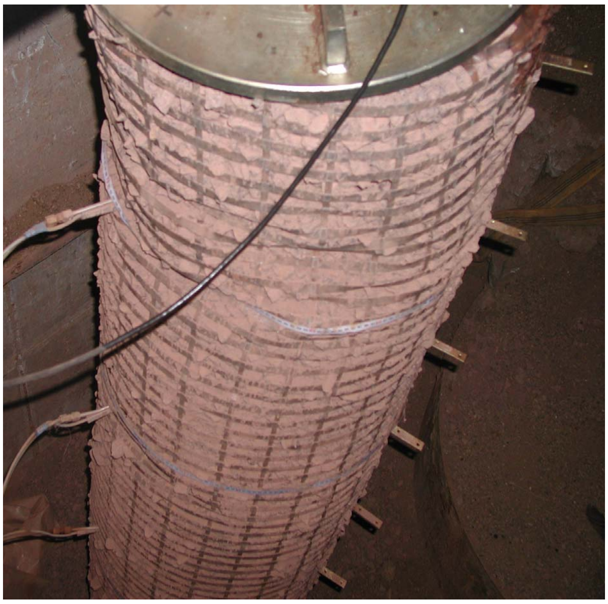


Figure 5 Secugrid-wrapped ballast column at the end of the trial (Buckling after overload)

In order to prevent a filtering out of the filler material in the case of the sand columns, Secutex fibrous-web material was inserted placed on the inside. In the case of the brokencrushed-stone ballast columns, this was initially not necessary because of the very good intermeshinglocking between the geogrid and filler material.

The degrees of compaction were checked before and after loading. The entire test procedure was observed photographically. Figure 4 and 5 give an overview of the test procedure.

3.1.2 *Experimental results*

The orientation tests resulted in the following classification with regard to the support characteristic behavior.

Uncompacted gravel sand column (F_{max} = 50 kN) < uncompacted crushed-stone ballast column (F_{max} = 150 kN) < compacted gravel sand column (F_{max} = 250 kN) < compacted crushed-stone ballast column (F_{max} = 400 kN; here capacity loading of the loading equipment reached). Figure 6 gives a summary overview of the load-strain characteristic behavior of all Secugrid ground columns of the first experimental phase.

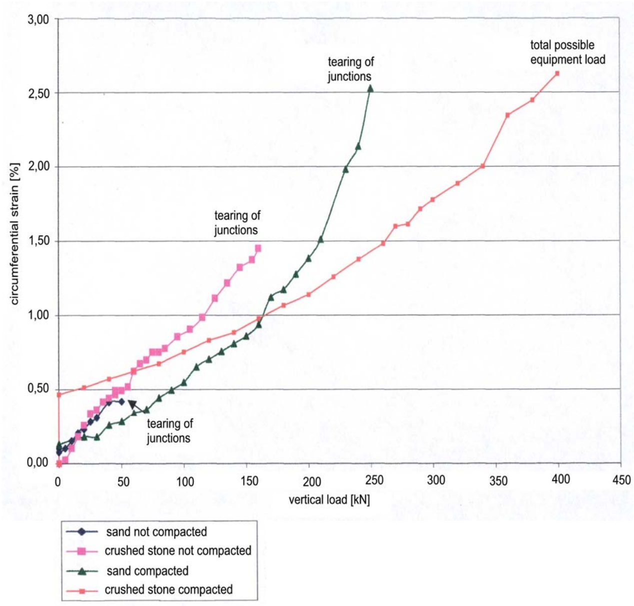


Figure 6 Increase of the circumferential strains of 4 Secugrid-wrapped, mineral-material columns as a function of the vertical loading

The orientation tests indicated that Secugrid-wrapped, mineral-material columns have generally a high load-bearing capacity for vertical loads with a high level of inherent stability and shape retention, and can transfer it to subsoil layers with sufficient load-bearing capacity without damage. The supporting effect of the lateral soil was not taken into consideration or modeled with the tests.

3.2 *Detailed tests*

3.2.1 *Testing procedure*

After the positive results of the orientation tests, further detailed tests were carried out at the Gropius Institute of the Anhalt University, Dessau under changed test conditions. Further manufactured columns were tested, analogous to the orientation test under stationary and non-stationary / dynamic loading. The support characteristic of 3 m high Secugrid freestandig columns was tested, likewise free-standing, which were filled with the compacted broken-stone ballast mixture these having proved to be the best load-bearing characteristic with the initial test phase. The crushed-stone ballast mixture was compacted with a concrete vibrator, as in the first series of experiments.

3.2.2 *Experimental results [PAUL et al., 2003]*

In the first test, a static load was applied in stages of 50 kN, which was held constant for up to 7 days, in order to be able to also assess load time characteristic. The maximum load under these conditions was approx. 350 kN, this corresponding to a vertical stress of approx. 1250 kN/m^2. The strains occurring in this case in the horizontal grid-elements were only a maximum of approx. 2%. A significant tendency of the system to creep could not be observed in any loading stage. The load-bearing capacity was exceeded during the last load increase with a vertical load of approx. 400 kN, a vertical stress of 1400 kN/m^2 (Figure 7). The values for the Young's modulus of elasticity of the different columns under stationary constant load – without supporting lateral ground - could be derived from the measured strains in a range from 30 to 80 MPa, with regard to the different loading stages for this support system.

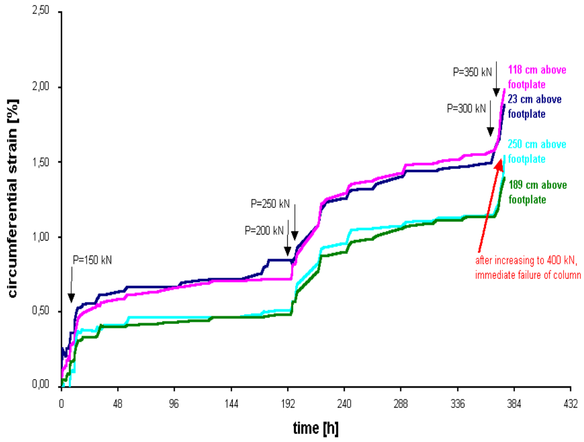


Figure 7 Circumferential strains of the geogrid in the case of the pressure test with static loading results

A further Secugrid ground column was subjected to a vertical load (F_{max} = 100 kN according to SLW 60, frequency 1 Hz), increasing and decreasing in sinusoidal form, for the simulation of truck loads. During the entire test procedure, the column indicated no deformations or deformation increases indicating a failure. No damage was observed. The test was ended after 2 million load cycles. This corresponds to approx. two years of traffic loading on a well-used expressway. The maximum ring-tensile strains had a value of approx. 0.5% and were achieved after approx. 1 million load cycles. After this strains remained constant (Figure 8). The Young's modulus of elasticity was in the same range as above mentioned.

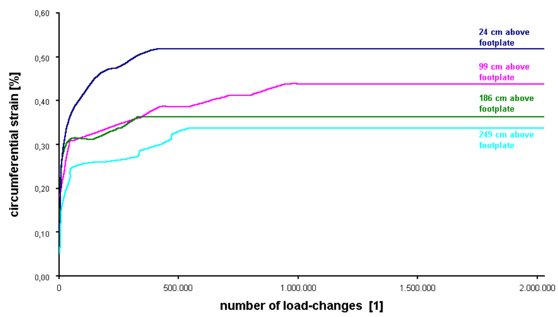


Figure 8 Circumferential strains of the geogrid with the dynamic pressure test (F_{max} = 100 kN, 1 Hz frequency)

Further loading tests are performed with dynamic and, in part also alternating vertical loads acting eccentrically. These indicated that Secugrid-wrapped ballast columns are also capable, under these conditions, of carrying high vertical stresses and of transferring these into soil layers with sufficient load-bearing capacity. However, these tests could not be carried out as planned to higher load levels, due to the non-existing lateral support at the top of the columns, as would be the case in situ. Insufficient position stability of the columns on the back plate was provided and due to this there resulted a lateral deformation and rotation, with subsequent buckling of the columns. This effect would however not take place in the practical case of application.

4 FIELD TRIALS

Within the framework of several field trials, the installation of the geogrid column with the bottom feed vibrator and the required developments for the bottom feed vibrator resulting from this, the foot formation and foot construction of the reinforcement column, the diameter of the reinforcement column and the production procedure were optimized.

The installation of the geogrid column was performed with a bottom feed vibrator, which was mounted on a Keller vibrocat.

In the first step, different foot formations and foot constructions for the geogrid column were used. Here, it had to be ensured that the foot construction provided a secure penetration through the soil layers without damages for the installation of the reinforcement column and the filling and compaction of the material. Of particular interest was finding an economical design which ensures a versatile application on the construction site and which also offers sufficient protection while penetrating through more-solid soil layers above the weak ground layer to be improved and, where necessary, existing obstacles in the underground, such as wood or root residue.

Furthermore, different column diameters were examined with regard to the installation into the ground without any damages resulting, where appropriate, and the secure and shape-stable plugging of the columns with pulling up the bottom feed vibrator.

Special attention was directed towards penetrating through potential existing solid layers above the weak ground layer, to be improved. Particularly in the case of low-load-bearing weak ground layers, it had to be considered the implementation of the future structure (here in particular excavation works), a working level is required. Otherwise the foundation works, which are necessary for the establishment of the structure, could not traverse the weak ground layer without ground failure and large deformations. Unlike the above test in the laboratory, it can be assumed that a normally 0,30 m to 0,80 m thick and load-bearing layer generally holds the columns in the head range laterally.

In order to be able to determine any possible damage through the installation and the plugging of the column, columns were exposed and the status of the reinforcement column and the degree of compaction of the installed material, were checked.

An advantage of the technique presented here being is that the filler material can be installed in the reinforcement column with a high degree of density, so that further settlements and deformations with load application are much smaller compared to other systems. It is necessary, on the one hand, to check and to retain the material quantity during the installation, while, on the other hand, to select the contact pressure and the length of stroke during the compaction process, in order to be sure to avoid an overloading of the reinforcement, which would have as a consequence the splitting of the reinforcement column.

The experimental data indicate that a splitting of the reinforcement column through the plugging is highly unlikely due to the strength properties of the reinforcement products employed.

5 PROJECT VILLA BORSIG IN BERLIN

On instruction from the Ministery of Foreign Affairs, a training center at the Tegeler See Lake will be extended for the Ministery of Foreign Affairs. Due to existing organic layers and weak ground layers, foundation elements and ground improvement elements are to be implemented to a depth of 13 m.

Concrete stone columns are used here as foundation elements. These will be provided with a Combigrid, geogridcolumn, in order to prevent, with sufficient lateral support, an uncontrolled leakage of the concrete into the soft underground.

The geogrid column does not have any further function after curing of the column, so the only consideration is the short-term strength and short-term compatibility of the geogrid column with the introduced concrete and the surrounding ground.

The long-term compatibility against concrete and water is not a requirement, although this would not represent any obstacle to the implementation feasibility.

6 SUMMARY

The combination of a geogrid as reinforcing covering and a compacted column of soil, mineral materials or concrete, constructed using a bottom feed vibrator, opens new and further possible applications for the employment of ground improvement and foundation elements for the foundation of building construction, engineering or excavation works on low load-bearing ground with a high level of deformability.

In laboratory experiments, the load-strain and support characteristic behavior of geogrid mineral material or soil columns was examined under static and dynamic loads, without lateral support through the surrounding ground or its modeling. The system indicates low lateral strains and high load-bearing capacities. Deformability and load-bearing capacity of the individual elements lie between those of vibro stone columns and vibro concrete columns.

Material, foot constructions and insertion technologies, as well as the dimensions of the geogrid columns, were tested and optimized in situ with the in-depth concrete vibrator in field trials. The geogrid column is installed with the inside-located bottom feed vibrator and the soil, mineral material or concrete inserted and compacted in a controlled way. The lateral strains with load application are small and have values under 2% with soil or mineral materials.

In case of low, undrained shear resistance soils of the existing ground the geogrid columns presented here offer an interesting variant to existing techniques for foundation elements with high load-bearing capacities and ground improvement methods.

7 REFERENCE

PAUL, A.: Die präventive Sicherung von erdfall- und tagesbruchgefährdeten Straßen mittels einlagig verlegter Geokunststoffbewehrung. 27. Baugrundtagung in Mainz, 2002. Proceedings, Ed.: DGGT, Essen

SCHWERDT, S: Die Überbrückung von Erdeinbrüchen unter Verwendung von einlagig verlegten Geogittern – Vergleich zwischen Versuchsergebnissen und den Ergebnissen von analytischen und numerischen Berechnungen. Geotechnik, No. 2, 2003, S. 95-105

SCHUESSLER, M: Anwendungen neuer, innovativer Gründungslösungen – Ist das Risiko für den Auftraggeber überschaubar? 27. Baugrundtagung in Mainz, 2002. Proceedings, Ed.: DGGT, Essen

SMOLTCZYK, U: Zur Bewehrung des Bodens mit Geotextilien und Drahtgeweben. Proc. 14. Geotechnische Konferenz in Brünn (CSSR), 1986, p. 118-125

SMOLTCZYK, U: Geogitter schafft biegesteife Schottersäulen. Bauen mit Textilien. 1999, No. 1, p. 30-35

PAUL, A., SCHWERDT, S: Untersuchungen zum Tragverhalten vertikaler Gründungselemente aus gelegten Geogittern – Perspektiven für neue Anwendungsmöglichkeiten im Tiefbau. Vortrag/Proc. Informationsveranstaltung der NAUE Fasertechnik GmbH in Adorf, 24.1.2003