EARTH PRESSURE REDUCTION BY GEOTEXTILE-REINFORCED LIGHTWEIGHT FILL

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ABSTRACT: The embankment near the bridge on the railway line at Kněžice in W part of Czech Republic had been suffering for several years from continuous deformation. The settlement of the embankment crest exceeded 100 mm per year. The geotechnical study had proven that very steep embankment slope (45^0 in the upper part), insufficiently compacted, highly saturated clay soil and too slim bridge wing wall that was unable to resist the earth pressure had led to embankment spreading (sliding) and rather important deformation of the stone wing wall. Due to limited financial resources of the Client (Czech Railways) the embankment stabilisation designed by SG Geotechnika was divided into two phases. The phase 1 composed of excavation of the soil in the approach zone to the bridge, improvement of the soil by lime and reinstatement of the new embankment. In order to reduce the earth pressure on the damaged stonewall the soil near the wing wall was reinforced by woven polypropylene geotextile and we used lightweight ceramic fill in the first 2 m next to the wing wall. The following year the phase 2 was realised that included removal of the old damaged wing wall and construction of the new concrete wing wall with stone cladding under the full railway traffic operation.

1 INTRODUCTION

The second-class railway line at the Kněžice village near Žatec (W Bohemia) suffered in the past several years continuous settlement of 12 m high embankment near the bridge over the local stream. The deformation of rails ranged about 100 mm and more every year and required frequent filling up and tamping of the ballast to keep the railway line trafficable. Deformations of embankment influenced also deformations of the bridge abutment and wing walls. The rising costs for the track maintenance and apprehension from the continuous degradation of the stone wing walls forced the Czech Railways to call a tender for design and execution of the most suitable and economic solution. Deformed track is evident at Figure 1, deformed wing wall on Figure 2.

Figure 1 Deformed rail track near the bridge

Figure 2 Deformed wing wall

SG – Geotechnika won the competition and was asked by the Client (Czech Railways) to analyse the reasons of deformations, design stability measures and supervise the execution of works.

2 ANALYSIS OF DEFORMATIONS

A detailed geotechnical investigation was undertaken. Boreholes were drilled by coring from the top of embankment and dynamic cone penetration test with heavy weight penetrometer were done near the boreholes. Three boreholes (one at the top of embankment, two at each side near the toe) were used for observation of horizontal deformations by inclinometer. After the laboratory test of undisturbed samples, taken from the boreholes, a numerical 2-D model was compiled and various boundary conditions analysed.

The geotechnical study had shown that the embankment was constructed from highly plastic clay (CH) that was poorly compacted. The upper 3 m of embankment were built from burnt coal slag (ash) with important quantity of unburned coal. Thickness of the ballast layer reached 2 m some places due to continuous tamping of the deformed track. In this way the weight of the track had gradually increased. The numerical analyses, supported by the field observation prove that the mechanism of the embankment deformations was combination of sliding and spreading. This movement was due to low shear strength and ductile behaviour of the poorly compacted clay soil and ash fill. Bringing more ballast to the top of embankment for filling depressions in the track was increasing weight that resulted in increase of driving forces. Weight increase at the top of the embankment and higher water table at the toe generated sliding (spreading) of the fill over the terrain surface. In addition to that the wing walls of the bridge were gradually shifted (rotated) by the earth pressure for almost 0,5 m along the vertical joint with the bridge abutment. This movement caused separation of the left wing walls from the abutment by 0,3 m wide vertical crack (see Figure 3). The right wing wall was also separated from the abutment but the width of the crack was substantially less. It was quite surprising that the highly damaged walls were still standing.

Figure 3 Vertical cracks separating wing walls and bridge abutment (inner side)

The movement of the wing walls by earth pressure was caused mainly by insufficient design (over 100 years ago) of the wall. Less than 2 m thick gravity wing walls could not resist the earth pressure of 12 m high fill of mostly clay soil. However, the stone wing wall was shifted in one piece with some local distortions.

3 TECHNICAL MEASURES

As the Czech Railways had a limited budget for repair of this railway line in 2002 it was decided to improve the embankment, only. Repair of the bridge abutment and wing walls was postponed till year 2003.

After studying various alternatives of repair (deep mixing, gravel columns, piles, etc.) the cheapest and simplest alternative appeared to be excavation of the damaged fill in the approach zone to the bridge, construction of geosynthetics reinforced drainage layer at the embankment base, improve the excavated soil by lime and return it properly compacted back into the embankment. The contact between embankment and the bridge wing walls was reinforced with geosynthetics in order to reduce the earth pressure on the damaged wing wall to minimum. In order to further reduce the possible earth pressure on the damaged wing walls we decided to use lightweight ceramic aggregates in the 2 m wide contact zone between the wing wall and the embankment. The lightweight ceramic aggregate is manufactured from the granulated tertiary clay that is burned in the rotary furnace at temperature of 1200 ^{0}C. The resulting material is graded according to its size (1 to 4 mm, 4 to 8 mm, 8 to 16 mm) The density of the lightweight aggregate depends on the size and varies between 2 and 5 kN/m^3. Shear strength of this aggregate is high, φ_{ef}=35 to 40^0. Interaction between geosynthetics and lightweight ceramic aggregate is very good due to rough surface of the aggregate grains. As the aggregate is light it causes practically no damage to geosynthetics during dumping and spreading.

The proposed solution reduced substantially the vertical stresses near the damaged stonewalls as well as horizontal pressure that had to be taken by the geosynthetic reinforcement. Resulting lower horizontal stresses could be taken by geosynthetics with much lower strength than it would be necessary to use when current soil was placed there.

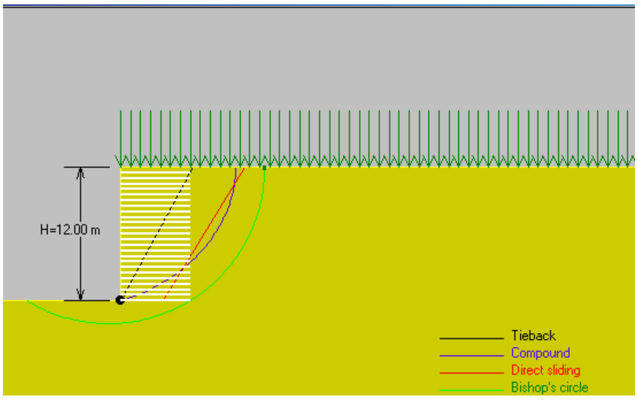

Figure 4 Calculation scheme of the wall reinforcement

For the design of the wall reinforcement we used “ReSlope (3.0)” software (ADAMA Engineering, Inc. USA). The calculation scheme is in Figure 4. Maximum design tensile force that was necessary to retain was 15 kN/m. The tensile strength of the recommended geosynthetic reinforcement was 60 kN/m. The calculated vertical separation of the reinforcement was 0,5 m, length of reinforcement 6 m from the inner face of the wall. The wrap-around system was proposed in order to prevent fall out of the aggregate during demolition of the stonewall. The design respected the Czech technical code for use of geotextiles and geotextile-related products in the fills of highway constructions TP 97 where the design of reinforced soil structures is described.

The reinforcement was designed for two loading conditions – full loading by the passing train for temporary condition (less than 5 years exposure) when the existing retaining wall is demolished and the earth pressure is taken by geosynthetic reinforcement only. The permanent loading condition took into consideration partial retaining effect of the new slim concrete retaining wall with stone cladding. The new wall is not designed on full active earth pressure but only on part that is not taken by the geosynthetics in the long term.

As majority of the soil placed in the new fill was mixed with lime, we decided to use polypropylene geotextile for fill reinforcement, in order to avoid danger of possible effect of higher pH of water seeping through the soil on the geosynthetics reinforcement. Polypropylene is usually not affected by high pH value of the surrounding environment. The geotextile used for soil wall reinforcement had tensile strength 60 kN/m. This low value of the tensile strength was possible due to the use of lightweight ceramic aggregates at the contact with bridge abutment and wing wall. The density of compacted lightweight fill was 3 kN/m^3 only, i.e. more than 6 times less than density of the compacted soil fill. Laying the geotextile reinforcement and its temporary fixing on the wing wall is on Figure 4.

Figure 5 Laying geotextilie reinforcement on the compacted soil

The lightweight ceramic aggregate was spread on the geotextile by using a small loader that could ride on the geotextile without damaging it. The installation damage factor was considered F_{dam}=1,15, however in reality the measured value was F_{dam}=1,04. The placing of the lightweight ceramic aggregate on the geotextile near the damaged stone wing wall is at Figure 6.

Figure 6 Placing lightweight ceramic aggregate on the geotextilie near the abutment

Loose character of the original fill can be documented by the fact that after returning all excavated and lime-improved clay soil back into the new embankment there was still 3 m height of the fill needed to complete it to its original level. Lime stabilised fly ash from the nearby power station was used to reach the designed track level. Lime stabilised fly ash is cheap fill material with very good strength and deformation characteristics. As it is approximately 40 % lighter than compacted natural soil it also reduces settlement.

General view of the limited space at the construction site during lime improvement of the soil by mixer, soil compaction and geotextilie reinforcement of the lightweight ceramic aggregate is on Figure 7.

Figure 7 General view of the site during the stabilisation and soil reinforcing works

Measured settlement, after completion of the embankment reconstruction was 50 mm and have practically stabilised. Horizontal movement of the embankment, as measured by inclinometers, was negligible and confirmed stable condition of the reconstructed embankment. Monitoring of the wing walls shape showed no movement at all during the construction. This confirmed that all earth pressure was taken by the geosynthetics reinforcement.

4 DEMOLITION OF THE WALL

The following year the damaged wing wall was carefully dismantled. Due to its very bad condition the work in the upper part of the wall had to be done by special team of mountaineers. Lower part was demolished by use of hydraulic and mechanical breakers mounted on the crane (see Figure 8).

Figure 8 Demolishing of the upper part of the stone wing wall

The work had to be done with utmost care in order not to inflict any damage to gradually exposed geotextile. There were benchmarks and stakes all along the crest and the slope of the reinforced soil wall for permanent topographical observation of the deformation of the reinforced soil wall. This measure was needed because the wall removal was done during full railway operation as can be seen on the Figure 9. During the demolishing work and the new wall construction as well as after the completion no deformation has been recorded. The reinforced soil wall has behaved well and even the Contractor caused no damage to the geotextile reinforcement during the stonewall removal.

Figure 9 Reinforced soil wall after the stonewall removal

5 CONCLUSION

Highly deformed railway embankment was stabilised by replacement of the old fill with the same soil that was improved with lime and reinforced with 60 kN/m strength geotextile. In order to completely eliminate the earth pressure on the damaged bridge abutment and wig walls, lightweight ceramic aggregates were used in 2 m thick contact zone between the damaged walls and lime-improved soil embankment. The damaged stonewall was removed the next year and a new concrete wall with stone cladding was built (see Figure 10). No deformation of the track, embankment or the new wall has been observed.

Figure 10 Reconstructed bridge and the embankment

6 REFERENCES

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