Geosynthetic Reinforced Retaining Walls and Bridge Abutments – Best Practice

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ABSTRACT: Retaining walls made out of geosynthetic reinforced soil (GRS) are used for an increased number of applications as an alternative to conventional concrete retaining walls because of their advantages like the saving potential due to material use, construction time and their environmental benefits as well as their variable constructible facing. For geogrid reinforced bridge abutments the use of active or passive concrete panels (segmental or full height) is common. On the basis of two large-scale experiments (1:1) and five real projects, this paper deals with the basics and the advantages of geosynthetic reinforced soil structures, which become increasingly important for infrastructural and railway projects.

Keywords: walls, abutments, reinforcement, panel, geogrid

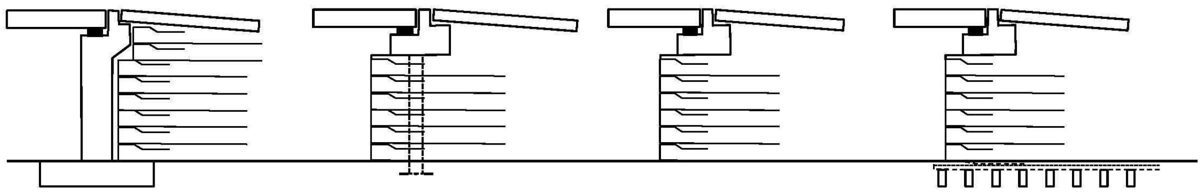
1 INTRODUCTION

The potential in cost saving and reduction of carbon footprint are reasons that geosynthetic reinforced soil structures became an integral part of the design works for slopes, retaining walls and bridge abutments over time. In the last years a lot of projects have been successfully carried out using geosynthetic reinforcement technology. This was possible based on research results, leading to design approaches published in EBGEO and allowing a reduction of lateral stress on the facing constructions. Concrete panels as facing elements can be used as a statically relevant element or as passive element to increase the robustness of the structure. To increase the robustness of geosynthetic reinforced structures the use of gabions or similar systems can be used as well. Based on the following large-scale experiments as well as in-situ projects these topics will be explained more detailed.

2 BRIDGE ABUTMENTS – OPTIONS WITH GEOGRID REINFORCED STRUCTURES

Conventional bridge abutments of reinforced concrete have several disadvantages in comparison to geosynthetic reinforced bridge abutments. Construction time, construction costs and carbon footprint can be reduced significantly. Further than that due to the high ductility of geosynthetic reinforced structures they are characterized by a high robustness against unexpected loads, dynamic impacts or earthquake loads. In combination with piling systems it is possible to bridge nonhomogeneous subsoils. Thus differential settlements between bridge abutments and embankments can be minimized by using this construction method.

Depending on the subsoil conditions and other boundary conditions several innovative construction techniques using geosynthetic reinforced structures have been developed in the meantime. These include geogrid reinforced structures to protect the structure against earth pressure, geogrid reinforced structures below a piled or non-piled bridge foundation or geogrid reinforced structures on top of a piled load distribution platform (see Figure 1).

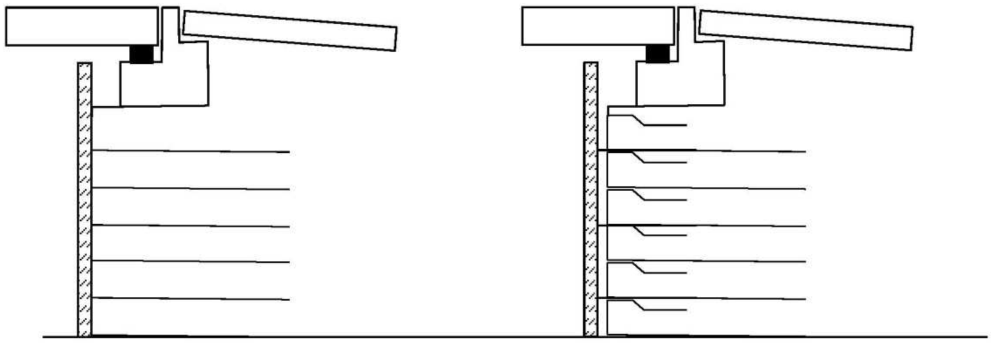


a) Protection against earth pressure
b) GRS below a piled bridge foundation
c) GRS below a bridge foundation
d) GRS on top of a piled load distribution platform

Figure 1: Bridge abutments options with integrated GRS

2.1 *Facing elements*

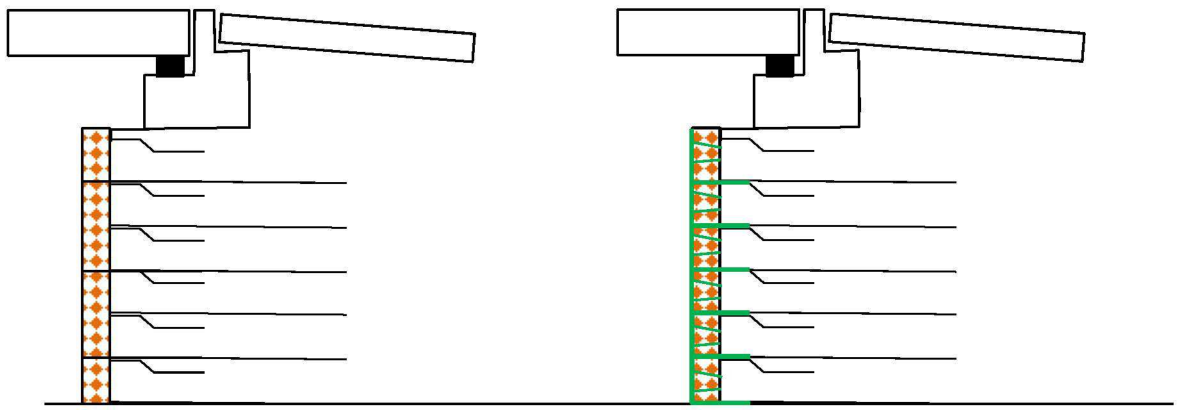
During the planning phase of bridge abutment constructions it is required to be aware of the possible impact load as a result of an accident. Therefore in general the considered facing elements for geosynthetic reinforced bridge abutments are robust to be able to resist such impact loads. Concrete panel elements are typically used as facing element for bridge abutments, because the high robustness is a significant characteristic of concrete panels. In the execution the concrete panels are classified in active and passive elements.



a) Active concrete panel
b) Passive concrete panel

Figure 2: Classification of concrete panel elements

To increase the robustness of a geosynthetic reinforced structure also gabions or similar facing elements can be used. The NAUE DW (double walled) System is a specific facing system, which was developed for geosynthetic reinforced structures in areas with a high risk of accidents. The first wall – the soil body - will be carried out with static relevant geogrid wrap around on the rear side of a lost formwork. The second wall – the facing element - consists of a stone filling between the first wall and galvanized steel mesh element. This galvanized steel mesh elements are fixed with spacers to the static relevant geosynthetic reinforced structure. The thickness of the stone filling is in general 30 cm. In case of an accident against the wall this facing system allows a sectional repair without big efforts. This topic will be further explained in session 4.1.



a) Total repairable double walled system b) Sectional repairable double walled system

Figure 3: Classification of doubled wall systems

3 FUNDAMENTALS OF DESIGN

The proofs for geosynthetic reinforced earth structures are performed according to the valid design guidelines based on the well-established Eurocode 7 (DIN EN 1997-1) and the national annexes (DIN EN 1997-1/NA, DIN 1054:2010-12 (Germany)). It has to be recognised, that the use of Eurocode alone is not satisfactory for geosynthetic reinforced soil structure, as no partial factors of safety are given by the Eurocodes, leading to unsafe results. Therefore, the use of national annexes and recommendations dealing with this topic is not only recommended but required. Within the framework of the design of geosynthetic reinforced structures, the latter refers to the EBGEO 2010, which defines the state-of-the-art concerning the technical rules. The proofs are performed for the ultimate limit state and the serviceability limit state.

3.1 *Classification of geosynthetic reinforced earth constructions in terms of geotechnical category*

The classification of geosynthetic reinforced earth constructions in terms of geotechnical categories is carried out based on EBGEO 2010 according to Table 1 below. As far as a classification into a higher category is required according to DIN 1054, this higher geotechnical category applies.

Table 1: Classification of geosynthetic reinforced earth constructions in terms of geotechnical category based on EBGEO 2010

Geotechnical Category 1	Geotechnical Category 2	Geotechnical Category 3
Height of GRS < 3m	3m ≤ Height of GRS < 9m	9m ≤ Height of GRS

3.2 *Proofs*

3.2.1 *Ultimate Limit State (ULS)*

Similar to a conventional retaining wall, the following proofs (see Table 2) for the ultimate limit state of the geosynthetic reinforced earth construction are carried out according to EBGEO 2010.

Table 2: Analyses for the ultimate limit state (GZ 1 / ULS) and the serviceability limit state (GZ 2 / SLS) (EBGEO 2010)

Proof	GZ 1 / GZ 2 (ULS / SLS)	Figure
General failure / Slope failure	GZ 1C (GEO 3)	Figure 4-a)
Bearing capacity failure	GZ 1B (STR, GEO 2)	Figure 4-b)
Sliding	GZ 1B (STR, GEO 2)	Figure 4-c)
Overturning with the position of bearing pressure resultant	GZ 1A (EQU)	Figure 4-d)
Failure on slip planes that are going through the retaining structure	GZ 1C (GEO 3)	Figure 4-e)
Design strength of reinforcement	GZ 1B (STR, GEO 2)	-
Pull-out resistance of reinforcement	GZ 1C (GEO 3)	Figure 4-f)
Analysis of connections	GZ 1B (STR, GEO 2)	Figure 4-g)
Analysis of reinforcement overlapping / reinforcement junctions	GZ 1B	-
Position of bearing pressure resultant	GZ 2 (SLS)	Figure 4-d)
Deformation of the structure	GZ 2 (SLS)	Figure 4-h)
Base area settlements	GZ 2 (SLS)	Figure 4-h)

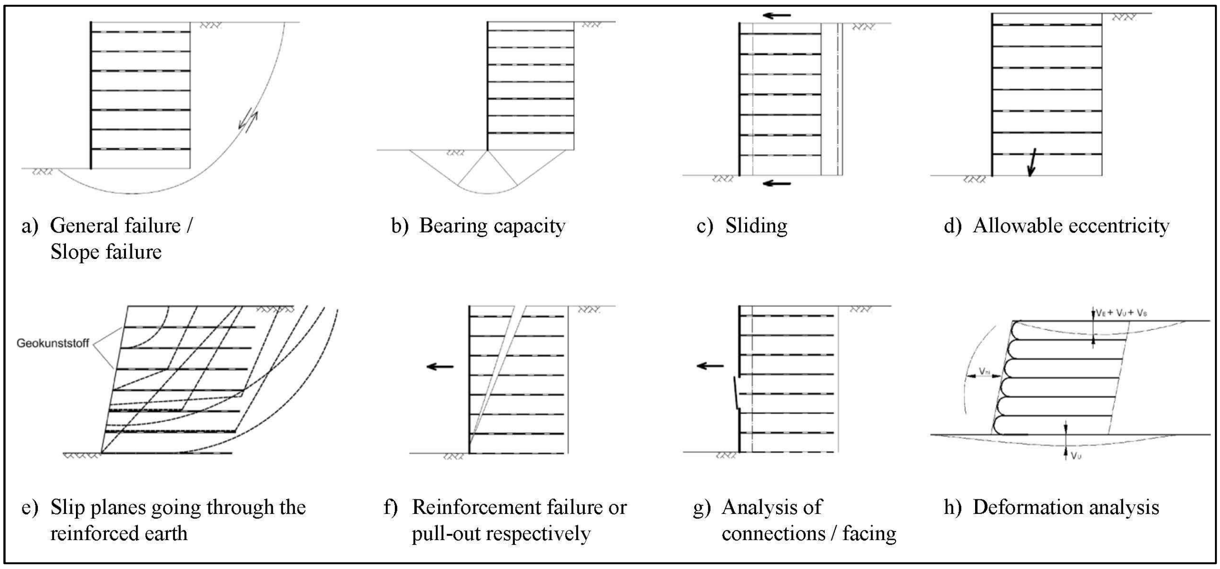


Figure 4: Analyses for the ultimate limit state (GZ 1 / ULS) and the serviceability limit state (GZ 2 / SLS) (EBGEO 2010)

3.2.2 *Serviceability Limit State (SLS)*

Serviceability limit state analyses include the analysis of the position of the base pressure resultant analogous to e.g. DIN 1054, chapter 7.6.1 (figure 4-d) and compatibility proofs regarding the deformations of the reinforced earth (figure 4-h). Hereby, subsoil settlements, fill material's own settlement as well as facing displacements of the reinforced earth and the resulting surface displacements on the top of the construction must be considered. The composite effect between the fill soil and the geosynthetic can influence the deformation behaviour significantly (EBGEO 2010). According to the state-of-the-art, it is expected that the composite material (geogrid + soil) shows considerably less deformation than those which would result solely from the stress-strain-behavior of the geosynthetics. Within the framework of the serviceability limit state analyses, the following table can be used to estimate the deformations.

Table 3: Expected deformations for geosynthetic reinforced earth structures according to Herold (2007), in Vollmert et al. (2012)

Max. horizontal deformation: Total: Post-construction:	 $h_{total} = 0{,}005 \ldots 0{,}01 * H$ $h_{post} = 0{,}15 \ldots 0{,}3 * h_{total} = 0{,}00075 \ldots 0{,}003 * H$
Max. vertical deformation: Total: Post-construction:	 $v_{total} = 0{,}01 \ldots 0{,}02 * H$ $v_{post} = 0{,}15 \ldots 0{,}4 * v_{total} = 0{,}0015 \ldots 0{,}008 * H$
H: max. height of construction h: horizontal deformation v: vertical deformation	
All above mentioned deformations refer to the deformations within the reinforced earth construction itself. The deformations of the subsoil have to be investigated separately. The above mentioned upper limits refer to deformations of reinforced earth constructions with a surcharge above them, whereas the lower limit considers the constructions with no surcharge.	

The subsoil settlements must be calculated according to e.g. DIN 1054, 7.6.3 whereas the geosynthetic reinforced soil can be assumed as a flexible load (non-rigid load). A geosynthetic reinforced earth construction is hereby advantageous as the structure itself is sufficiently resistant to settlements. Differential settlements can generally be absorbed by the construction as a result of an improved load distribution within the fill soil. If necessary, the deformation behavior of the soil-geogrid-system can be analysed numerically (e.g. by means of FEM). The results of the numeric calculation have to be checked in terms of plausibility. The deformation behavior of geosynthetic reinforced earth structures of geotechnical category 3 should be monitored in addition to the deformation prognoses (observation method analogous to DIN 1054). As far as geogrids are embedded in concrete panels at the factory or on site, the resistance proof against e.g. pull-out has to be performed. For the product group Secugrid® R6/Q6 (PET), the corresponding system checks and certificates are available.

4 LARGE-SCALE TESTS (1:1)

4.1 *Large-Scale Test I / B6n, Bernburg, Saxony-Anhalt, Germany*

Within the framework of the project Federal Road B6n near Bernburg, Germany, a 1:1 experiment was carried out with the support of the State of Saxony-Anhalt in order to analyse the behavior of a geosynthetic reinforced soil structure after a vehicle impact and fire. First, a car (with a weight of approximately 800 kg) was driven against the 6 m high retaining wall with a velocity of approx. 80 km/h and an angle of 20°. Afterwards, a 375 kg heavy weight (wrecker's ball) was moved and crashed into the wall facing orthogonally with a velocity of 40 km/h. Finally, a fire was applied in front of the wall for 10 minutes at temperatures of between 1100°C and 1200°C. The facing of the geosynthetic reinforced earth structure was made out of a double-skin system, where the reinforced soil body is separated from the front surface literally. In the geosynthetic reinforced earth structure, accelerometers were installed which recorded the impact and the resulting forces. Before and after the experiment, the facing was scanned with the help of a laser-scanner in order to keep a record of the deformations on the facing. Vertical inclinometers have been installed within the retaining wall to measure the deformations and determine the impact effect within the geosynthetic reinforced soil structure. By means of the comprehensive measurements and evaluations afterwards, it has been proved that the geosynthetic reinforced earth construction showed a high robustness towards impact loads and fire. The damaged part of the construction is mainly limited to the statically-non-effective facing. The damaged part could be repaired relatively easily and economically. Moreover, the dismantling of the wall showed that the construction can easily be disassembled into its components, be separated and be recycled by approx. 100 %. A video of the test is available on www.naue.tv. Contrary to conventional retaining wall systems, where a weakening of the facing directly affects the stability negatively, the statically effective reinforced earth wall remains unaffected with the help of a sufficient dimensioning of the double-skinned facing system. Thus, in regions with a high risk of earthquakes or other unexpected effects, the geosynthetic reinforced earth construction is required as a standard construction type for high-speed railway lines and serves e. g. as a sole retaining wall or the reduction purpose of earth pressures on integral bridges (Tatsuoka et al. 2014).

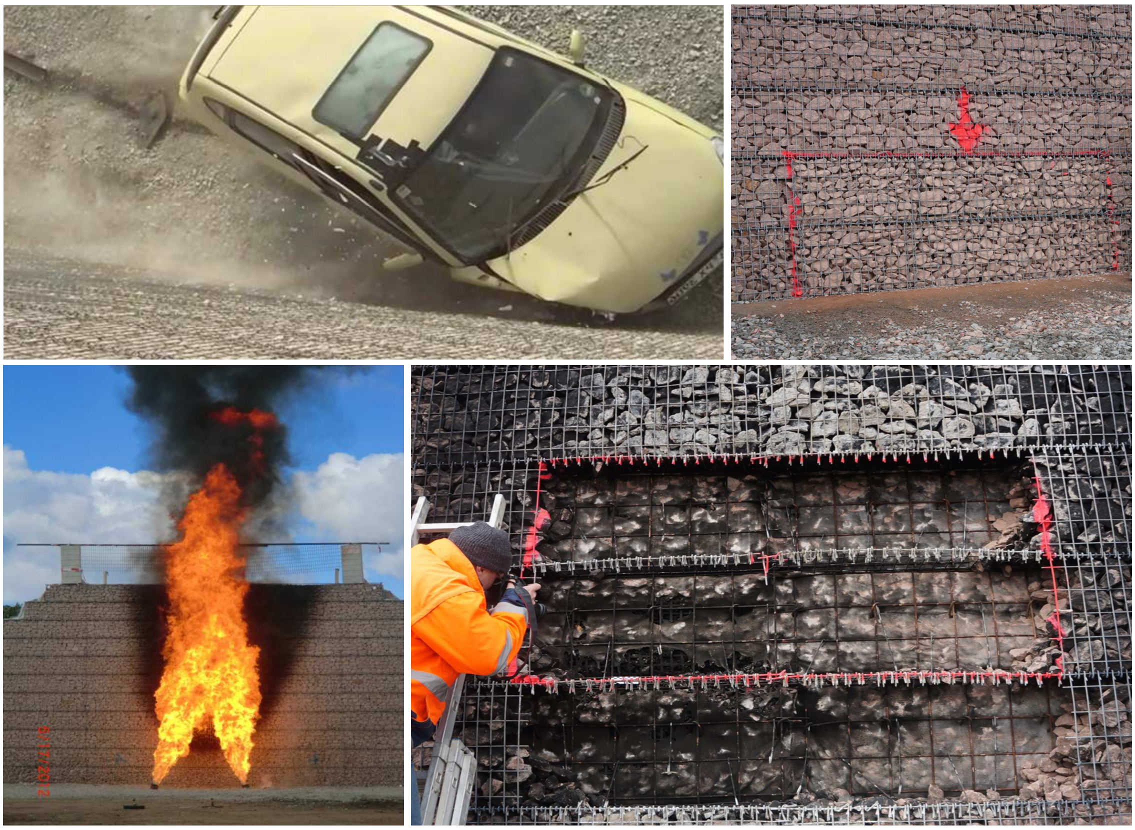


Figure 5: Large-scale test / B6n, Bernburg, Germany (Herold & Vollmert 2013)

4.2 *Large-Scale Test II / Test Wall KWS Utrecht, the Netherlands*

In order to analyze the load-bearing behavior of a geosynthetic reinforced earth construction with a non-deformable facing element, a geosynthetic reinforced earth cube has been built with different facing types on the premises of the company KWS Infra, Utrecht/the Netherlands. The load-bearing behavior of the facing which was constructed by using a full-height concrete panel was of particular interest. Therefore, in a chosen test-cross-section, some strain gauges have been installed both on the high strength PET-geogrids which were embedded in the concrete panel at one edge (as an attachment) and on the concrete panel itself. Additionally strain gauges have been installed on a temporary prop, in order to determine the deformation behavior (see Figure 6). The concrete panel was delivered to the site as a precast concrete element. As an additional measure to consider possible deformations in the cube, the corner points of the construction have been measured geodetically. For chosen time periods, based on the known time-dependent stress-strain behavior of the geogrids and the measured strains, the resulting earth pressures were back-calculated according to the equilibrium of horizontal forces $\Sigma F_H = 0$. Hereby, the friction of the facing element on the bottom was small because of the chosen slide joint. For comparison purposes, the earth pressure behind the facing has been calculated analytically according to EBGEO and with the help of FEM as shown in Figure 7. By means of these results, it was proved that the measured deformation in the large-scale test refer to considerably lower earth pressures compared to those calculated analytically according to EBGEO (without a reduction of the earth pressure for non-deformable facing elements). The difference of at least 30% was in line with the current state of research concerning geosynthetic reinforced earth structures.

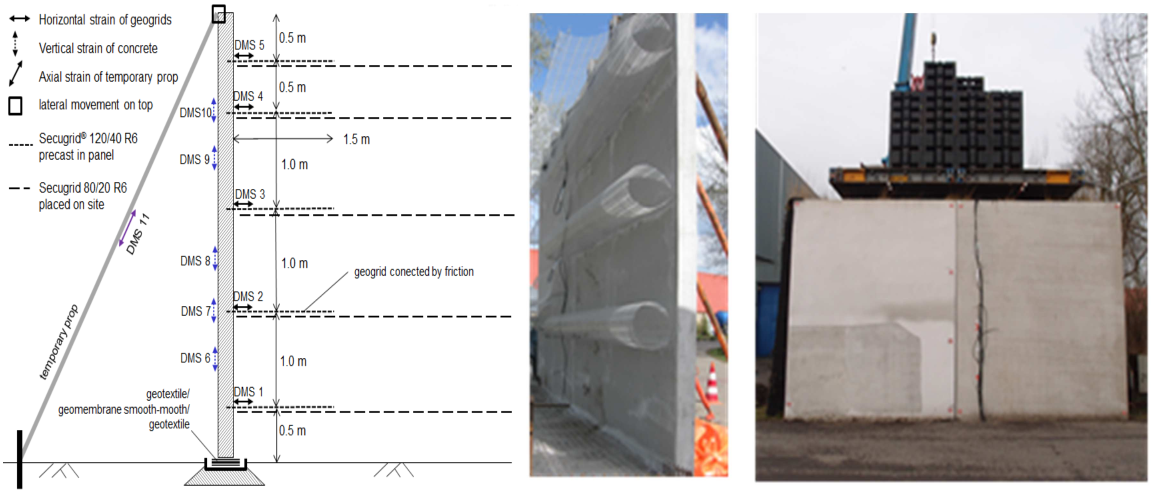


Figure 6: Large-Scale Test / Test Wall KWS, Utrecht, the Netherlands (Vollmert et al. 2012)

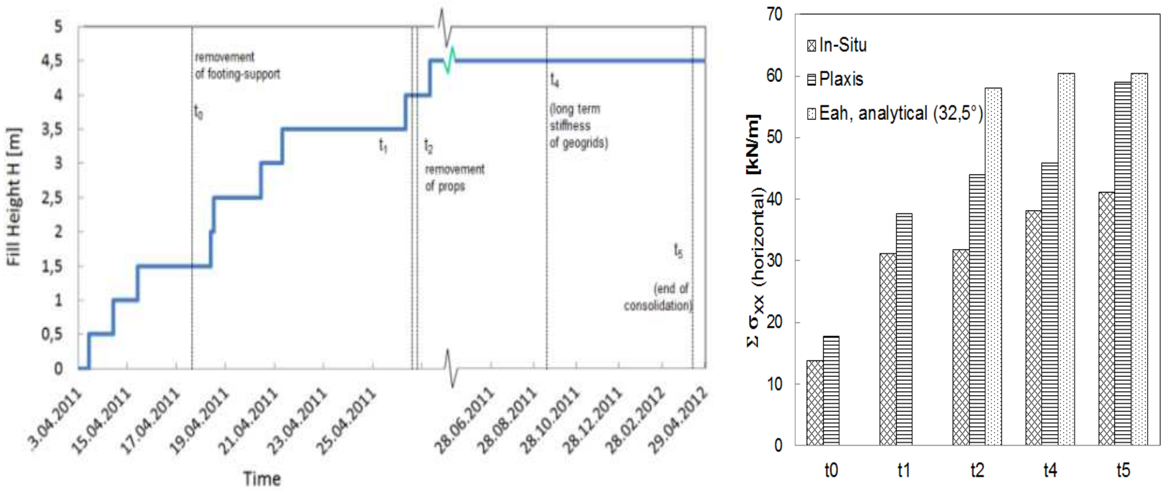


Figure 7: Earth pressure distribution for the geosynthetic reinforced earth (test) wall KWS, Utrecht, the Netherlands (Vollmert et al. 2012)

5 PROJECTS

5.1 *Project I / Ecoduct Laarderhoogt, Laren, North Holland, the Netherlands*

Within the framework of the new construction of a green bridge (for animals) crossing over the Naadestraat and the motorway A1 in Laren, North Holland, four bridge abutments were built with the help of geosynthetic reinforced earth construction.

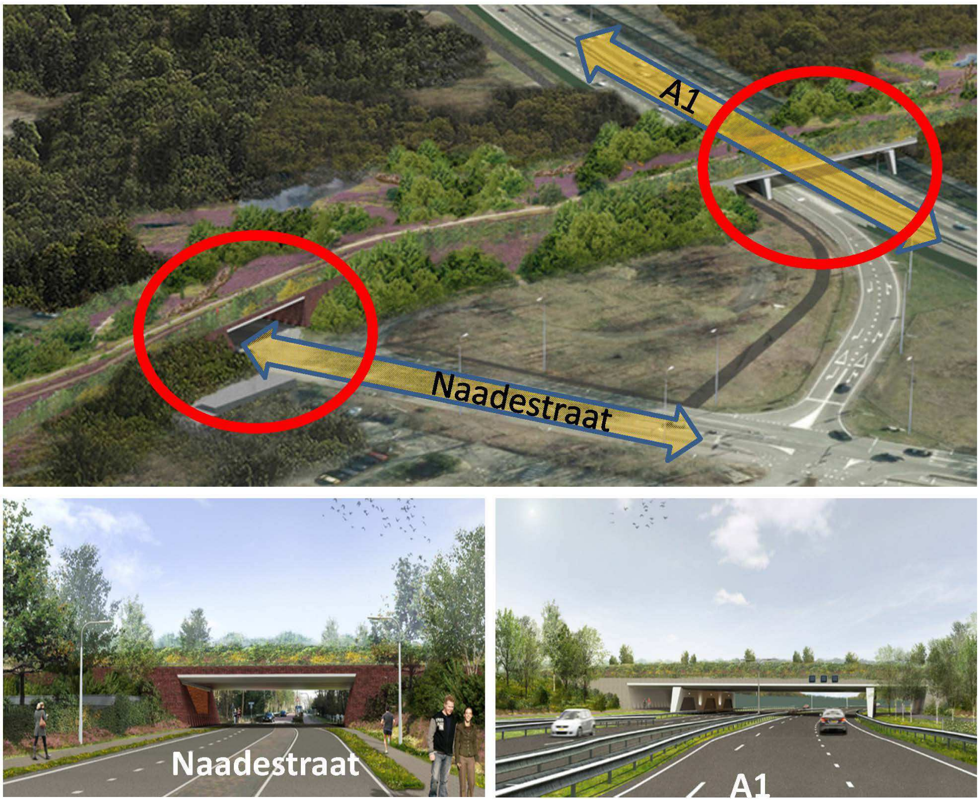


Figure 8: Project Ecoduct Laarderhoogt, Laren, North Holland, the Netherlands (http://www.wurck.nl/projecten)

The total height of the construction amounts to approx. 8 m, whereas the visible brick facing and concrete panel facing (passive system) respectively has a height of approx. 4.5 m. The facing has an inclination of approx. 70°. The geogrid wrap around method was chosen as statically effective facing system (NAUE WRAP). This statically effective system is separated completely from the concrete or brick facing, which solely serves the aesthetic and constructive purposes. The required static function to absorb the resulting loads from the bridge construction was completely undertaken by the reinforced earth structure itself, whereas the additional facade was only attached to the geosynthetic reinforced earth structure constructively.

Figure 9: Project Ecoduct Laarderhoogt, Laren, North Holland, the Netherlands

5.2 *Project II / Ecoduct Zwaluwenberg, Utrecht-Hilversum, the Netherlands*

Within the scope of the construction of three additional green bridges crossing over the national road N417, the motorway A27 and the railway line between Utrecht and Hilversum in Zwaluwenberg, North Holland, the Netherlands, six bridge abutments were built by using geosynthetic reinforced earth construction.

Figure 10: Project Ecoduct Zwaluwenberg, Utrecht-Hilversum, the Netherlands

The height of the construction is approx. 4.5m. The inclination of the facing varies between 35° and 70°. The statically effective facing was carried out by means of the geogrid wrap around method (NAUE WRAP & NAUE STEEL T). In case of the A27, the statically effective facing was covered with a concrete block paving, in case of the N417 the facing was covered with a concrete panel and by the railway line, the facing was covered with an erosion control mat. Also in this project, the geosynthetic reinforced earth structure fulfills the static requirements, where the resulting load from the bridge amounts to approx. 450kN/m².

5.3 *Project III / Bridge Ramp, Trencianska Tepla, Slovakia*

Within the framework of the new construction of a bridge crossing over the railway line between Opatova and Priles in Trencianska Tepla, North-Western Slovakia, a bridge ramp was built by using geosynthetic reinforced earth construction in 2012. The maximum height of the vertical construction in the connection zone to the bridge abutment is approx. 10 m. The facing was built by means of the system NAUE PANEL with pre-cast, cross-shaped concrete panels (active system). By simply wrapping the geosynthetic reinforcement around a steel bar which is connected with the panel and by anchoring a statically required geogrid-tie-back length within the soil body, a very rigid retaining wall with a high bearing capacity and small deformations was built which fulfills its function as a bridge ramp at this project perfectly.

Figure 11: Project Trencianska Tepla, Slovakia

Similar to the construction method chosen for this project, various facing element types with PET-geogrids embedded in concrete facing are also used other European countries and worldwide.

5.4 *Project IV / Ecoduct Boele Staal, Soesterberg, Utrecht, the Netherlands*

Within the scope of the new construction of a green bridge crossing over the road N237 in Utrecht, the Netherlands, a bridge abutment made out of geosynthetic reinforced earth is being constructed based on the large-scale-test “KWS- test wall” (see 3.2) research results currently. The total height of the construction amounts to approx. 8 m, whereas the visible concrete panel facing has a height of approx. 4.5 m. The inclination of the visible facing is 75°. The construction of the facing is carried out with the help of the geogrid wrap around method combined with full-height concrete panels. Hereby, the concrete panels are used as formwork (construction phase) and facing (final phase). In the final phase, the stiff PET geogrids embedded in the concrete panel serve as anchorage of the concrete panel within the statically bearing geosynthetic reinforced earth structure. Therefore, the system can be seen as an innovative combination of an active system with additional safety by an implemented passive system.

Figure 12: Project Ecoduct Boele Staal, Soesterberg, Utrecht, the Netherlands

6 CONCLUSION AND OUTLOOK

The gained international experience with geosynthetic reinforced earth structures over the last thirty years allows today the use of this construction method as bridge abutment without additional structural elements to carry the bridge loads. On the one hand, the high ductility of the construction is utilized. On the other hand, the differential settlements between bridge abutments and embankments can be minimized by using this construction method. The performed large-scale test has shown that the resulting earth pressure on a non-deformable facing (based on the measurements) is considerably smaller, if using a high performance geogrid with high tensile stiffness, than the results which were gained from FE- and analytical calculations, which indicates a possible optimization of the concrete panel dimensions. Furthermore, it was shown that geosynthetic reinforced earth structures keep their robustness with the help of suitable facing systems even after impact loads and fire. They can easily be repaired when damaged. The advantages of the construction are not only referred to the constructive-technical properties and cost saving by using of cheap construction material (soil) and reduction of the construction period but also the almost 100% recyclability of the construction. The use of geosynthetic reinforced earth structures leads to an approx. 75% less “non-renewable cumulated energy consumption” and an approx. 85% reduction of greenhouse gas emissions compared to a technically equivalent steel-reinforced concrete retaining wall (Ehrenberg & Elsing 2013). Regarding environmental factors, the environmental product declaration (EPD, available from NAUE on request) for geosynthetics make a valuable contribution by representing an objective database for the comparison of different design alternatives for infrastructural projects in terms of their environmental effects (Frischknecht & Wallbaum 2013).

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