GEOSYNTHETIC REINFORCED HIGH RAILWAY EMBANKMENT: DESIGN & MONITORING

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ABSTRACT: The modernisation project of the railway track from Bratislava to Trnava includes an construction of the Senkvice relocation that is 2,4 km long. One section (length: 1,2 km) was built on soft and very compressible subsoil with low bearing capacity. A designer proposed to accelerate of subsoil consolidation, to reinforce the embankment and lay it on on the top of geocells. The geocells mattress assembled of stiff uniaxial integral HDPE geogrids was designed to increase the stability of embankment and to reduce differential foundation settlements in both lateral and longitudinal direction. To facilitate monitoring of the construction of railway embankment and to observe the performance of geodrains and geocells, five measuring profiles were designed. The instrumentation of the reinforced section consisted of vibrating wire piezometers, hydrostatic profile gauge, digitild inclinometer probe and sliding deformeter. Small excess pore pressure in the foundation soils had developed during the construction. Beneficial influence of the geocell mattress is evident. The settlement of embankment constructed on geocell mattress is approximately three times lesser than the settlement of the embankment without geocell mattress. The magnitude of surface settlement along cross-sections is almost the same, and the settlement curve is uniform.

1 INTRODUCTION

Within Slovakia's recent integration into the European Union, a huge railway network modernisation project had started. Domestic financial resources, as well as resources from EU's support funds were mainly invested into modernisation of corridors Nos. IV and V. The modernisation project of the railway track from Bratislava to Trnava includes an construction of the Senkvice relocation that is 2,4 km long. One section (length: 1,2 km) was built on soft and very compressible subsoil with low bearing capacity. The relocation is composed of sections, where embankment's height is 7,0 m and railway viaduct's length is 750 m.

The Slovak Railways Authorities requested to establish the railway without any limitations, right after constructing a viaduct.

2 SUBSOIL CONDITIONS

Geological conditions under railway embankment are very complicated. There are Quaternary deposits overlying Neogene sediments. Thickness of Quaternary sediments varied from 4 m to 10 m. These sediments are mainly composed by loams, clayey loams, sand, clayey sand, loess, and clayey sediments with organic matter. Composition of the sediments is very erratic (sediments' presence is presented in Table 1 and 2 below). In clays that have middle and high plasticity, there are calcareous concretions present. A size of these concretions is from 3 to 20 mm, in content of 3 to 25 percent**.**

Ground water table ranges between depths of 0.5 to 1.5 m. It is prestressed and it rises up to the surface. In some sections, the surface remains wet all the time. There is no corrosivity water against concrete present, but this setting is characterized for steel as high corrosive (according to STN 03 8375).

The designed embankment is situated according to STN 73 0036 in the 4th seismic risk area with ground acceleration a_r = 0,3 m.s^{-2} and seismicity of 6 – 7^{o} M.C.S., DANKO et al. (1999).

Table 1 Part of the soils laboratory test results (after DANKO et. al., 1999)

	F4 CS soft	F4 CS firm	F6 CL soft	F6 CI firm	F6 CL stiff	F8 CH firm	F8 CH stiff
w_n	23	22.7	30.1	24.7	18.58	25.8	21.93
ρ_n		1941		2045	2077	2035	2085
ρ_d		1584		1641	1755	1636	1720
ρ_s		2733		2755	2773	2758	2781
γ		19.0		20.1	20.4	20.0	20.4
w_L	25	34.3	31	43	42	54	57
w_P	17	20.3	20	21.8	23	23.5	26
I_p	18	14	11	21.3	19	30.5	31
n		42		40	37	41	38
e		0.72		0.67	0.08	0.69	0.6
S_r		84.9		96.9	87	96.8	91.5
I_c	0.22	0.8	0.09	0.86	1.22	0.93	1.12

Table 2 Oedometer modulus (after DANKO et. al., 1999)

	Oedometer modulus E_{oed} (MPa)			
Loading step (kPa)	F4 CS firm	F6 CI Firm	F8 CH firm	F8 CH stiff
0 – 50	7.62	7.93	6.17	4.65
50 – 100	7.28	6.02	4.85	12.09
100 – 200	8.78	6.93	20.67	10.09
200 – 300	13.93	11.5	9.06	
300 – 400	14.46	12.49	10.04	11.10
400 - 0	21.26	14.65	17.13	18.95

3 DESIGN OF EMBANKMENT

A designer proposed to accelerate of subsoil consolidation, to reinforce the embankment and lay it on on the top of geocells. Moreover, a use of some monitoring methods according to Eurocode Geotechnics 1997-1, TURINIC (2001) was proposed as well.

To accelerate the embankment subsoil consolidation ($c_{v,h}$ = 3 . 10^{-8} $m^2.s^{-1}$), a vertical drains were installed in triangular net (1,4 m and 1,0 m), into the depth of mainly 10 m. A standard proposal of vertical drains anticipates the degree of consolidation of 95 percent. A subsoil consolidation should be achieved during construction, before finalizing and establishment of the railway.

The project of embankment's construction takes into consideration an intermission to consolidate the basement in the entire length of 18 months. Moreover, there will be an intermission of approximately 1 year after finishing the viaduct's and embankment's constructions. Both embankment's construction and subsoil consolidation are expected to take 3 years to finalize.

The geocells mattress was designed to increase the stability of embankment and to reduce differential foundation settlements in both lateral and longitudinal direction. The geocell mattress with 1 m triangular cells was assembled of stiff uniaxial integral HDPE geogrids 80RE. The geocells were constructed directly on the embankment formation to form a stiff load transfer the 1 m thick bottom layer of embankment. The normal slip failure mechanism is changed by geocells. Geocells increase embankment's stability and mobilize the shear strength of soils in subsoil, which is caused by their rough surface in contact with a soft foundation. Besides that, geocells reduce a total settlement near the centre line of the embankment.

Use of geosynthetics had increased both embankment's stiffness and its local stability. Stiff uniaxial integral HDPE geogrids were placed along the embankment's edging in the entire section. Moreover, a centre part of the embankment (in transient sections in front of the bridge) was reinforced as well.

Based on a geological survey a calculation model for the Limit State Approach was created. Designer computed the settlement of embankment by using GEO 4 Program (according to Slovak technical standards) in eight cross-sections. In the most adverse embankment's profile, the Plaxis (FEM) Program was used. Total surface settlement of between 275 mm to 497 mm was calculated on foundation under embankment that had been laid on geocells. An influence of geocell mattress was not taken into consideration. The vertical deformations calculated by programme GEO 4 were lower than values calculated by programme Plaxis, TURINIC (2001). The difference was 100 mm in average.

Program Plaxis was used to model an increasing embankment height and to analyze a stress process and the excess pore pressures beneath the embankment. Because the exact calculating method of surface settlement of an embankment with the geocells in place is not known in the meantime, the analogy from other constructions is being used. Then the vertical deformation of subsoil had decreased by ⅓ to ½ of the calculated settlement without geocells.

The average secondary settlement in active zone of compression of 15 m at the end of consolidation is 40 mm.

4 INSTRUMENTATION

During the period of construction and the design life, either Ultimate Limit State or Serviceability Limit State must not be exceeded. In consequence of the surcharge load an increase in the excess pore pressures in subsoil is developed. Vertical drains will reduce both total and excess pore water pressures and shorten the period of consolidation.

There were some apprehensions that some damages may occur during the embankment's construction. Because of that, the projector had decided to monitor the embankment. The rate of increasing embankment height is based with respect to those monitoring results. Five cross-sections (labeled IS-1, IS-2, IS-3, IS-4 and IS-5) of the geocell mattresses were fully instrumented.

The philosophy was to measure parameters to control stability of embankment, monitor the excess pore pressure and foundation movements and determine long–term embankment behavior. Comprehensive instrumentation ensures that critical sequences of construction can be assessed from different instruments to confirm the design assumptions.

To facilitate monitoring of the construction of railway embankment and to observe the performance of geodrains and geocells, five measuring profiles were designed. The instrument layout was selected based on the results of stability analysis together with the results of finite element analyses. The instrumentation of the reinforced section consisted of vibrating wire piezometers, hydrostatic profile gauge, digitild inclinometer probe and sliding deformeter, MATYS, BASLIK (2001). A typical fully instrumented section IS-4 is shown in Figure 1.

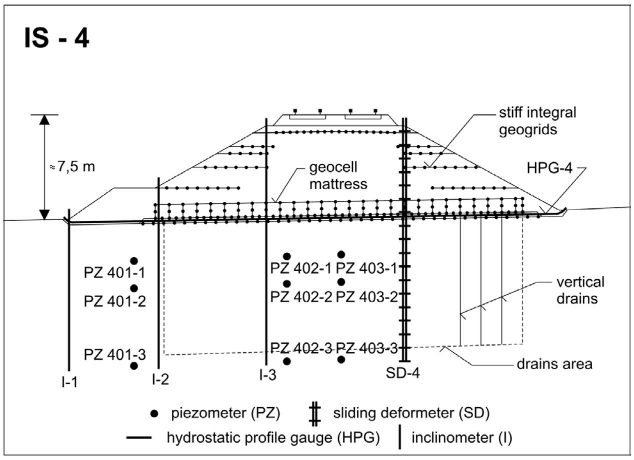

Figure 1 Typical fully instrumented section

5 MONITORING AND RESULTS

This section shows the results of measurements from IS-4 profile, which is situated in most adverse geological conditions. For comparison purposes, we also present some typical results of measurements from other instrumented sections.

Construction history in IS-1 and IS-4 is shown in Figure 2.

5.1 *Pore water pressures*

Basic measurements in 45 piezometers were performed on 16 December 2002. Since that, 14 stages of measuring for embankment thickness were realized. Presently, the thickness of embankment is approximately 3,5 m.

According to the computations from the PLAXIS programme, pore pressure was supposed to increase under the influence of surcharge load approximately by 15 to 35 kPa. Pore pressures had increased, but vertical drains had influenced an excess of pore pressure and its time process. Total pore water pressures had increased short-term locally, by the maximum of 5 to 10 kPa.

The Figure 3 presents the average total pore pressure from three piezometers at the same depth beneath embankment. The excess pore pressures had always dissipated quickly. In instrumented section IS-4 at 3,0 m depth, the pore pressure had changed just within the allowance from 20,6 to 23,3 kPa. An increase in the excess pore pressure from 12 March to 3 October 2003 was 0,2 kPa. At depth 5,0 m, the total pore pressure was changing in the range of 41,7 kPa to 49,8 kPa (a difference was just 8,1 kPa) and the excess pore pressure from 12 March to 3 October 2003 was just by 1,7 kPa. At depth 9 to 10,5 m, the total pore pressure varied in allowance from 93,8 kPa to 95,7 kPa. From 12 March to 3 October 2003, the pore pressure had decreased by 1,3 kPa (Figure 3).

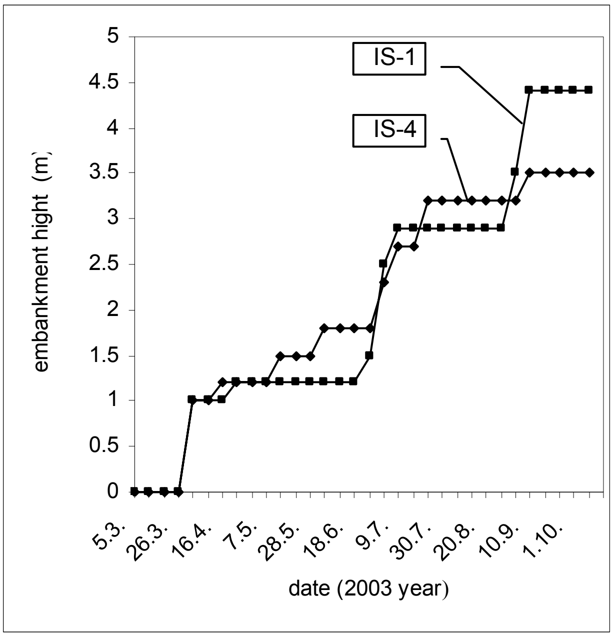

Figure 2 Construction history

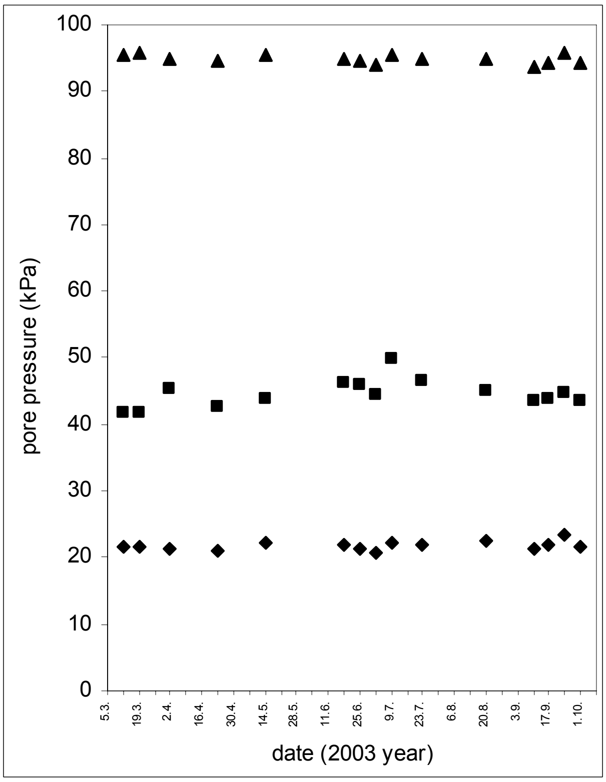

Figure 3 Total pressure development in IS-4

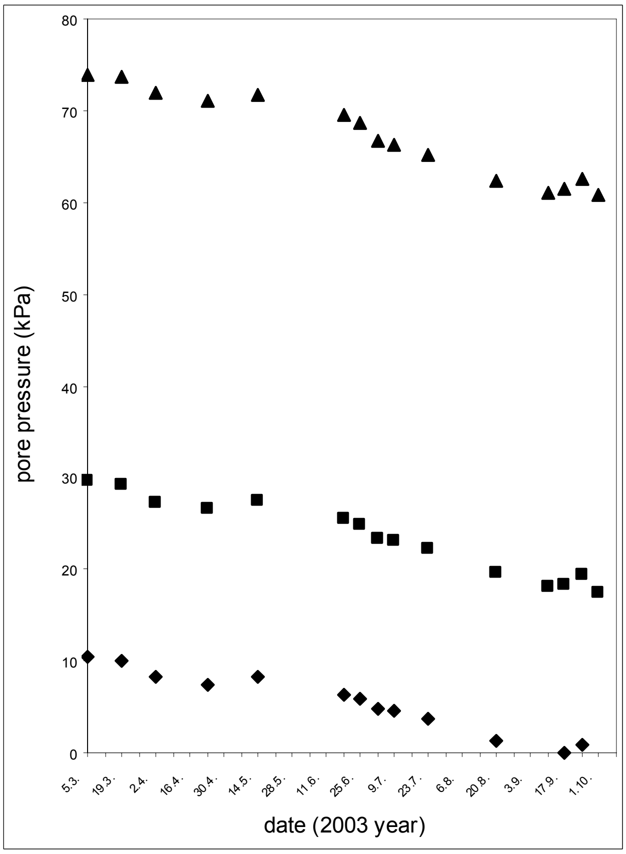

Figure 4 Total pressure development in IS-1

For comparison purposes, the total pore pressure development in IS-1 was showed in Figure 4. In more favorable geological conditions, there is reduction of pore pressures present in all of the piezometers, despite the surcharge of foundation. From March 2003 to September 2003, the pore pressures had decreased approximately by 9,5 kPa (at depth of 3,0 m), by 9,7 kPa (at depth of 5,0 m) and by 11,0 kPa (at depth of 10,0 m).

5.2 *Surface settlement*

A hydrostatic profile gauge that is laid across an instrumented section records surface settlements under the geocells. Figure 5 shows settlement values that were computed and measured. There are stresses under the embankment without geocells. Because of that, the settlement is greatest at its centre. Figure 5 shows calculated settlement curves for full embankment height and for a height recorded on 3rd of October 2003. Calculated settlement for the height of embankment is 200 mm (3rd of October 2003). Total settlement is 381 mm. Table 3 shows a settlement values.

Table 3 Settlements in IS-4

Settlement type	Settlement value (mm)
Calculated, full embankment thickness, without geocells	381
Calculated, embankment thickness of Oct. 3, 2003, without geocells	200
Estimated reduced, embankment thickness of Oct. 3, 2003, with geocells	95 - 157
Measured, embankment thickness of Oct. 3, 2003, with geocells	61

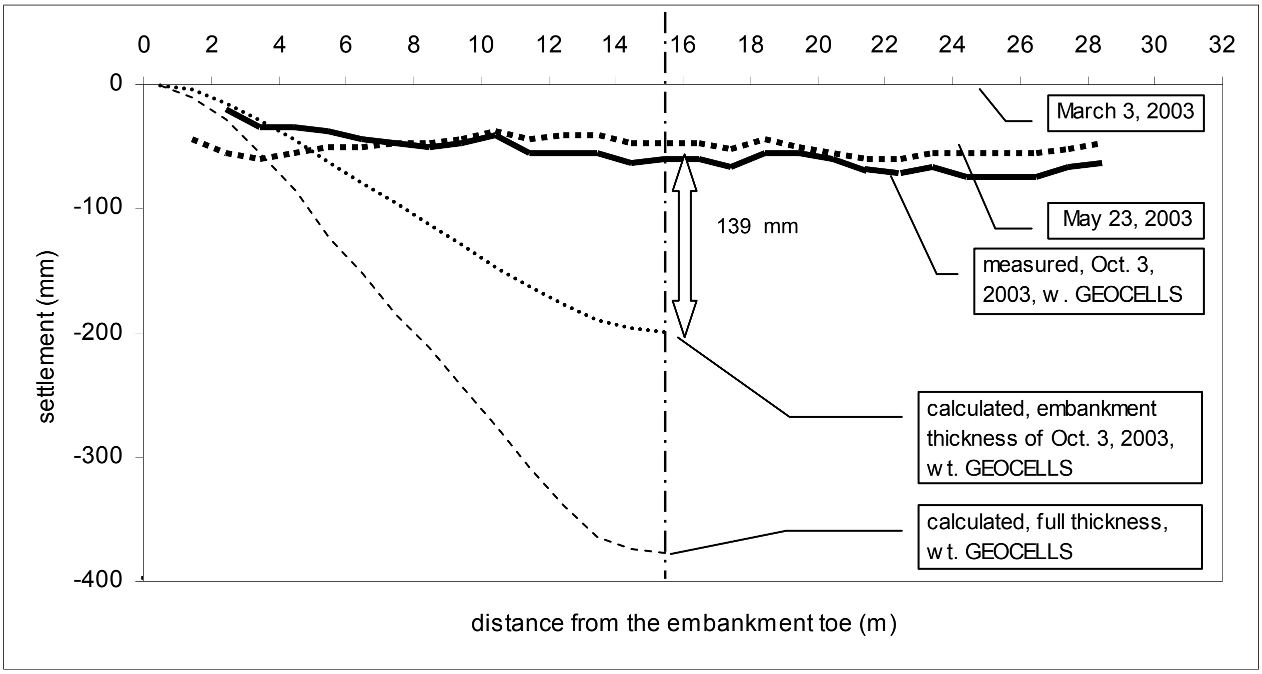

Figure 5 The surface settlement profiles at the bottom of geocell mattress

Results of the measurements had revealed one interesting fact. The surface settlement profiles beneath geocell assembled from stiff integral geogrids shows totally different characteristics, in comparison with typical embankment without geocells. Not only the magnitude of settlement in the central zone of the embankment is changing considerably, but also a shape of settlement profile in entire cross-section. The magnitude of surface settlement at the centre of the embankment that was measured on 3rd of October 2003 underneath the geocells is 61 mm. The difference in the magnitude of the settlements between estimated and measured value at the centre of the embankment is approximately 100 %.

The difference in the magnitude of the settlement between the maximum and minimum values is 20 mm (23 May 03) and 56 mm (3 October 03). The magnitude of the settlement on the instrumented cross section IS-4 is almost same and the settlement is relatively well uniform. The presence of this phenomenon was observed in all instrumented sections. In IS-1, IS-2, IS-3 and IS-5, the measured settlements were in the range of 20 mm to 50 mm which is considerably less than estimated.

Besides uniform settlement on cross section, the other interesting fact was observed. Geocells are located only under embankment, but not under a berm. The settlement profile shows that the magnitude of the settlement under the 2 m high berm was higher than under the higher embankment.

5.3 *Lateral displacements*

Large horizontal movements may occur beneath the embankments constructed on a soft compressible deposit. Geocells as a thick bottom layer of embankment were meant to decrease estimated horizontal deformation. The distribution of the horizontal movements in the embankment and the foundation were monitored by biaxial inclinometers. At height of 0ct. 3, 2003, the maximum lateral displacements between 1 mm to 4 mm were measured. Just one inclinometer between 2 to 4 meters below the ground surface localized the lateral movement in the range of 16 mm to 20 mm. Analysis of this anomaly revealed that there are lens of a soft silty clays at that level. Lenticular soft deposit is probably closed, so, there is no danger of possible bulging.

5.4 *Subsurface settlements*

In each instrumented section, one sliding deformeter was used. The maximum settlement from the start of construction was 59 mm which occurred at the ground surface in IS-4. The settlements between 20 mm to 30 mm were measured in rest of the instrumented sections. Advantage of these measurements is the fact, that they separately measure compression of subsoil layer with a thickness of 1,0 m. To find out the most compressible ones, the magnitude of compression may be confronted with subsoil deformation characteristics set in geotechnical survey. It is also possible to determine the thickness of active zone beneath embankments.

In instrumented section IS-4 there are more compressible layers up to a depth of about 7,0 m and active zone is more than 10 m (Figure 6). The shape of compression curve in Figure 6 indicates that the entire layer is composed of the soil of just about the same quality. The maximum compression is 8 mm of the 1m thick layer in depth from 2 - 3 m. The settlement curve that is composed from cumulative subsoil compressions in Figure 7 shows that the total surface settlement is 59 mm (3 Oct. 03).

In other instrumented sections the soft clay stratum varies in thickness and is interbedded with stiffer layers. The results of these measurements are providing us with not only time rate of settlement but they can also be used to determine relationship between these characteristics:

- time / embankment height / subsurface settlement,
- time / embankment height/ compression.

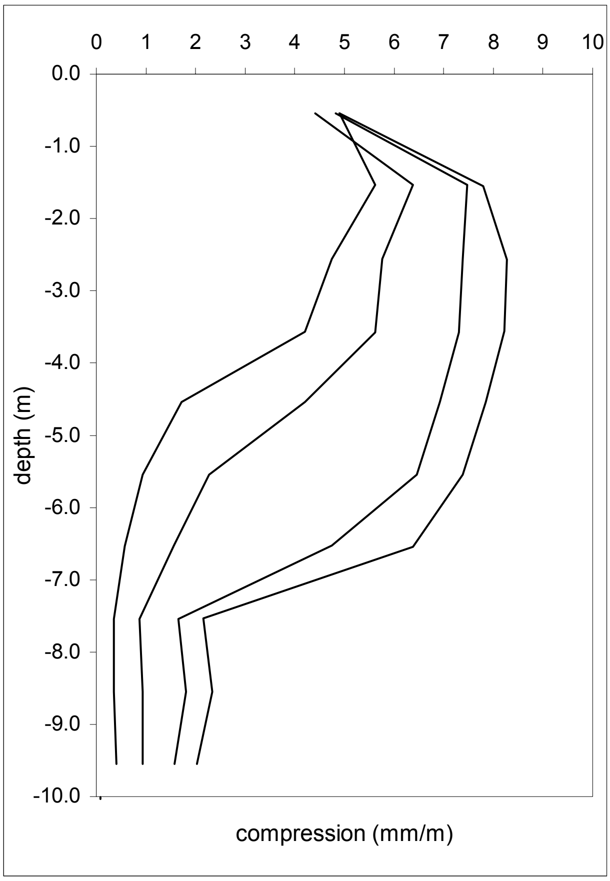

Figure 6 Subsoil compression for IS-4

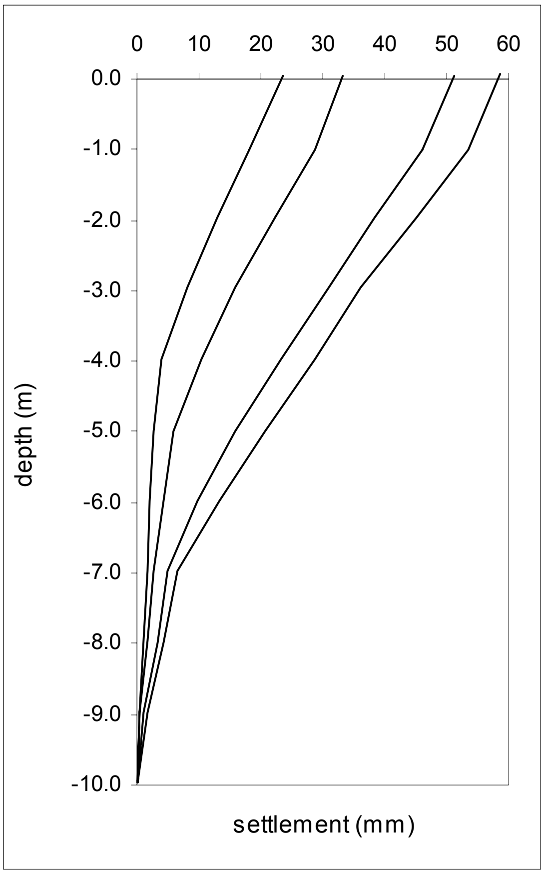

Figure 7 The cumulative settlement curve for IS-4

6 CONCLUSION

This paper presents an application of geosynthetics for a railway embankment project in Senkvice. Three geocell mattresses were constructed to form the foundations for a 550, 190 and a 100 m length of the embankment over soft clay. The high strength mattress filled with crushed rock with the range of grading from 8 mm to 125 mm provides a stiff platform at the base of the embankment and minimizes the effects of differential settlement of the underlying soil. The geocell mattress ensures the stability of embankment. Pre-fabricated band vertical drains were installed beneath these mattresses to speed up consolidation of the soft subsoil. The vertical drains were spaced 1,4 m and 1,0 m and installed from working platform that consisted of stiff biaxial integral geogrid SS20 covered with 200 mm of granular sub-base material. The embankment slopes were reinforced with three and four layers of HDPE geogrids 40RE and 55RE.

These calculations were performed in project: number of construction stages, embankment thickness per stage and waiting time between stages. The original estimate of the construction's length was 570 days, Table 3, TURINIC (2001). In October 2003, the embankment was built in around 75 percent of its designed thickness. A length of the construction was approximately 210 days. The rate of embankment construction will be continuously governed according to the results of monitoring. In each of the instrumented sections, there are 36 steps of monitoring proposed, MATYS, BASLIK (2001).

A railway embankment was monitored with extensive instrumentation. The following partial conclusions can be made:

- Combination of the designed technology methods and reinforced structures on Senkvice relocation (vertical drains, geocell mattress, reinforced embankment and berm in embankment toe) was effective.
- Both the fully instrumented embankment (vibrating wire piezometers, hydrostatic profile gauge, digitild inclinometer probe, sliding deformeter) and monitoring proved themselves to be justified.
- Both of the conclusions mentioned above are supported by the monitored readings. Small excess pore pressure in the foundation soils had developed during the construction. Maximum value of excess pore pressures recorded to date in IS-4 was just 1,7 kPa. In other IS's the reduction of pore pressure between 10 kPa to 15 kPa was recorded after 210 days from the start of construction. As a result of using vertical drains, the excess pore pressures slowly dissipated.
- In IS-4, maximum surface settlement of 61 mm under geocells was measured by means of hydrostatic profile gauge. The further measurements revealed that in other instrumented sections was settlement only in the range of 20 mm to 50 mm. The actual vertical settlement was considerably less than calculated. Beneficial influence of the geocell mattress is evident. The settlement of embankment constructed on geocell mattress is approximately three times lesser than the settlement of the embankment without geocell mattress. Moreover, the magnitude of surface settlement along cross-sections is almost the same, and the settlement curve is uniform. The embankment formation is despite the overburden load almost horizontal. The difference between minimal and maximal value of settlement along the cross-section is

fractional. The settlement profiles in the embankment with geocells and embankment without geocells are different.

- Results recorded by hydrostatic profile gauge affirmed the results recorded by sliding deformeter which is more accurate. The maximum surface settlement of 59 mm was recorded in IS-4. The monitored values indicated soft compressible ground to the depth of 4 to 5 m, and around the IS-4 even to the depth of 7 m. The results indicate the thickness of active zone at a depth of 10 m. In IS-4, the active zone is deeper.
- Positive effect of vertical drains and geocell mattress on foundation deformation is verified by vertical inclinometers. The horizontal movements were minimal, maximum recorded value was 4 mm. In IS-2 alone, there was locally recorded horizontal deformation in the range of 16 mm to 20 mm which was caused by lens of soft soil.
- Monitoring had proven itself to be very effective. Favorable development of both the pore water pressures and the foundation settlement allowed shortening a planned time of construction approximately by one third.
- These partial conclusions will be supplemented with further results of monitoring during the conference.

7 REFERENCE

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