Geosynthetic reinforced soil structure - problems faced and lessons learned. Case studies from Romania

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ABSTRACT: Geogrid-reinforced soil structures proved in many cases worthy to consider for the construction of tall embankments and they are especially adopted whenever the land availability is limited and the structures have to be developed vertically. Such structures allow building with inclinations up to 90 degrees, minimizing their footprint on the formation soil. They bring several other benefits, one of them being the possibility of using locally available material. Nevertheless, they are highly engineered structures and require careful design and execution in order to be properly constructed and become functional. This paper presents 2 case studies from Romania – a vertical back-to-back geogrid-reinforced wall with concrete block facing for ensuring access to a transfer platform for municipal waste and a 1:1 inclined geogrid-reinforced dike for flood protection of a sorting and treatment plant, also for municipal waste. For both structures the paper describes briefly the geotechnical conditions and the design calculation, but also aspects regarding the inadequate execution and consequential problems. For both structures problems were recorded during the execution phase due to inappropriate materials and lack of attention for construction-related details. Such cases reveal that reinforced earth structures must not only be correctly designed, but also properly executed and part of their success resides in the attention paid to all design details. One can also conclude that further dissemination of information about the design and execution of geosynthetic-reinforced structures is required.

Keywords: Reinforcement, Geogrid, Interlocking, Fill, Facing

1 INTRODUCTION

The geogrid reinforced soil structures proved in many cases worthy to consider for the construction of tall structures and they were especially appreciated whenever the land availability was limited and the structures had to be developed vertically. Such structures allow building with inclinations that can go up to 90 degrees, minimizing their footprint on the foundation soil.
Depending on the fill material, the difference between the footprint of a reinforced structure and a naturally inclined, non-reinforced one can be significant and create a major advantage when the land availability is limited.
The reinforced soil structures bring several other benefits, one of them being the use of local material (in most of the cases, depending on the geotechnical parameters). Nevertheless, they are highly engineered and require careful design and execution in order to be properly con-

structed and become functional. The key for success is not only to correctly design such structures, but also to execute them according to the design by:

- respecting the recommended geotechnical parameters of the fill/backfill, especially grain size distribution (to allow for interlocking with the geogrid) and friction angle, volumetric weight and cohesion of the soil;
- respecting the type of reinforcement (geogrids having identical nominal tensile strength can have different design (long term) tensile strengths, mainly due to the creep behavior);
- respecting the technology for the installation of the facing and especially the connection between the facing and the geogrid to insure sufficient pull-out strength;
- executing properly the foundation for the facing and the compaction of the fill material;
- executing properly the drainage of the reinforced soil structure.

This paper presents 2 case studies from Romania – a vertical back-to-back geogrid-reinforced wall with concrete blocks facing for ensuring access to a transfer platform for municipal waste and a 1:1 inclined geogrid-reinforced dike for flood protection of a sorting and treatment plant, also for municipal waste. For both structures the paper describes briefly the geotechnical conditions and the design calculation, but also aspects regarding the inadequate execution and consequential problems. For both structures problems were recorded during the execution phase due to inappropriate materials and lack of attention for construction-related details.

In case of the back-to-back wall, bulging of the facing was observed during execution due to installation of improper soil fill, lack of drainage and the use of a woven geotextile instead of a geogrid. The non-conformities were so severe that the structural integrity of the retaining wall was endangered as a result of the self-weight of the fill, even without additional traffic on top of the structure. It was therefore recommended to demolish the already built structure and to rebuild it.

In case of the flood protection dike, the contractor complained that the fines fraction of the fill material eroded through the apertures of the geogrid during the construction phase and he feared that this would lead to instability problems. Some execution problems were found and the paper will detail and present an analysis.

Such cases reveal that reinforced earth structures must not only be correctly designed, but also properly executed and part of their success resides in the attention paid to all design details.

2 BACK-TO-BACK GEOGRID REINFORCED WALL WITH CONCRETE BLOCK FACING

2.1 *Introduction*

For an integrated management system in one of Romania's county, a geogrid reinforced soil structure was planned and designed as part of a transfer station, in order to allow the access of the waste dumpers to a sorting /treatment platform. The narrow ground surface available for this ramp imposed a very steep or even vertical structure to be adopted.

The access ramp has a curved shape and reached a maximum height of 6m. It was designed for 2 trafficable lanes of 3 m width each, considering a uniformly distributed traffic load of 18.26 kPa, as given by the waste dumpers.

A back-to-back reinforced wall was the designers' option in order to be able to ensure the required footprint, but also strength and durability in service. This was reinforced with 10 layers of mono-axial PET laid & welded geogrids of 80 kN/m nominal tensile strength and minimum 45 kN/m long-term design strength in combination with a concrete block facing. One layer of geogrid was placed every 3 rows of blocks resulting in a vertical spacing of approx. 60 cm. The embedment length of each layer was of 5 m. The inclination of the facing was 90º, being designed with hollow concrete blocks having dimensions of 450(W) x 190(H) x

295(D) mm. The hollow blocks are filled with gravel (16/32 mm), which ensures the necessary pull-out strength, together with 2 plastic pins which equip each facing block to prevent any horizontal movement during backfilling and compaction
The soil considered in the design was a granular type fill, with less than 15% fines, an internal friction angle of minimum 30º and a volumetric weight of 19 kN/m^3, with a pH of 4 to 9. The subgrade is the natural ground composed of a clayey, silty sand, having a friction angle of 32º and a volumetric weight of 19 kN/m^3. Being on the safe side the cohesion portion was left unconsidered.
The total width of the reinforced structure, between the outer faces of blocks is 7.2 m.
Figure 1 shows a typical cross section of the reinforced wall for the maximum height.

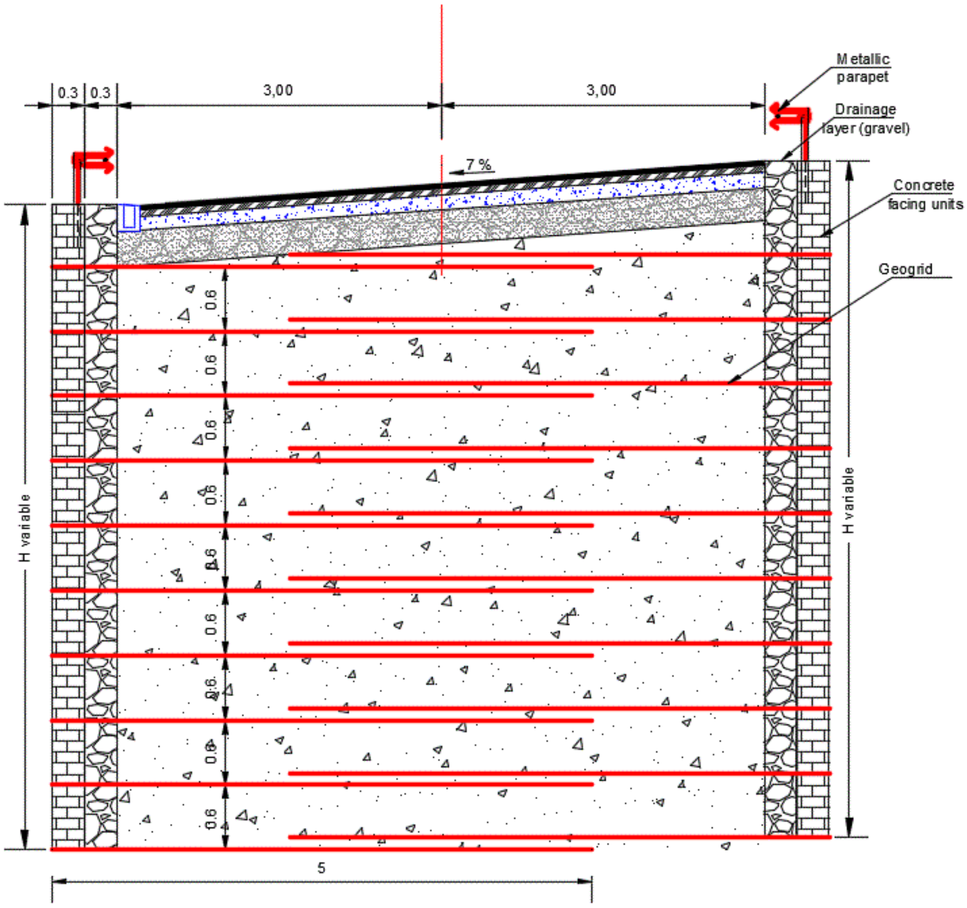

Figure 1. Typical cross-section of the designed back-to-back reinforced wall

2.2 *Design calculation*

The stability analyses were performed according to Eurocode 7 (EN 1997-1), national technical norm NP 124 - 2010 and Eurocode 8 (EN 1998-5) as an earthquake with a seismic acceleration $a_g = 0.12g$ had to be considered.
The design of the back-to-back reinforced wall was performed using recommendations of the national technical guide GP 093 - 2006 and of FHWA-NHI-00-043.
Figure 2 presents the results of the overall analysis (global stability) (Comment: the slip circle shown in Figure 2 doesn't show an overall failure, but much more an internal-type failure as it is only going through the reinforced fill and not through the backfill and subgrade soil), while figure 3 shows the results for the internal stability check using the two-part-wedge method.

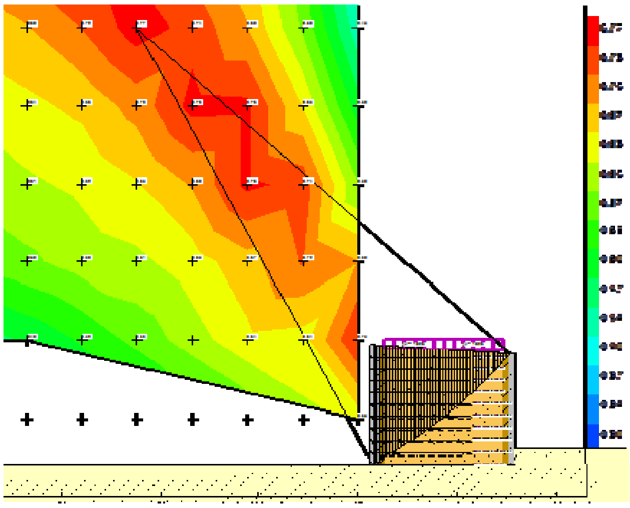

Figure 2: Bishop's overall analysis - critical sliding circle, maximum utilization degree μ=0.77 - calculation according to EN 1997-1 in design approach 1 combination 2 = design approach 3

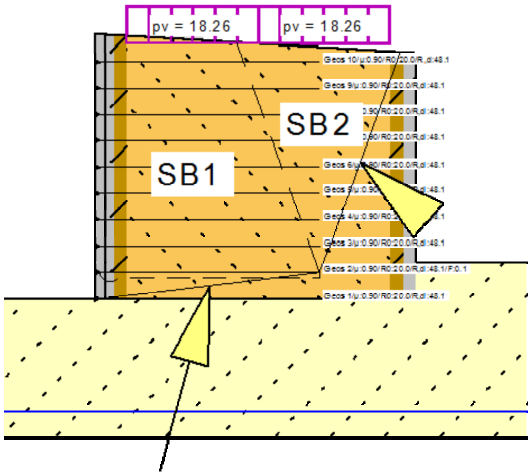

Figure 3. Two-part- wedge method internal stability analysis - critical wedge, maximum utilization degree μ=0.81 - calculation according to EC7 in design approach 1, combination 2

2.3 *Execution problems*

Once the construction was started (by a company without experience in this type of construction), the engineer who verified the project was informed that, as the ramp increased in height, bulging of the block wall facing appeared and some blocks were even falling (figure 4).

Figure 4. View of the structure during execution, showing fallen facing blocks

Following an investigation on site major non-conformities were observed:
A woven geotextile was supplied and installed instead of the proposed geogrid (figure 5a). The geotextile provided a nominal tensile strength higher than required, but due to its structure without openings it couldn't interact with the fill material by interlocking; due to this reason there was also no sufficient connection with the facing blocks.
The fill material that had been used was a clayey soil, different from the one considered in the design (figure 5b).
The drainage layer installed behind the block facing was not enough permeable (figure 6a). Proper drainage of the fill material is essential in order to avoid saturation with water and buildup of hydraulic pressure behind the facing.
The facing blocks were partially filled with mortar instead of gravel (figure 6b) (the gravel was meant to provide the connection between the reinforcement and the facing in case the proper geogrid would have been used).

(a)

(b)

Figure 5. Execution of the back-to-back wall (a) reinforcement material (geotextile); (b) fill material (clayey)

(a)

(b)

Figure 6. Execution of the back-to-back wall – improper treatment of the facing (a) improper and insufficient drainage material behind the facing; (b) mortar filling between and partially inside the blocks

The non-conformities were so severe that could endanger the whole structure, which would have not been stable even to support its own weight, without any traffic loading on top, therefore the verifier recommended the demolition and a complete reconstruction of the ramp. The ramp was demolished and rebuilt with proper materials under close technical supervision (see figure 7).

Figure 7. Rebuilt back-to-back reinforced wall with proper materials

The encountered problems demonstrate how sensitive reinforced soil structures are in relation to the use of proper building materials, either natural or pre-fabricated and to the proper construction technology. An improper reinforcement material (in this case: woven geotextile) will not interact with the granular fill material. A material with higher short term strength will not help in terms of interlocking and friction behavior. Unqualified execution leads to serious mistakes causing detrimental consequences and high costs (repair / reconstruction).

3 GEOGRID REINFORCED FLOOD PROTECTION DIKE

3.1 *Introduction*

In the framework of a municipal waste management project, a station for sorting recyclable waste and for treating biodegradable waste was required.
As the site was situated in a flooding area, a small river had to be deviated and flood protection dikes were designed. The protection dikes have variable heights, between 0 and 5 m, based on the site topography and the water level with a 2% probability of exceedance plus 0.50 m. Some of the dikes also allow the access to the site from the national road.
Also, in this case the land availability was an issue as the construction was placed in the immediate vicinity of agricultural lands belonging to private owners, therefore dikes outer slopes couldn't be designed to a lower inclination than 1:1 and a geogrid reinforcement was required to provide adequate stability at the desired inclination
The subgrade was composed of 1 – 1.40 m sandy, clayey silt, soft to medium soft (ϕ = 15º, c = 14 kPa), followed by 3.50 – 4.20 m depth of highly compressible silty clays and sands, followed by a sand layer. The groundwater was found at a maximum level of -0.5 m bgl. Due to the low quality of the subgrade in terms of bearing capacity and the high level of the underground water, it was decided to construct the dikes over a load distribution platform using a geogrid with 80 kN/m nominal strength in both directions.
The dike slopes were reinforced with layers of mono-axial geogrids with 80 kN/m short term strength in main direction, installed at 0.50 m vertical distance.
The design required a non-cohesive soil as dike fill, having a minimum friction angle of 27º.
The face of the dike on the water side was designed to be covered with a 1.5 mm textured geomembrane to insure the waterproofing, followed by 50 cm of soil with an erosion control mat on top and 3-5 cm of pre-seeded topsoil for the establishment of the vegetation layer (figure 8).

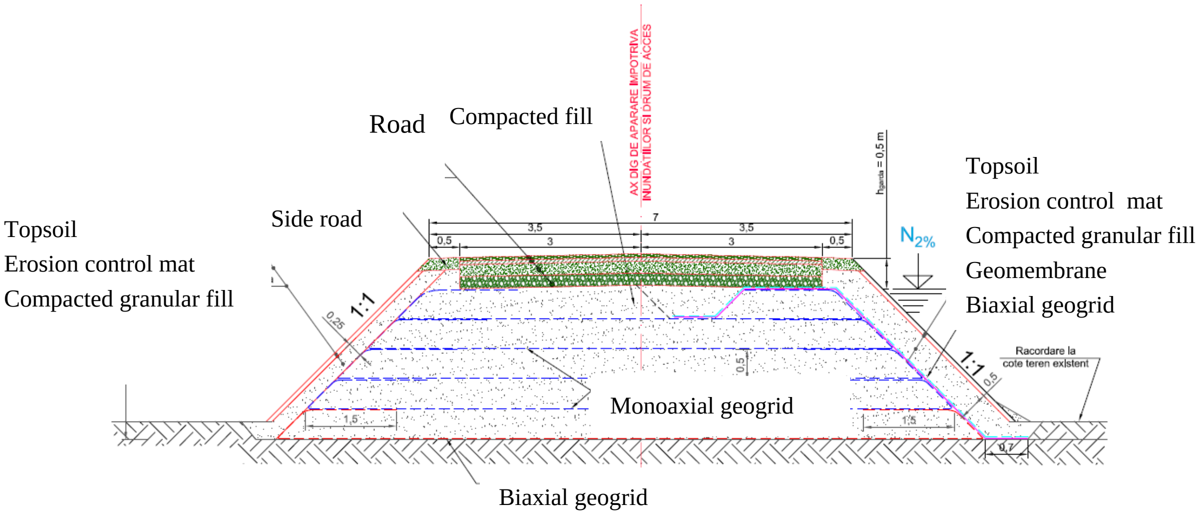

Figure 8. Typical cross-section through the flood protection dike

3.2 *Design calculation*

The dikes were designed with 2 lanes of 3 m each on top and a safety zone of 0.5m to the left and to the right. The traffic load considered for the trafficable length of the dike was 25 kPa. A seismic load also had to be considered, corresponding to a design acceleration of a_g=0.15g. Figure 9 presents the results of the overall stability analysis (global stability), while figure 10 shows the results for the internal stability check using the wedge method.

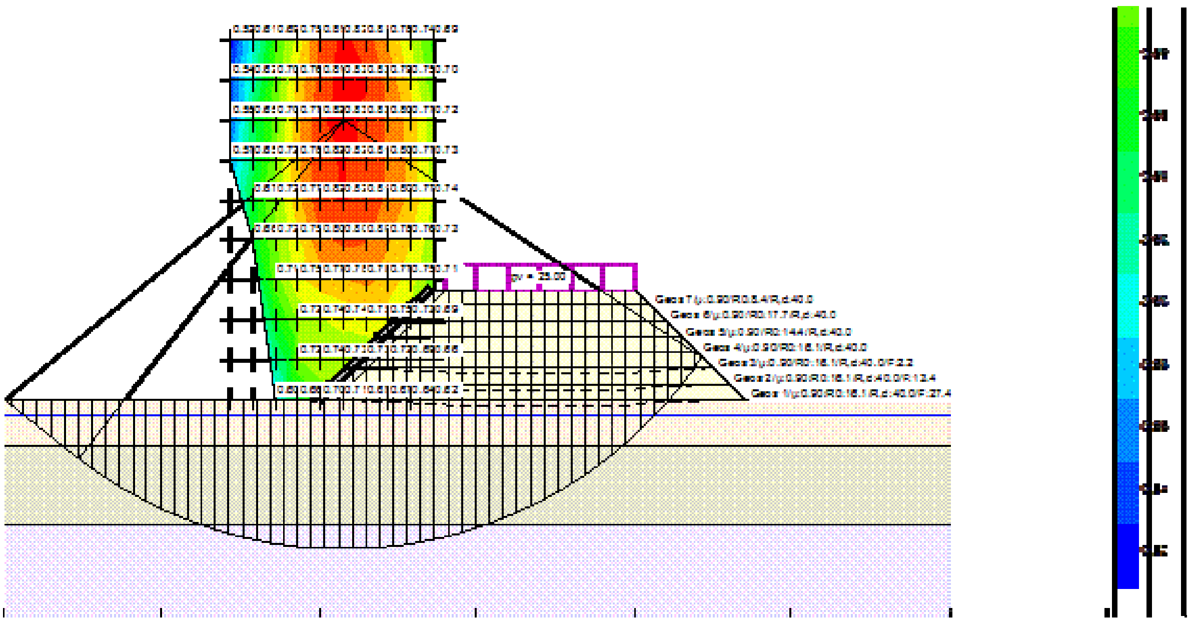

Figure 9. Bishop's global stability analysis - critical sliding circle, maximum utilization degree µ=0,83 - calculation according EN 1997-1 using design approach 1 combination 2 = design approach 3

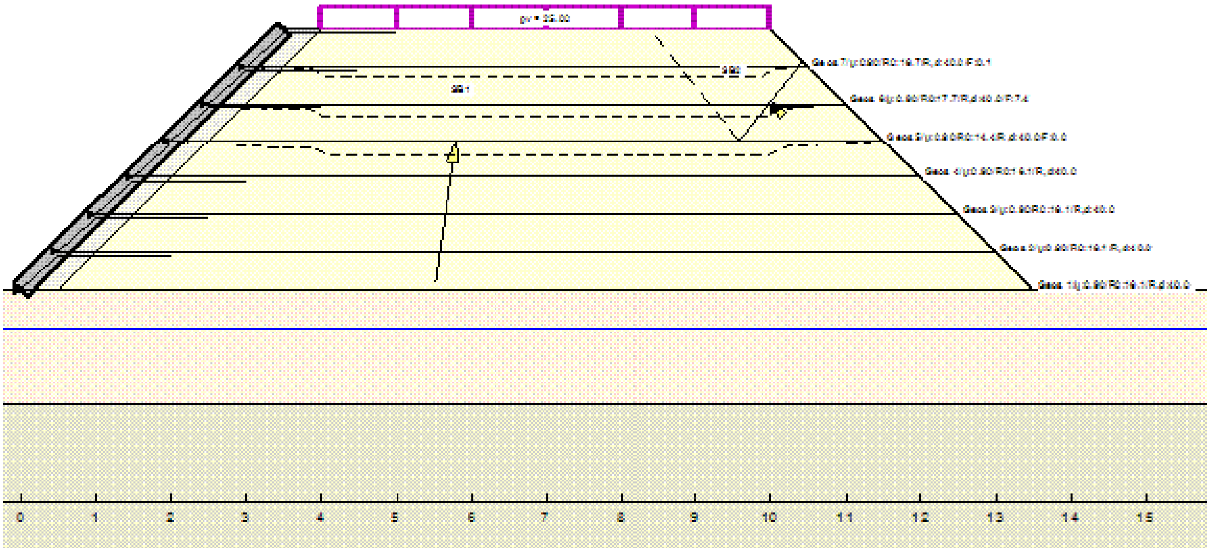

Figure 10. General wedge method internal stability analysis - critical wedge, maximum utilization degree μ=0,38 - calculation according EN 1997-1 in design approach 1, combination 2 = design approach 3

3.3 *Execution problems*

During the construction phase, the contractor complained that the fine fraction of the fill material eroded through the openings of the geogrid and he feared that this would lead to instability problems.

The investigation performed on site revealed that the problem was local, only on the outer faces of the dike and involved several other aspects.

The granular fill material being used was well-graded aggregate, with a grain size distribution curve (represented in green on figure 11) fitting in the range recommended by the designer (red and blue curves in figure 11). As the fill material was supposed to have a higher friction angle than required by design, no stability issues were to be expected. But, the fill material also had more than 88% of the particles smaller than 31.5 mm, which is close to the width of the geogrid openings (73 mm x 30 mm), meaning that it was very easy for the small particles to erode through the openings of the geogrid in the absence of a geotextile installed behind the geogrid in the wrap around area (figure 12).

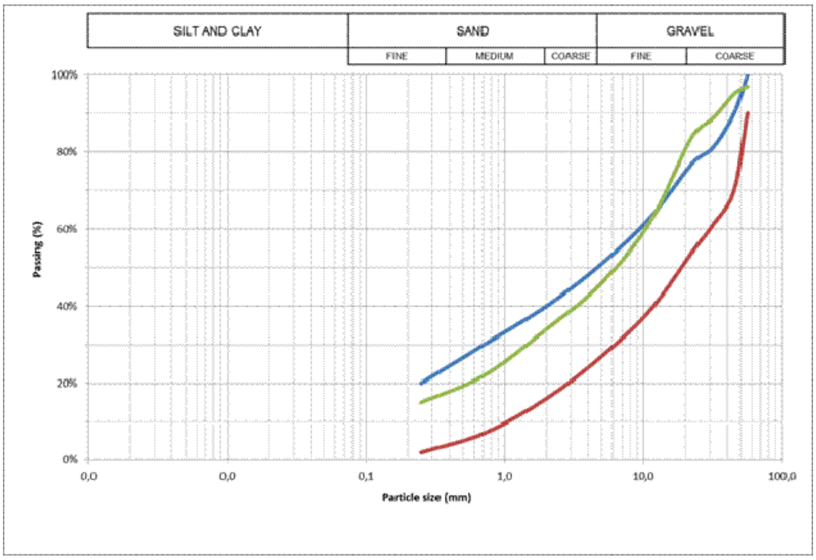

Figure 11. Fill material: recommended granular domain (between the limits represented by red and blue curve) and grain size distribution curve of the fill (green curve)

Figure 12. Fill material: more than 88% of the fill material is passing through the openings of the geogrid in absence of a geotextile

The compaction of the last meter towards the edge of the dike was not properly performed. In some cases the granular material near the edge was not compacted at all (figure 13a), while in other cases a heavy vibro-compactor was driven over the edge which is completely against the working procedures recommended for such structures (figure 13b). According to these procedures, the last meter of the fill material towards the edge must not be compacted with anything else but a hand operated vibro-compaction plate.

(a) (b)

Figure 13. Execution: (a) improper compaction on the edge; (b) use of heavy vibro-compactor at the edge

Another execution problem was that no temporary frame (as the one shown figure 14) was used for the wrap-around facing, therefore the compaction quality at the edge of the dike was affected. As well, the visual aspect of the reinforced soil in the wrapped - around area was negatively affected.
The very dry season, with extreme temperatures (38-39 ºC in shadow) caused the quick loss of humidity of the fill material, making the fine grained fraction highly mobile.
No geotextile or erosion control mat with very small openings was used behind the geogrid in order to prevent the migration of the small particles through the apertures of the geogrid.
Also, the execution of the dike did not respect the succession of operations recommended by the designer, meaning a complete sequence of construction of small sections of dike, comprising reinforcement, sealing and cover.
All those problems were addressed by the designer who required the proper compaction on the last meter towards the edge of the dike using a manually operated vibro-compaction plate, the use of a thin non-woven geotextile behind the wrap around area of the geogrid on all the areas still to be constructed. It was also recommended that in the areas where the fine grained

particles eroded through the openings of the geogrids (the wrap-around area at the outer face of the dike) the constructor should use “T”-shaped tools to grab the material from the toe of the dike and drag it upwards to fill the gaps. Immediately after this the constructor was asked to install the waterproofing geomembrane, before the humidity of the fill material is lost, and cover it with the 50 cm of cover soil, properly compacted, followed by the installation of the erosion control mat.

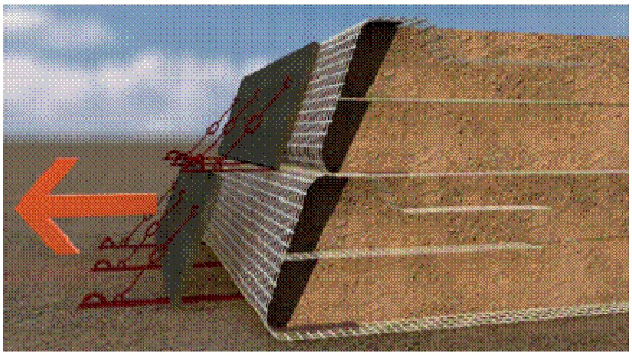

Figure 14. Temporary frame used to support the reinforced earth structure in the wrap-around area, during the construction phase (images belonging to NAUE GmbH & Co.KG)

Luckily in this case the works were in a stage that allowed corrections without major loss. But such works show once more that neglecting small but important details or particular conditions on site can lead to the development of serious problems.

4 CONCLUSIONS

Geogrid-reinforced soil structures are cost-effective and safe solutions in many cases, but their success is strongly dependent also on the execution details. They are highly engineered structures and require careful design and execution in order to be properly constructed and become functional. The paper presented 2 case studies from Romania – a vertical back-to-back geogrid-reinforced wall with concrete blocks facing and a 1:1 sloped geogrid-reinforced dike for flood protection. Both structures experienced execution problems which were described in detail, together with some aspects related to the design.
Such cases reveal that reinforced earth structures must not only be correctly designed, but also properly executed and part of their success resides in the attention paid to all design details. One can also conclude that further dissemination of information about the design and execution of geosynthetic-reinforced structures is required.

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