GEOGRID REINFORCED STEEP SLOPES SUBJECTED TO RAILWAY LOADING – CASE STUDY

TALUS RAIDIS PAR GÉOGRILLES DE RENFORCEMENT ET SURCHARGES FERROVIAIRES : ÉTUDES DE CAS

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ABSTRACT – The use of geosynthetic reinforced retaining structures has become more and more established, especially because of its ecological and economical advantages. However, for railway embankments, these constructions were quite uncommon. This was mostly due to the fact that the behaviour of the structures and particularly the geosynthetics, under high dynamic loading was not well known. Furthermore in the field of railroad embankments there are specific questions like foundations for power supply, signal posts or noise protection walls to be considered. Additionally, there are increased demands with regard to the outer facing. This publication presents the experience gained from two representative projects implemented by Deutsche Bahn AG. Apart from results of deformation measurements the paper will describe constructive and structural details.

RÉSUMÉ - L'utilisation des géosynthétiques pour le renforcement des talus raidis et des murs de soutènement est devenue de plus en plus courante, principalement pour ses avantages écologiques et économiques. Cependant ces techniques étaient peu communes pour des remblais ferroviaires. Cela était dû à une connaissance pas assez fine du comportement des structures et des géosynthétiques sous des charges dynamiques élevées. L'interface avec les fondations du réseau d'alimentation, les poteaux de signalisation ou les murs anti-bruit est également à étudier. Un intérêt croissant se porte aussi sur les parements de ces structures renforcées par géosynthétiques. Outre les mesures de déformation de deux projets du réseau Deutsche Bahn, cette publication en présente la conception et la construction.

1. Introduction

The use of geosynthetics for reinforcement of embankments and retaining structures, besides the use as a filter and classic separation layer, is now among the common applications. Over a period of several decades, a variety of theoretical and practical construction experience is now available. To date the design principles of such structures are similar as for non-reinforced earth embankments or conventional retaining structures. The currently available design methods are, independent of the building height and loads, to be considered as being sufficiently safe and appropriate, see, e.g. EBGEO (2009), Alexiew (2005).

Within the jurisdiction of the German Rails (Deutsche Bahn, in the following DB AG), the use of geosynthetic reinforced soil (GRS) has, with few exceptions, however, been limited to areas outside of railway-specific impact.

The reason for this was that there is little experience to date about the behaviour of geosynthetic reinforced soil structures, in particular of geosynthetics under high dynamic loads. Furthermore, an accurate prediction of the expected deformations of GRS structures has shown to be difficult. This applies to buildings with static as well as to dynamic loading. Often, deformation predictions are undertaken using the finite element method (FEM). It must be noted, however, that the calculated deformations do not always represent the real deformation behaviour in an inadequate manner.

Significant differences to non-reinforced embankments and conventional retaining structures can be observed in the execution. Geosynthetic reinforced embankments, in this respect, can be compared neither to pure earthworks nor to traditional retaining structures; a classification as "constructive earthwork" comes closest to being correct. Especially in the field of railway structures, specific demands are placed on the condition of the outer surface and several specific practical construction requirements are also in place. For example, foundations of signalling or overhead line poles or foundations of noise barriers may require specific solutions.

In planning and design of GRS structures within the jurisdiction of the DB AG, in addition to the generally accepted standards, guidelines and recommendations, the company-specific rules of DB AG, and in particular the Directive RiL 836, DB Netz AG (2008) are to be considered. Furthermore, the implementation of GRS structures within the jurisdiction of the DB AG is currently subject to a corporate internal approval (Unternehmens Interne Genehmigung, UiG) and an individual approval (Zustimmung im Einzelfall, ZiE) by the Federal Railway Office (EBA). Part of such approvals is usually a requirement to monitor the behaviour of the structures in the form of periodical reports and geotechnical measurement programs. This would built up a systematic base for future actions.

Two selected projects by Deutsche Bahn AG, which were monitored in the course of their construction and service, will be presented in detail in this paper. These are the so-called *Nordhafengleis* near Hanover-Ledeburg, and the hub of Köln-Mülheim, NBS Cologne-Rhine/Main.

Apart from the results of deformation measurements, constructive and practical construction solutions will also be outlined.

2. Railway-Specific Loading

2.1. Actions

Design of railway infrastructure, structural elements as well as earthwork, necessitates the careful consideration of actions. These include in particular the occurrence of centrifugal and braking forces, the high variability and the influence from dynamic effects of the loading. The question, however, whether at all and if so, to what extent such influences have to be taken into account for the design, depends largely on the distance to the track. According to RiL 836 (2008), the track can be divided here into a so-called inner and outer pressure zone. For the design of elements or structures which are located within the inner pressure zone, the variability of load effects, particularly for the evaluation of their resistances, therefore, must be taken into account. In those zones that are located in excess of 5.5 m under the top edge (TOR), dynamic loads are considered negligible.

Figure 1 shows an example of how a retaining structure that is directly arranged underneath the railway tracks is largely located in the internal pressure zone and, therefore, dynamic influences must be considered in design.

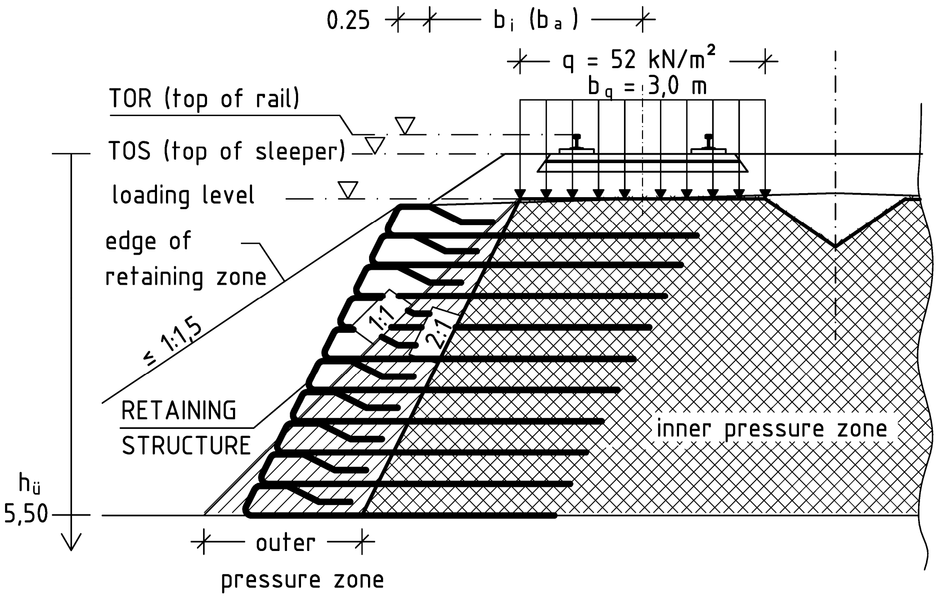

Figure 1. Definition of pressure zones, as in RiL 836, Module 836.2001 [1]

If, beyond the definition in RiL 836 (2008), a closer look is to be taken, depending on the actual characteristics of the dynamic loading, frequency, amplitude and load ratio R, additional criteria should be investigated. In the second edition of the EBGEO, DGGT (2010), different approaches concerning this are shown.

In the case of the buildings presented below, the design was based on static equivalent loads. Additional increase of the loading for consideration of the cyclic component was not applied due to the relatively low speeds according to the requirements of the UIG. In determining the resistance of the geosynthetic reinforcement, an additional reduction factor, A_{dyn}, however, was taken into account, see Section 2.2.

2.2. Resistance

Figure 2 shows an example of how the impact of dynamic loading on the design strength of geosynthetic reinforcement in Germany for rail routes has been considered thus far.

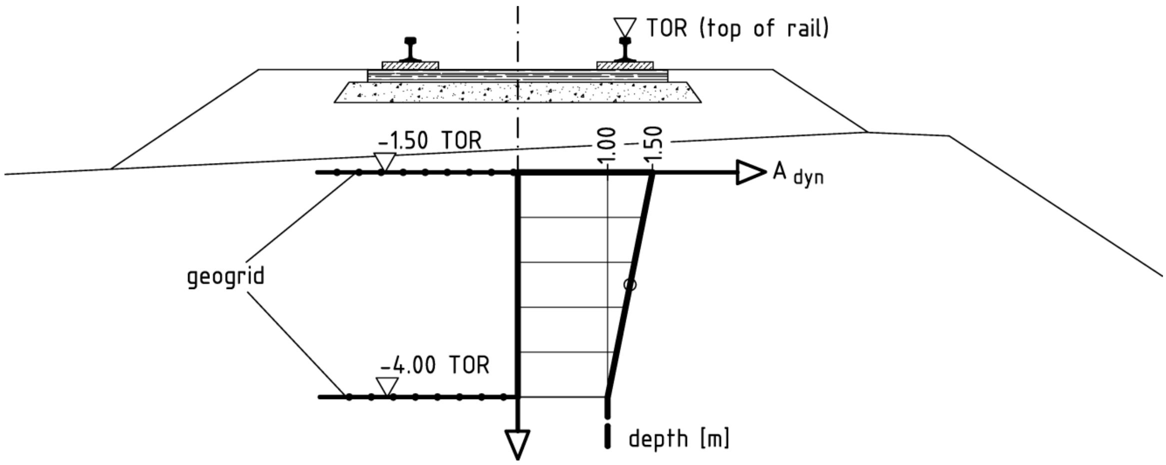

Figure 2. Definition of A_{dyn}

Factor Adyn describes a reduction depending on the distance to the track system, which in addition to the reduction for creep rupture, installation damage, environmental conditions and connections, needs to be considered for the determination of the so-called design strength of the grid. The dependence of Adyn with depth is oriented on the results of vibration measurements of existing railway embankments, the factor of the actual derating could not be indicated thus far. The currently used Adyn values, on account of initially missing experiment results, were therefore specifically determined and considered a conservative estimate. Recent studies on the mechanical behaviour of geosynthetic reinforcement under cyclic load, Zanzinger (2007), Retzlaff (2007), confirm this approach for typical train loads and speeds as being on the safe side.

In addition to material parameters at break, required for design of the ultimate limit state (ULS), the studies also investigated behaviour of the materials before rupture. Significant changes in the material, in particular the axial stiffness, which is required for calculation of displacements in the service ability limit state (SLS 2) or for applications where stiffness-dependent evidence is required for the ULS, were not found.

3. Experience with existing buildings

3.1. General information

In favour of a more comprehensive presentation of measurement results, this publication foregoes a description of the general boundary conditions for the construction of the projects shown here.

It is, however, remarkable that both buildings, concerning geometry, facing and construction materials used (filling soil and geogrid reinforcement) are very similar. The design speeds and overall height in the Cologne-Mülheim project, however, are significantly higher than in Hanover Ledeburg. The dates of commissioning of the two retaining structures are about 10 years apart.

Table 1 and figures 3 and 4 show the most important key data of both buildings.

With the construction year of 1997, the construction project in Hanover Ledeburg counts among one of the first applications of GRS within the jurisdiction of the DB AG. The steep slope of the so-called *Nordhafengleis* thus provides first valuable systematic evidence concerning the construction and its deformation behaviour for a medium-term period of observation. The comparison of the two buildings shows how boundary conditions have evolved for the construction of a GRS (higher design speed and greater height of building) within the observation period of 10 years.

Table 1. Key data of reference projects

	Cologne - Mülheim	Hanover - Ledeburg
Vehicle / Category	ICE / TSI: III (urban)	Cargo track (VW-Works)
Design speed	60/80 km/h (max. 100 km/h)	ca. 40 km/h
Height	ca. 8 m	ca. 5 m
Inclination	57°	60°
Facing	Green	Green
Subsoil	Sand / gravel	replacement with sand (0.5 m) loam (1.5 m) sand (2 m) clay (2 m)
Fill-material	Fine and medium grain sand, SU*	Gravel sand, G,s,u‘ (0/32) mm
Geogrid	Fortrac 80/30-20 (PET)	Fortrac 80/30-20 (PET)
commissioning	December 2007	April 1997
Occasion for the construction	Upgrading an existing embankment for ICE traffic (improving stability)	Widening of existing embankment to create an additional track

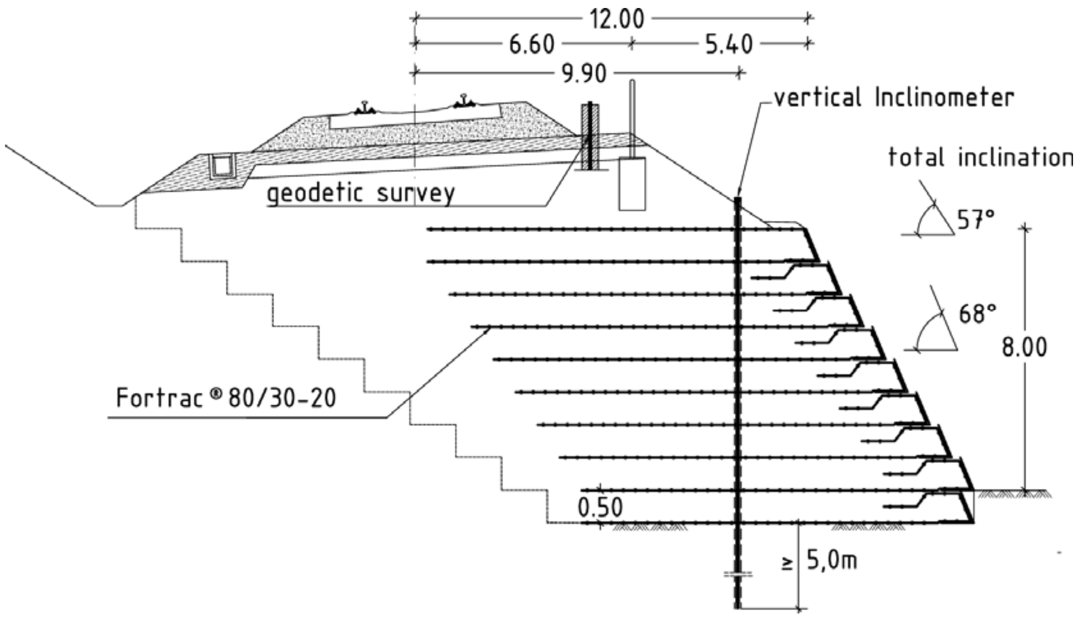

Figure 3. Hub Cologne-Mülheim, Typical cross-section measuring point MST1 and MST2

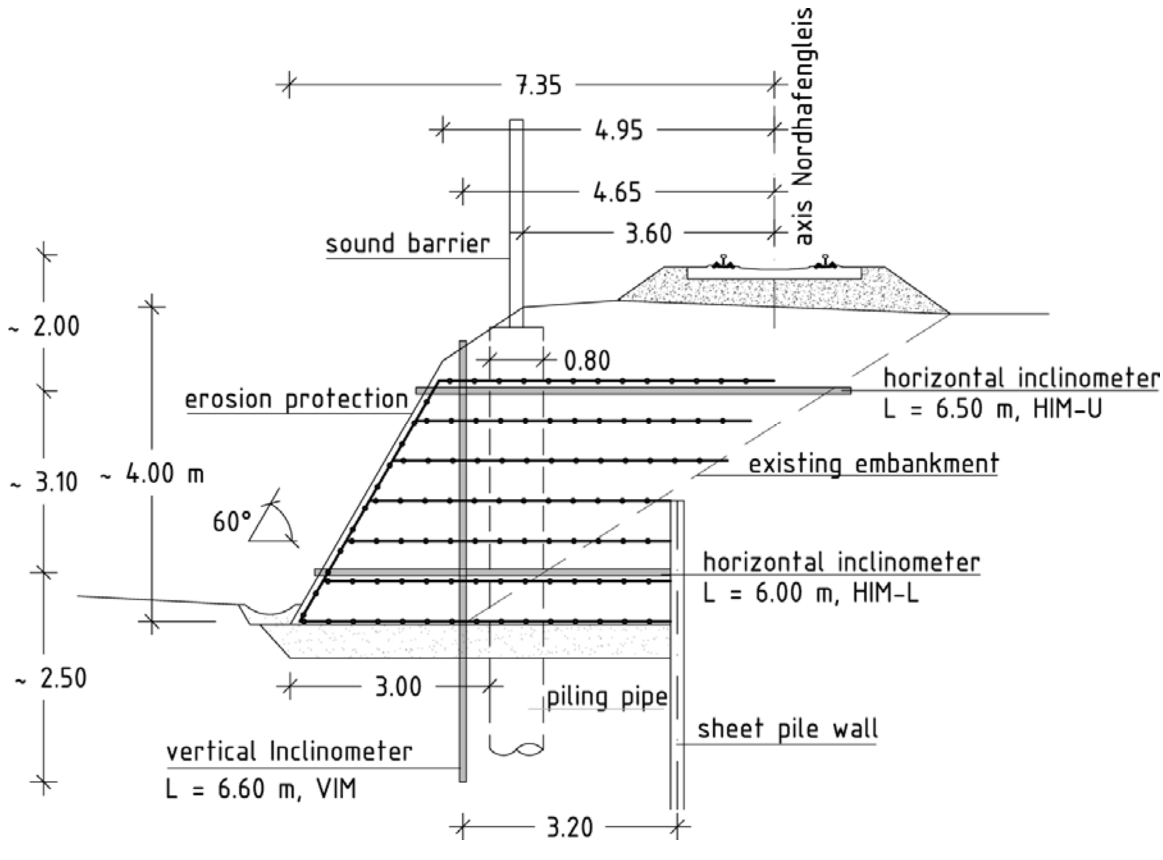

Figure 4. Nordhafengleis Hanover-Ledeburg, Typical cross-section measuring profile

3.1. Monitoring Hardware

The motivation for geotechnical monitoring of GRS-structures was shown in section 1. As it allows conclusions, both concerning track position and related maintenance costs, as well as concerning any creep or location of potential rupture zones to be drawn, measurements of deformation, therefore, are of particular interest. To keep the costs for monitoring within bounds, only geodetic measurements at the outer facing or inclinometers (vertical and horizontal) are often provided. Earth pressure measurements, strain gauges or geophones to record the dynamic effects are more likely to be used for specific problems.

For determining the horizontal deformation, for both cases shown below, vertical inclinometers were used. The evaluation of settlements was carried analyzing the readings of geodetic measurements of selected measuring pins and/or quality-based information about the maintenance of the tracks. In Hanover-Ledeburg, furthermore, two horizontal inclinometers were available at different heights.

3.3. Measurement results Cologne

In Cologne-Mülheim, accessing the inclinometer pipes and bolt measuring took place between late 2007 and January 2009, that is, about one year after commissioning of the structure.

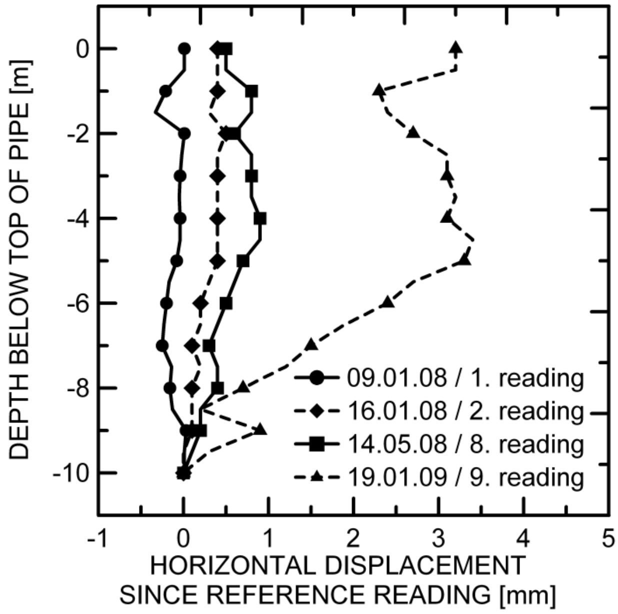

Figure 5. Cologne-Mülheim, Vertical inclinometer, MST1

Since, both horizontal as well as vertical deformation behaviour did not differ significantly, only the results of one of the two monitoring sections that were set up, MST 1, will be shown representative for both sections.

Figure 5 shows the horizontal displacement of the inclinometer pipe perpendicular to the track axis relative to the reference reading for the date of the first, second and last follow-up measurement. The displacements are observed are less than 4 mm. Focusing on the increase of deformation over time, no uniform trend is identifiable; the deviations of the individual readings are rather within the bandwidth of the measurement accuracy of the chosen system. Including the geodetic surveying of the measuring bolt, as shown in Figure 3, the displacements vary for the entire observation period only in a range between a maximum of -1 and + 1.5 mm. Overall, the horizontal deformation is very small and, hence, to be considered uncritical.

A comparable conclusion can be drawn for the analysis of vertical deformation since no relevant vertical displacement could be identified in the period under consideration.

3.4. Measurement results Hanover-Ledeburg

In the *Nordhafengleis* structure near Hanover-Ledeburg, accessing the inclinometer pipes took place between 1997 and 2000, thus over a period of three years after commissioning of the track. The position of the individual inclinometer pipes is shown in Figure 4, where "VIM", in the following graphs, means the vertical inclinometer, "HIM-U" the upper and "HIM-L" the lower horizontal inclinometer.

Figure 6 shows the horizontal displacement of the measuring pipe perpendicular to the track axis relative to the reference reading for the date of the first, second and last follow-up measurement. The overall deformation is less than 6 mm and, hence, to be considered uncritical. It should be noted also that the deformations and distortions in the base of the inclinometer do not return to zero. During the analysis of the available readings, this was taken into account by correcting the measured deformations on the basis of the geodetic survey. Regarding the increases of deformation over time, similar to the measurements in Cologne-Mülheim, it was not possible to establish a uniform trend; the deviation of readings, between subsequent measurements, are throughout within the bandwidth of the measurement accuracy of the system used.

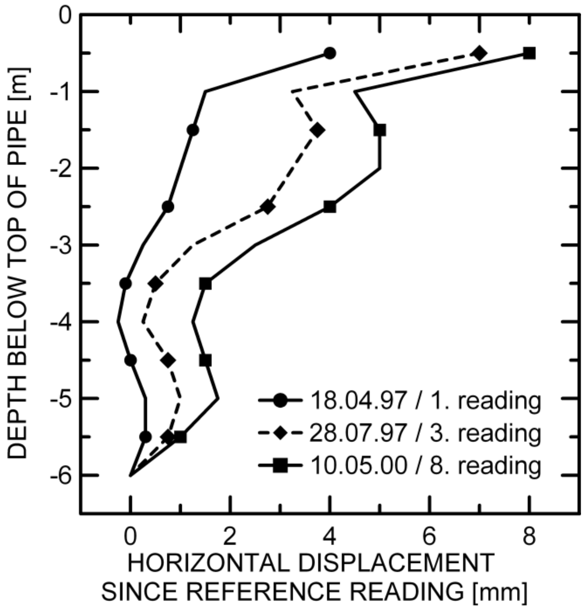

Figure 6. Hanover-Ledeburg, Vertical inclinometer

Figures 7 to 9 show the vertical displacement of the measuring pipes relative to the reference reading always for the time of the first and second follow-up measurement and/or select positions for all follow-up measurements thus far (HIM-L). Accordingly, the maximum settlement at the foundation level of the GRS (reinforced zone) at the time of the last measurement, was about 30 mm, Figure 7. Extending the time-settlement curve shown in Figure 8, one may assume a total of vertical displacements in the order of 35 to 40 mm. This value is well within the range of the vertical deformation predicted in advance.

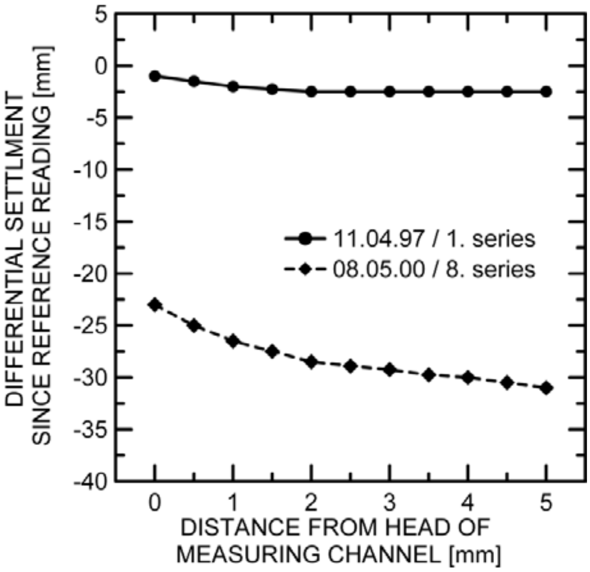

Figure 7. Hanover-Ledeburg, lower horizontal inclinometer, HIM-L, displacements of the channel head taken into account

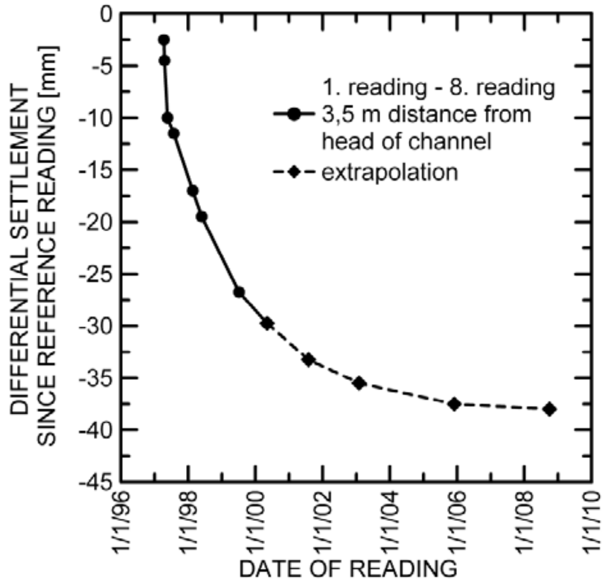

Figure 8. Hanover-Ledeburg, lower horizontal inclinometer, HIM-L, Analysis for measurement point at 3.5 m distance from head of measuring channel, displacements of channel head taken into account

Figure 9 shows the deformation behaviour of the upper inclinometer, which extends through the reinforced sections down to the existing embankment, see Figure 4. The transition between geosynthetic reinforced retaining structure and existing embankment is at about 3.5 m distance from the channel head, see Figure 4. Within the reinforced section, there is a very uniform settlement behaviour to be observed; passing the transition to the existing dam, on the other hand, settlement clearly increases with increasing distance from the channel head. It thus shows that the deformation behaviour of the newly created geosynthetic reinforced retaining structure is significantly more favourable than that of the existing embankment.

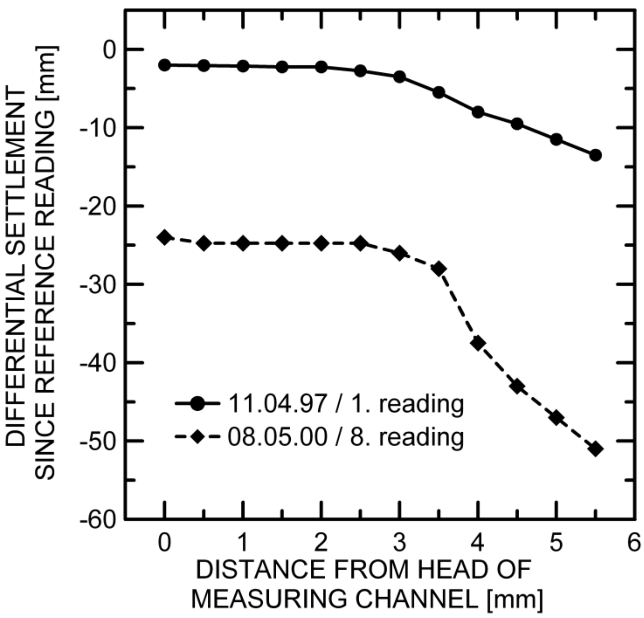

Figure 9 Hanover-Ledeburg, upper horizontal inclinometer, displacements of the channel head have been taken into account

3.5. Summary of monitoring results

The analysis of the monitoring results of two geogrid reinforced retaining structures well comparable in terms of design and loading shows that the deformation behaviour of such structures has no abnormalities even under dynamic impacts due to rail traffic. The horizontal displacements perpendicular to the track axis do not exceed a magnitude of 1.5 mm (Cologne) and 5 ... 8 mm (Hanover).

The vertical deformation is characterized by the deformation behaviour of the soil below the retaining structure. In Cologne, due to the gravels and sands reaching down to greater depths being relative insensitive to settlement, and the years of preloading by the existing embankment, no settlement has been observed. In Hanover, however, settlement, even 3 years after commissioning, was not completely over. The measured deformations and its development over time are, however, well in line with expectations. Also in terms of track position, neither in Cologne nor Hanover, hence even after a periode of time of currently more than 13 years, no peculiarities were evident. The absolute deformation of the two structures under observation, hence, is within a magnitude acceptable to railway operations. Peculiarities which would allow for conclusions to be drawn concerning relationships between geosynthetic reinforced retaining structure and dynamic effects of its loading cannot be observed for the buildings under observation, even for great periods of observation (Hanover-Ledeburg).

4. Implementation

4.1. Facing

Besides the meanwhile well-documented load capacity of geosynthetic reinforced soil structures, questions concerning the design of the outer facing were often the reason for a rather restrained muted implementation of GRS within the jurisdiction of the DB AG. The requirements for the outer facing are diverse: on the one hand, the outer facing must protect the reinforced soil sections and the geosynthetic reinforcement from UV radiation, fire and mechanical destruction, on the other hand, it needs to fit into the environment and shall require as low maintenance as possible. In addition, the materials must meet the high demands of public transport in terms of durability; ease of handling during construction and low cost are something to be rather taken as a matter of course.

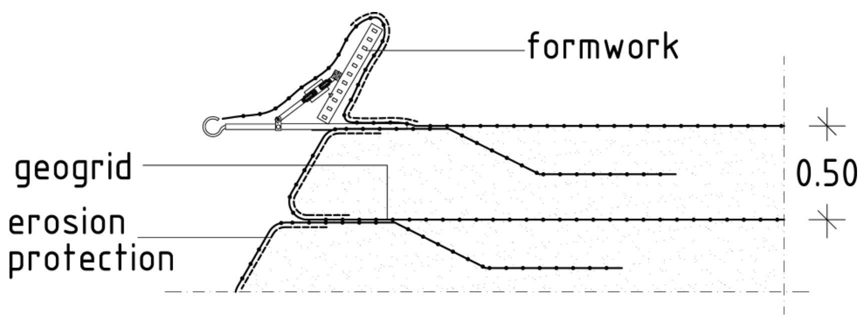

Figure 10. Front facing in the form of a wrap back structure

Initially, GRS structures were often designed in the form of a so-called wrap-back wall. The geosynthetic reinforcement was simply guided upward on the outside together with the soil filling and folded back, see Figure 10. Essential demands, in particular the protection of the reinforcement, do not appear to be met. Meanwhile, the market offers several options, however, for design according to requirements, e.g. systems such as

Muralex (Huesker), Delta Green (Rothfuß) or Dynatex (Fränkische Röhrenwerke). Figures 11 and 12 show two possibilities that have been applied recently with rail projects and that meet the requirements of the RiL 836. A crucial difference between these new systems and the traditional wrap-back wall is in the separation, implemented as a result of the folding back of the geogrid, between the highly compacted fill-material and an exterior vegetation support.

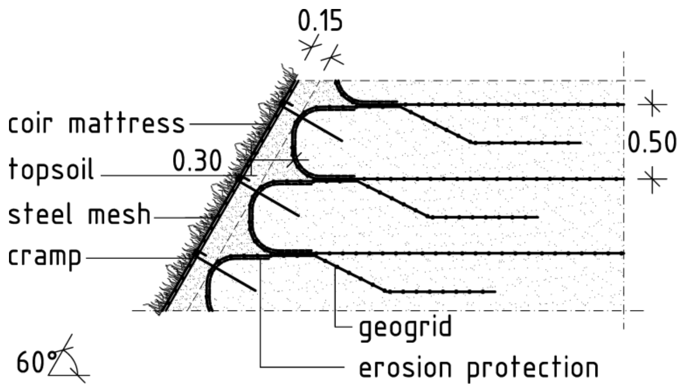

Figure 11. Wrap-back wall with separate topsoil cover provided on-site

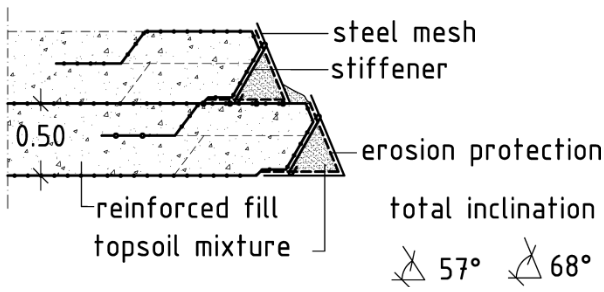

Figure 12. Wrap-back wall with outer facing made of corrosion-resistant vegetation supports, System Delta-Green

Figure 13 shows that, in addition to detailed questions concerning structural design, for green walls very basic parameters, too, such as slope inclination and direction of the structure, may be crucial for successful planting. Both images show the same embankment, a really successful planting is, however, only present on the north side of the embankment.

Figure 13. Different success of vegetation depending on direction, inclination up to 60° (left=North; right=South)

To prevent such failures in planting, it is advisable, in the planning phase already, to consult a landscaping professional. Often the choice for (customized) location- specific seed mixtures or the use of evergreen ground covers can be a remedy already.

Similar experiences were also made with the GRS-structure in Hanover Ledeburg. The hydroseeding initially implemented there was subsequently supplemented by location-specific planting.

4.2. Sound barriers / pole and mast foundations

In addition to the dynamic effects discussed in Section 2, foundation elements for signal poles and overhead line masts or noise barriers constitute another feature in the planning of GRS structures for railway embankments. If shallow foundations on top of the GRS structure do not make sense economically, the horizontal forces and bending moments must be transferred via the vertical elements, into or through the GRS structure, where required all the way into the existing foundation soil.

Figures 4, 14 and 15 show this procedure for the project in Hanover-Ledeburg. For the foundation of the sound barrier mounted on the GRS structure, empty conduits were initially rammed in. After completion of the GRS structure, these were then drilled and filled up with concrete. Material missing in the geosynthetic reinforcement due to the existence of the conduits were taken into account by a reduction of the geogrid design strength corresponding to the cutout width of the conduits.

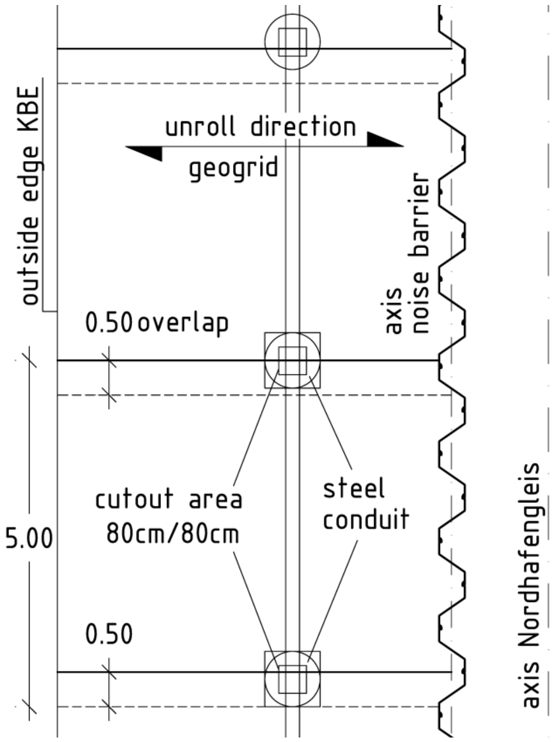

Figure 14. Nordhafengleis Hanover-Ledeburg, site plan

Figure 15. Nordhafengleis Hanover-Ledeburg, construction

With regard to the stability and serviceability of both the sound barrier and the geosynthetic reinforced retaing structure, the foundation implemented in Hanover is a satisfactory solution; practically more advantageous, however, is the execution of the piles after completion of the GRS. Initial experience with prefabricated concrete piles show that the subsequent penetration of the geosynthetic reinforcement is not a problem for the GRS structure and its use is expected to increase in the future.

5. Summary

In this publication, the deformation and serviceability behaviour of two geosynthetic reinforced retaining structures (GRS) that are within the zone of influence of dynamic loading was presented. The analysis of inclinometer readings in one case carried out over a period of several years, shows that the structures have acceptable deformation behaviour for rail traffic throughout. With regard to the track position in both cases, no abnormalities were shown.

Using select project examples, the construction of GRS structures was presented with respect to the special requirements of railway embankments. Particular importance is placed on the formation of the outer facing, section 4.1, and the execution of deep foundations for poles and sound barriers, section 4.2. The examples show that practicable solutions are being offered for both tasks.

This publication shows that geosynthetic reinforced retaining structures can be designed to suit the particular requirements of a railway route. GRS structures are therefore a technically equivalent and often more cost-effective alternative (also considering the life-cycle cost) to traditional retaining structures, even when subjected to dynamic loading.

6. References

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Huesker, *Patent text and product information on the Muralex system*

Rothfuss, *product information on the Delta Green outer skin system*

Fränkische Röhrenwerke, *product information on the Dynatex facing system*