Stiff geogrids for Slovak railways

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ABSTRACT: The paper deals with the use of stiff integral geogrids in the railway fills and track substructures. Geogrid(s) and a crushed stone layer provide a composite – geoplate. This composite provides a stiff foundation for above structures. Both technical and technology benefits achieved by using of stiff geogrids are commented in presented applications. Special attention is given to the first part of the modernized track Bratislava-Trnava which is part of European corridor No.V.

1 INTRODUCTION

Stiff integral biaxial geogrids (SIBG) became standard products for Slovak railways especially in a track subbase. These geoproducts provide a new solution for both railway problems with the railway track substructure and day-to-day ones. The paper describes some of stiff geogrids applications used by Slovak Railways. Two ways of geogrid use are presented. First of these is reconstruction of old railway track and second one is repair of damaged railway embankment or railway track superstructure/substructure only.

International activities of Slovak Railways Authorities aim to an integrity of Slovak railway network with European railways resulting in some strategy decisions. These decisions determine both the tendency ways and a necessity of the Slovak railway net modernization. Two of the TransEuropean corridors Nos. V and VI between Poland, Hungary and Ukraine that were agreed in Crete runs across Slovak Republic area.

The following four successful stages of Slovak railway network modernization are considered:

- to improve the track technical level and to remove the greater part of slow sections,
- to reach a standard level of the selected tracks,
- to fulfil the AGC and AGTC requirements for higher speed (160 km/hod.), higher load (22,5 tons per axle), and higher traffic comfort on the selected tracks,
- further increasing of the track speed and a construction of high-speed rail link connected to Europe's railway network.

Paper presents the design and technology process of six mentioned projects. It gives special attention to both the design of reinforced subbase layer in the railway track foundation and the practical efficiency of this structure.

2 GEOGRIDS USED IN PROJECTS

Practice verifies to be very suitable to utilise very good index and performance properties of SIGBs in railway repairs and reconstruction. Unbound granular layer reinforced by this geosynthetic reinforcement is a composite consists of a high quality crushed stones and stiff integral biaxial geogrid(s) - Geoplate - which provides the one layer or multiple layer system with a higher stiffness and bearing capacity. A number of types of geoplate using have been developed. One of these is a track substructure.

The geogrids used in the projects for reinforcement application in truck substructure shall conform to the properties required by designer. These specifications allow a geosynthetic reinforcement effectiveness when it is subjected to cyclic loading caused by passing train wheels. SIBGs functioning as a lateral confinement-type reinforcement restrain a movement of soil particles in the substructure. This stiff reinforcement with large apertures (optimum relationship geogrid aperture/aggregate size is met) needs not to deform into a curved tension-membrane before it can act. A double reinforced substructure provides a higher stiffness and essentially higher bearing of capacity as a synergistic effect is developed there.

In above-mentioned modernisation project Tensar geogrids are used to provide the reinforcement into track substructure. Stiff integral biaxial geogrids of two different strength levels are used and are identified as the H-geogrid and the L-geogrid. Their properties are shown in Table 1.

Table 1. Specification of geogrids for track substructure reinforcement

Parameters	Specifications	
	L-geogrid	H-geogrid
Reinforcement function	Additional reinforcement	Main reinforcement
Type of geosynthetic reinforcement	Polypropylene stiff integral biaxial geogrid	
Thickness	1.1mm/0.8mm (ribs) 4.1mm (junctions)	2.2mm/1.35mm (ribs) 5.0mm (junctions)
Tensile strength	> 20.0 kN/m	> 30.0 kN/m
Elongation (strain at failure)	< 12 %	< 14 %
Junction strength (GRI:GG2 test)	> 90 %	> 90 %
Geogrid matrix stiffness (in-plane torsion rigidity test)	0.5 N.m/degree	0.9 N.m/degree
Agreement with application	Consent to use into track substructure was given by Slovak Railways Authorities	

3 EFFECTIVENESS OF SIBGS IN THE TRACK SUBSTRUCTURE

An immediately response of stiff integral geogrid with crushed granular particles interlocked in stiff aperture to cyclic loading is the main mechanism of this reinforcement included into track subbase. The ribs of integral biaxial grids are manufactured with a vertical face. This provides a bearing surface for the fill particles. This interlock, combined with high junction strength, high tensile stiffness at low strains and torsion stiffness, accounts for the high efficiency of these geogrids in strengthening thin subbase layers.

The action of SIBGs described above utilises in practice the results of grid performance testing, Kinney, Xiaolin (1995). The results indicate the following geosynthetic reinforcement properties govern its performance: /1/ rib thickness, /2/ rib and junction geometry, /3/ junction strength, /4/ rib and junction stiffness and /5/ stiffness of the geogrid matrix.

Stiffness is very important property in above list but not only tensile stiffness (tensile modulus) or also bending (flex) stiffness and torsion stiffness especially. The combination of all types of above-mentioned stiffness could be expressed by one parameter – a complex stiffness.

Positive influence of polypropylene SIBGs to increasing soft subsoil bearing capacity was verified during the construction of railway corridors in Czech Republic (Hubík et al., 2000), (Malá, 2000), where various geosynthetic materials were tested. Stiff integral biaxial geogrids were most effective among geosynthetic reinforcement and the contractor could always rely on them. The most of geogrids was used after changing of original reconstruction technology designed in project as the original technology was not possible to apply.

First layer of SIBG placed between the fill and the subgrade and second layer of SIBG(s) placed toward the surface of the thin layer of granular crushed stone improve the bearing capacity of the layer itself. For the assessment of system behaviour of that geoplate and for understanding mechanism of improvement the plate load bearing tests are carried out according to STN 73 6190 or DIN 18 134.

Usually, only negligible strains are in the subbase reinforced by several layers of SIBGs. The mobilised tensile strength in reinforcement is small and it is developed for a short time. Therefore, it is the complex stiffness of the SIBGs that is of greater significance since it governs the forces that can be mobilised in geogrids. Geogrids provide a structural support in geoplate through combination of two possible mechanisms such as: /1/ lateral restraint of the subbase, and /2/ increasing of the subbase bearing capacity. Each layer of SIBGs incorporate into multiple layer system acts as a bearing capacity type of geosynthetic reinforcement. This function of geosynthetic reinforcement of soils is fourth one added to the three presented reinforcement mechanisms, Koerner, 1994. Both the complex stiffness of the SIBGs and the SIBGs act as a bearing capacity reinforcement in thin geoplate and their influence on the system behaviour should be investigated in near future.

4 MELCICE TRACK REHABILITATION

4.1 *Problem*

Nowadays, there are two limiting factors which restrain to reach the requested higher track speed in Slovakia. First, the limiting direction conditions of the existing rail link and second, the subbase low bearing capacity in some link sections which decrease the track geometrical position stability.

In order to obtain the necessary practical knowledge on the new conception of the track rehabilitation there was decided to make a complex reconstruction of the short track section Melcice-Zlatovce which is the part of corridor No.V. Low railway embankment in the straight link was chosen for this purpose. A complicated ground conditions and soft subgrade demanded improvement of subgrade and to increase its bearing capacity.

4.2 *Design*

For the reconstruction of the Melcice-Zlatovce site it was required by the Slovak Railways Authorities to achieve the minimum values of modulus of deformation as follows:

- 50 MPa on the subbase surface,
- 80 MPa on the surface under sleeper.

Based on the detailed geotechnical investigation, and using the foreign and domestic knowledge about geoplate, a typical cross-sections were chosen for design. The cross-section with one layer of SIBG for modulus of deformation on the subgrade surface of E_{sg} = 11 to 21 MPa is shown on Figure 1. The track section was divided into several shorter sections with the identical modulus of

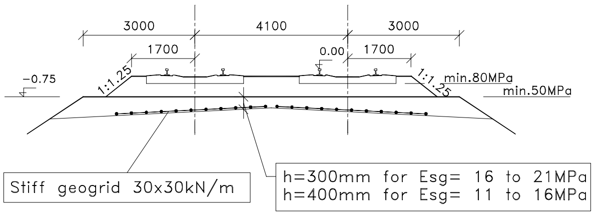

Figure 1. Typical arrangement of the track superstructure for modulus of deformation on subbase surface of E_{sg} = 11 to 21 MPa

deformation on the subgrade surface E_{sg} . For practical comparison, there were used in some sections with modulus of deformation on the subgrade surface of $E_{sg} < 15$ MPa not only SIBGs but also D.O.S. knitted geocomposite.

A nonwoven geotextile was placed onto the subgrade/subbase interface. Geotextile acts as a separator and filter layer simultaneously. There is potential benefit in combining separation and filter functions of geotextile. Geotextile is covered by a protective layer of sandy gravel a thickness of 150 mm. On protective layer the geogrid sheet was laid and on this was placed a 300 mm subbase layer of crushed stone.

4.3 *Construction*

The old parts of the track (rails, sleepers) and the foundation (ballast, subbase material) were removed and the new structure was laid on improved subgrade. Geogrid sheets (width 4,0 m is enough for load spreading) were placed by hand on compacted surface of sandy gravel layer. Subbase layer of crushed stone is placed and compacted in lifts. A compactive energy is controlled continuously.

The construction of a geogrid reinforced geoplate put into the track substructure generally follows the same procedure as that used for a road subbase. Quality of crushed stone (grading curve, effective size, uniformity coefficient, particle shape, hardness) and its compaction are the most important specifications for required quality of the track structure. Thus for CQA a placed material is periodically taken to confirm its properties. Continuous inspection of the placement of geogrids and crushed stone was realized to ensure that geogrids are placed without wrinkles and overlapped as required in the plans.

4.4 *Performance*

Using the SIBG in track substructure the above mentioned quality criterion for the subbase was fulfilled. The effectiveness of the reinforced subbase was validated by means of plate bearing control tests. Besides, a data collected by a railway diagnostic vagon set during last three years confirms the long-term stability of geometrical rails position. A track quality limit value after reconstruction as well as during three years fulfils the track quality limited value for particular speed range. This track geometrical position approach is used in Slovak Republic.

Economic, technical and technology benefits achieved by using geogrids at this site are following:

- unrestricted and immediate site access because geoplate is stable working area
- saving in subbase thickness of 30%
- reduction of material moving
- ensuring the required track substructure higher quality specification
- increasing a track substructure life (expected life is up to 50 years)
- reduction of maintenance costs

5 CADCA TRACK REHABILITATION

A track section Čadca-Skalité is part of corridor No. VI. On this site the railway superstructure/substructure rehabilitation was realized without removing of rails and sleepers. This frequently used technology process was supplemented with another step - unrolling of biaxial geogrids onto leveled, compacted subgrade surface. A nonwoven geotextile under the geogrid limits the rise of ground water from the subgrade.

The above reconstruction method was applied on the one track line sections between the railway stations. Good quality of the original track grating (rails and sleepers) enables to use this technology. An increased construction speed reduced the time of reconstruction. Thus a track continuous closure was not necessary.

If the conditions are suitable (e.g. not very soft subsoil), method based on leaving the track grating will be used for rehabilitation of the track substructure. Placement of stiff geogrid (unrolling) is a simple construction step.

6 REPAIR OF DAMAGED HIGH EMBANKMENT NEAR MALA LODYNA

6.1 *Problem*

During a particular heavy summer rainstorm, the track substructure and upper part of the high railway embankment were very damaged. That causes a critical situation on the main railway link at the north-east part of Slovakia. The traffic was partially restricted. One rail line was damaged and second one was affected by temporary train speed reduction. A very fast repair was required.

6.2 *Design and construction*

Stiff integral biaxial geogrids offered very quick and reliable solution. Three layers of geogrid were used to repair the considerably damaged upper part of embankment. The slope reinforcement was required to boost stability immediately after the repair completion.
Initially, the slope-failure soil was removed, and excavation was then carried out to the required level. Crushed stone fill was placed and compacted in layers. Three geogrid layers at a 0,8 m vertical spacing were installed in the upper part of the reconstructed embankment as shown in Figure 2. This number of geogrid layers was chosen to increase the efficiency so that the local stability of the slope was achieved.

The repair speed and its appropriate quality were decisive factors in this case.

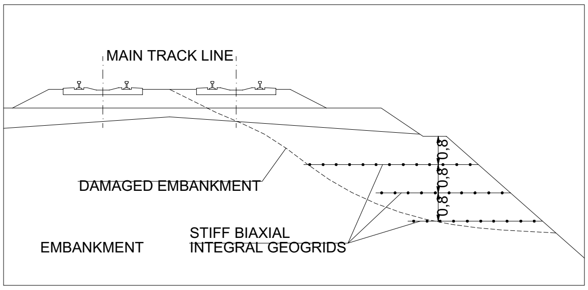

Figure 2. Reconstruction scheme for damaged embankment

7 DEVINSKA NOVA VES EMBANKMENT

7.1 *Problem*

The long-term differential rail settlement caused by changes in the condition of the foundation soil, such as moisture content, saturation, variable compressibility has created continuously problems on the main rail line (corridor No.IV) near Bratislava. When the number of maintenance operations increased to an unacceptable level, complete repair was required.

In the first phase of geotechnical investigation the high railway embankment was monitored to find out whether the problems are only in the upper part of the embankment or overall stability is insufficient. Horizontal movements were developed only in upper part of the embankment, the foundation is stable.

7.2 *Design*

Reconstruction works included the following steps: /1/ construction of stabilizing bench in the embankment toe, /2/ removing the upper part of embankment including a railway foundation and subgrade, /3/ construction of a special mattress consist of impermeable GCL, two layers of stiff biaxial geogrids with "wrap-around" side and crushed stone layer between geogrids, as shown in Figure 3. The mattress (stiff layer) had a maximum thickness of 0,7 m and it created an improved subgrade.

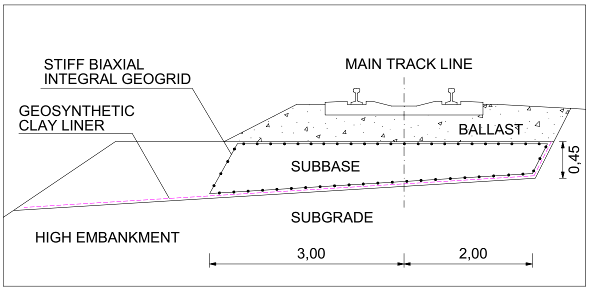

Figure 3. Reconstructed track substructure

7.3 *Construction*

The reconstruction of the upper part of the embankment and track substructure included some interesting steps as follows:

- excavation of soft subsoil in narrow strip under outside rail
- GCL placed onto leveled and compacted subsoil, see Figure 4
- lower geogrid placed on GCL
- arranging the massive geoplate consist of three sheets of geogrid
- joining of the parallel sheets of geogrids by HDPE braid.

Figure 4. Geogrid and underlying GCL placed on subbase

A track quality limit value in this section fulfils required criterion.

8 ZIRANY HIGH EMBANKMENT

8.1 *Problem*

The first stiff grids application in Slovakia was reconstruction of a collapsed the 16m high railway embankment on saturated clays. The destruction of this embankment was caused by the long-term bulging of its clay subsoil.

8.2 *Design*

The total volume of 33,000m^3 of failed embankment was excavate and fully reconstructed by using of reinforced soil structure. The design philosophy included improvement of the embankment foundation by vertical sand drains in subsoil and the stiff Geocell mattress onto subsoil as shown on Figure 5. In order to ensure embankment slope stability, geosynthetic reinforcement was installed into the embankment slope.

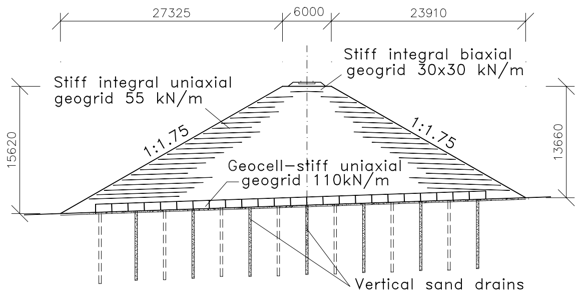

Figure 5. Typical cross-section, Zirany

8.3 *Construction*

The Geocell mattress was rapidly assembled from stiff uniaxial integral geogrids during winter time. The Geocell acts as a rigid, stiff foundation for the embankment, it increases the overall stability and decreases a differential settlement.

During the embankment construction and after that the geotechnical monitoring was carried out. Piezometric water levels, pore water pressure and earth pressure in the subsoil and settlement of both the subsoil and the new embankment were observed, analyzed and compared to the calculated values.

9 SLOVAK RAILWAY NETWORK MODERNISATION

9.1 *General*

According to the schedule of network realization (third step mentioned earlier) the first section length of 50 km between Bratislava and Trnava began in 2000.

The subsoil investigation was performed to access strength and compressibility properties of subgrade. Extensive plate load bearing capacity and dynamic penetration tests were carried out. A cross section of the ground with bearing capacity values along the track axis was determined.

In the preparation of a design and suitable construction methods, the following issues should be solved:

- existing traffic speed, 80 to 120 km/hod only
- low quality of the track superstructure (rails, ballast)

- subgrade and subbase problems, low bearing capacity on the subbase surface
- stability problems of the high railway embankments at brook/track crossing

9.2 *The track substructure arrangement*

For modernization project it was required by the Slovak Railways Authorities to achieve the minimum values of modulus of deformation as follows:

- 50 MPa on the subbase surface,
- 80 MPa on the surface under sleeper.

Therefore, the reinforcing technique was chosen by designer. Four types of the track substructure arrangement with SIBGs was developed. At the first section Cífer-Trnava two types of the track substructure was used. First type is shown on Figure 1 and second one is shown on Figure 6.

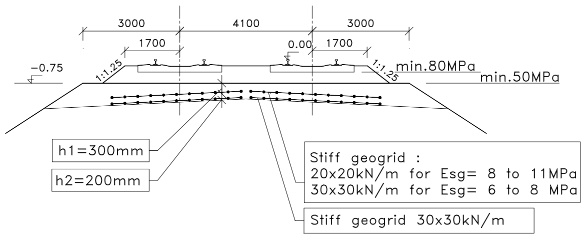

Figure 6. Typical arrangement of the track superstructure for modulus of deformation on subbase surface of E_{sg} = 6 to 11 MPa

The main components of the track substructure are: the subbase consisting of high quality crushed stone, a properly prepared subgrade and one or two layers of SIBG(s). Depending on the different subgrade bearing capacity, the subbase thickness, type of geogrid and number of geogrid layers are changed.

9.3 *Construction of the first section Cifer-Trnava*

The method based on bringing track grating down was used. The old track structure under line No.1 was excavated.

The widening of the high embankment was the first construction step on site. Existing railway embankment was excavated to the required benched profile, the higher steps of the benches coinciding with the required levels of the SIBG used as a temporary reinforcement. On soft subsoil of the new fill the SIBG 30x30 kN/m was placed, as shown on Figure 7. The stabilizing bench was constructed in the embankment toe. This design solved the problem of an expected differential settlement between the new fill and the existing embankment. The SIBGs are only required to ensure stability during the foundation consolidation.

Geosynthetic geocomposite was installed on the slope as a erosion control system.

Reinforcing of the subbase provided to decrease a excavation soil volume. A smaller vertical distance between the rail level of existing line No.2 and a subgrade surface level of the reconstructed line No.1 made possible to construct the new line No.1 without special support measures between lines. It was very important economical and time benefit. There was only necessary to reduce a speed to 30 km/hod.

Figure 7. Widening of the embankment

A nonwoven geotextile was placed onto the leveled subgrade surface. A layer of stiff geogrid 30x30 kN/m was placed onto geotextile prior to placing a well graded crushed stone layer, fraction 0-32 mm in several lifts, as shown on Figure 8, Figure 9. If there are expected the additional vehicle passes on the subbase surface the subbase design will be consider this special situation.

Figure 8. Placement of stiff geogrid. Line No.1

The construction quality control process for the track substructure is intended to accomplish four objectives: (1) to ensure that subbase materials are suitable, (2) to ensure that subbase materials are properly placed and compacted, (3) to ensure that geogrids are not damaged in any way and that their placement meets project specifications, (4) to ensure that the completed subbase has a requested bearing capacity. Quality assurance plan considers a plate load bearing capacity tests as a QC tests.

In-situ plate loading bearing capacity control tests were carried out continuously. The target E_{v2} values, 50 MPa on the subbase surface and 80 MPa on the surface under sleeper was exceeded throughout.

Inspection of the geoproducts installed onto track subbase surface (geotextile and geogrid) showed that nonwoven geotextile with a mass of 300 g/m^2 had locally failed by sharp soil particles. This fact induced to the following proposal:

- to use a nonwoven geotextile with a mass greater than 500 g/m^2, or
- to use a woven geotextile with higher puncture resistance, or
- a protective sand layer to place on geotextile

Figure 9. Site before placement of subgrade layer. Line No.1

10 CONCLUSION

Stiff integral geogrids are used for railway track structures. Various types of application are presented, such as reconstructions of the track substructure by method based on leaving the track grating as well as by method based on bringing the track grating down, a rapid repair of damaged track and reconstruction of a failed high railway embankment. Special attention was given to the first part of the modernized track Bratislava-Trnava.

The modernization of Slovak railway network is one of the most challenging tasks of this decade. This paper presents one aspect of this complex project: a track subbase reinforced by stiff integral biaxial geogrids. The reinforced subbase – geoplate – provides a stiff foundation for track superstructure and increases the structure overall quality.

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