Execution and field measurements of a 12 m high reinforced and lime stabilized noise protection wall

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Keywords: Monitoring, Geogrids, Earth Pressure, Facing Systems

ABSTRACT: In the course of site development measures an approximately 12 m high and 350 m long noise protection wall with a 6 m thick filling is installed at an existing slope. A construction with the use of in-situ cohesive soils, a treatment by adding mixed binders and geogrids in connection with a steel grid facing element was chosen. The steel grid elements are connected to the geogrid via frictional interaction. The basic approach of the earth pressure corresponds to the revision of the EBGEO 2009 as reduced active earth pressure. The construction is accompanied by an extensive monitoring program. The available test results achieved for the front area of the construction show very low deformations of the facing, low earth pressures and a very low rate of stress of the geogrids as well as of the steel grid elements.

1 INTRODUCTION

These days geosynthetic reinforced soil structures belong to the most economically attractive construction methods due to their flexibility and versatility. Also under the ecological point of view, as e. g. CO_2 reduction, further positive impulses for this type of application can be expected in future. DIN 1054:2005, DIN EN 14475 as well as the revision of EBGEO 2009 are corresponding state-of-the-art standards in order to safeguard the constructions.

In the case of this presented construction, design and verification elements of the revised EBGEO have already been implemented.

2 PROJECT

2.1 *Survey*

In the course of development measures for a residential area the installation of a noise protection wall is planned. This construction consists of an earth wall and a piled noise barrier on top of the construction. As a result of its hillside situation (see fig. 3) the total height of the construction is partly more than 18 m with an inclination of the facing of 70°. Ilchmann et al. (2009) already reported on this design (fig. 1) and the construction of this project.

2.2 *Building material*

During the profiling of the construction site of the residential area soil has been excavated in a significant amount. This should be used as building material for the earth wall. This building material mainly consists of loess, loess clay, residual clay and cohesive fluvial soils, i.e. cohesive soils with differentially high sand contents.

The in-situ soil on the construction area was mixed with binders (lime-cement-stabilization) on site, transported to the installation location and installed by compacting layers (fig. 2).

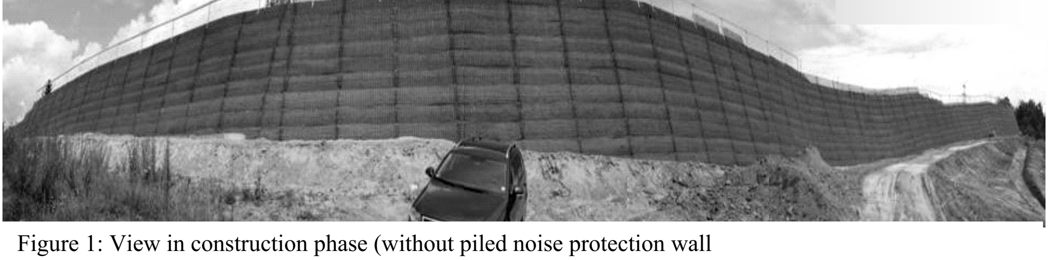

Figure 1: View in construction phase (without piled noise protection wall

The required shear parameters ($\varphi \geq 27{,}5°$ and $c \geq 10$ kN/m²) have been achieved and verified by shear box tests. Also the required compaction, especially in front of the system, has been observed carefully.

The facing of the geosynthetic reinforced soil structure consists of welded, specially aluminium galvanized steel wire grid mats (rectangular, 100mm x 100mm). A corresponding erosion control mat made of a synthetic monofilament is used in front of the elements.

Geogrids with a high extensional stiffness are used as reinforcing elements. For economic reasons and to improve the reliability of the construction (danger of confusion in the case of a similar visual appearance of the product) only two geogrid types, in this case Secugrid® 200/40 R6 and Secugrid® 40/40 Q6, are installed. The design strength according to EBGEO, taking creep, installation damage, pH = 12.5 and an partial factor of safety for material of 1.4 into consideration, is given to 87,3 kN/m resp. 17.5 kN/m².

The connection between front elements and geogrids is carried out - corresponding to the static verification - only via friction.

Figure 2. Construction Site

3 GEOTECHNICAL VERIFICATION

3.1 *Complete System*

The proofs are given in analogy to Eurocode 7 according to DIN 1054:2005-01and EBGEO using the partial safety factor concept. The verification of the stability of the geosynthetic reinforced soil structure is carried out - simplified shown - in three steps:

- proof of reinforced soil structure
  - internal proof (two part wedge failure mechanism, circular slip circles)
  - external proofs (sliding, lateral buckling, base failure)
- proof of ground failures of the complete system (wall and fill)
  - slice method according to Bishop, where the circular slip circles can cut parts of the geosynthetic reinforced soil structure
- proof of earth pressure on facing

3.2 *Steel grid facing*

The earth pressure affecting the facing has been reduced according to Pachomow et al. (2007). Therefore the dimensions of the steel grid elements could have been reduced and the connection geogrid/front element has been carried out as to friction. The comparing earth pressure measurements (see following information) show that the calculation approaches of the earth pressure have been on the safe side. In the meantime this process has been included into the dimensioning recommendations of the EBGEO.

3.3 *Serviceability*

In the run-up the ground expert has forecasted settlements. Following this forecast the settlements in the subsoil were supposed to occur in a range of 30 cm. In the soil body of the geosynthetic reinforced soil structure itself the settlements might be up to approximately 1 cm for each layer. Thus, during the construction it was planned to carry out settlement and deformation measurements in order to confirm the forecasts and to be able to adjust them, if necessary.

4 CONSTRUCTION WORK

Before installation of the geogrids an accurate formation level had to be prepared for the front elements in the front area. Afterwards the geogrids were installed up to the leading edge of the front elements, whereupon the layers were cut by using an angle grinder.

During an effective construction time of approximately 2 months the company Nacken Landschaftsbau with their average staff of 7 workers installed or moved, respectively, approximately 25000 m³ of prepared soils resulting from the construction site, 25000 m² geogrid, 4000 m² steel grid front elements as well as 300 m³ of gabions with a long arm excavator and a wheel-type loader. The compaction was carried out in three-steps with a tamper in the front area between the bars of the steel grid elements, vibrating plate up to approximately 1 m distance to the front and the single drum vibrating roller.

5 MONITORING

5.1 *Purpose*

For the dimensioning of reinforced soil bodies, which can be regarded as compound system due to their small layer distances, the question must be raised how to determine the earth pressure on the facing. Evaluations of literature and comparative calculations of Pachomow et al. (2007) clearly show - depending on the flexibility of the front elements - a reduced horizontal strength - compared to the active soil pressure - at the front side of a reinforced soil construction. Due to this fact the active earth pressure can - resulting from the compound effect of the reinforced soil structure - be reduced by 30% in the case of facing systems which are restrictedly deformable according to DIN EN14475:2006.

For cohesive soils with continuously increasing shear strengths only few experiences are available. As for the use of inferior construction materials which require the use of binders another increase can be expected as to the economic point of view, and additional validation of the above mentioned design approaches is required. Moreover a structurally engineered and complex constructive connection of the facing elements with the geogrids can be omitted under consideration of the reduced horizontal strengths.

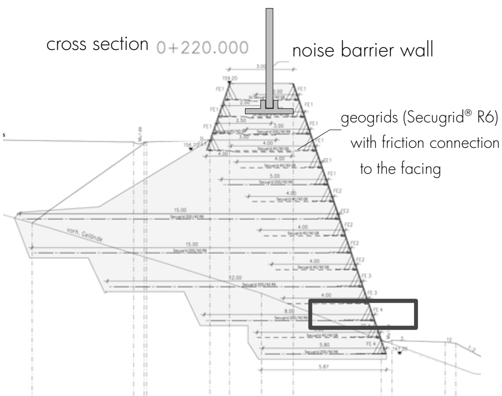

Figure 3. Typical cross-section and area of instrumentation

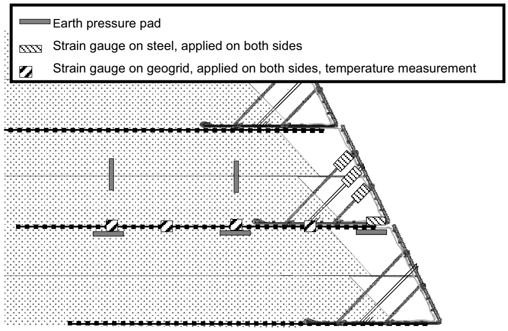

Figure 4. Instrumentation of the measuring cross-section

Thus, the instrumentation focuses upon the front area of the construction. It is the aim to determine the dynamics at a facing element and the subsequent reinforcement layer depending on the construction progress and the time-dependant development of the shear behavior of the soils.

5.2 *Measurement concept*

The measurement concept which has been established by allows a determination of the horizontal strengths affecting the facing by means of an instrumentation of the steel grid element. For the strains measured at the geogrid the influence of the thermoplastic properties (curing process with corresponding heat development, creeping, relaxation) remains partly undetermined and must be completed in the following by means of corresponding laboratory test results.

Moreover it is necessary to carry out earth pressure measurements in order to be able to register the influence and the effect of the formation of restraints and arches (see Pachomow et al. 2007) between two reinforcement layers as well as the vertical strains and thus the load distribution in the front area. This measurement concept has been realized by the tBU - Institut für textile Bau- und Umwelttechnik GmbH & Co. KG, Greven, Germany.

For the realization of this measurement concept the following detectors are used:

- Earth pressure cell (Glötzl)
- Strain gauge (HBM)
- Temperature sensor

In order to guarantee the long-term monitoring of the construction complex preliminary tests had been carried out in the laboratory before the detectors were installed. The preliminary tests were carried out under hindered simulated environmental conditions as e.g. an increased water pressure of up to

3 m water column on the applied strain gauges. For the strain measurements on the steel wire and the geogrid different - suitable for each subsoil / strains - strain gauges were used. Both strain gauge types were carried out as temperature and deformation compensated full bridges. The measured value acquisition was carried out by means of a carrier wave amplifier. Also undisturbed samples were obtained from the soil during installation to measure the shear strength at predefined time steps.

6 RESULTS STATUS MARCH 2009

6.1 *Deformation Measurements*

The settlement and deformation measurements which have been carried out up to now show:

- settlements in the soil body already occurred during the construction phase with values of predominantly < 1 cm per layer. The settlements could be balanced already during the construction process by means of corresponding corrections
- in analogy to the vertical deformations only very low horizontal deformations could be detected, which were within the measuring tolerance and which did not increase with the rising installation height
- the settlements in the subsoil were clearly below 30 cm
- already at the end of December 2008 only just minimum settlements in the range of millimeters were detected (fig. 5). It can be assumed that the decisive settlements have been subsided.

6.2 *Earth pressure strains*

For the earth pressure cell (vertical strains) corresponding absolute values were measured immediately after installation of the respective covering. The proceeding covering did not lead to another increase for the cell which was placed near the front area. The obtained values for all three cells were with an average value of 78 kPa in a range which was expected. However, a reduction up to the front area could be determined.

The horizontal strain gauges show at first - together with the increase of the coverage during the construction phase - a continuous increase up to 20 kPa in both gauges before - after finalization of all earth works - a continuous decrease occurred in the front gauge to up to approx. 5 kPa.

6.3 *Strains of the geogrids*

Fig. 6 shows the measured strains in the geosynthetic. For the instrumented product Secugrid 200/40 R6 an absolute force value of 3.5 kN/m was achieved - assuming a linear-elastic behavior without consideration of the thermoplastic material influences.

6.4 *Steel strains*

In analogy to the elongation of the geogrid also the steel tensile strengths for elongations < 0.01 % remain low.

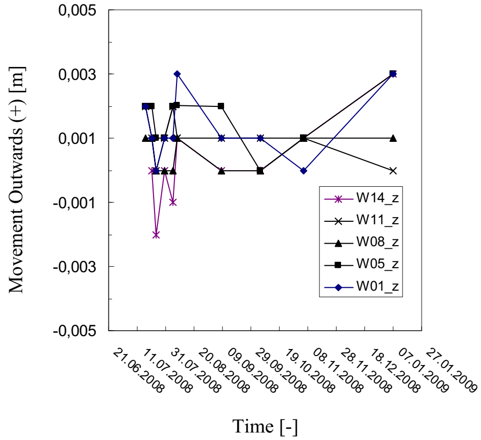

Figure 5. Horizontal Deformations (Layer 1 to 14)

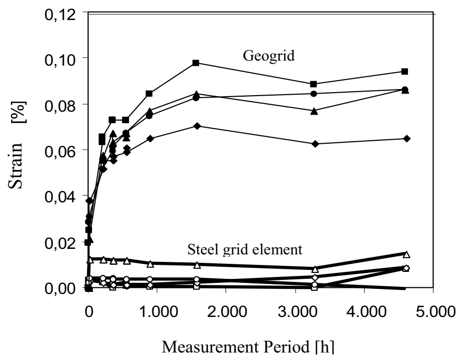

Figure 6. Strain measurements on geogrid and steel grid element

7 EVALUATION OF THE TEST RESULTS

Within the framework of the preliminary evaluation of the results the measured earth pressure strains were checked as to their plausibility. The values which were obtained directly after installation were verified with the values after the first covering and construction levels. Compared to the expected values the test values show qualitatively as well as quantitatively a good correlation - without any further corrections. Especially noticeable are:

- the very low horizontal strains of less than 5 kPa in the front earth pressure cell and the
- tendency to unitize the vertical stresses (relocation of the vertical stresses to the front area).

Besides the very low total level of the operational demands of the geosynthetics also the good correlation of the above mentioned force of average 3.5 kN/m together with the horizontal stress of less than 5 kN/m measured in the first strain gauge is noticeable.

Involving the horizontal stress derived from the steel grid element and the very low horizontal deformation which was determined by means of the geodetic measurement it can be noted that the horizontal stresses in the front area apparently remains very low despite increased vertical stress rates. Compared to the ratio of the active earth pressure approach, horizontal stresses are strongly reduced also under consideration of the specific soil properties with a high cohesive percentage of the shear strength.

8 CONCLUSIONS AND FUTURE PROSPECTS

For the noise protection barrier located on a slope very low horizontal deformations could be detected. These deformations correlate qualitatively very well with the small strains in the reinforcement and the very small forces which affect the steel grid element. The approach of the reduced earth pressure by 30% which has been used - according to EBGEO 2009 - could thus be verified also for fill material with strong cohesive properties. For this construction the approach is still clearly on the safe side for the currently measured strains and stresses.

Besides the calculative verification of the earth pressure distribution especially the long term monitoring of the forces affecting the steel grid element remain interesting, because the influences resulting from weather and thermal fluctuations could - near to surface - possibly result in a loosening and stress relocation. The instrumentation is dimensioned for a long-term monitoring of the construction.

9 ACKNOWLEDGMENT

The authors appreciate NAUE GmbH & Co. KG for the financial and technical encouragement of this technical study.

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