SEITENHAFENBRÜCKE – GEOGRID REINFORCED
EMBANKMENTS ON DIFFICULT GROUND CONDITIONS

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ABSTRACT:
For the reconstruction of the federal road “B14” in Vienna a new bridge crossing the “Donaukanal” is to be built as integral bridge. On both sides of the bridge up to 8 m high road embankments, designed as geogrid reinforced slopes, were carried out. The lengths of the embankments are approx. 110 m and 150 m, the crest width is 16 m and the inclination of the slope is 70°. Design calculations were carried out using the “EBGEO”, concerning the recommendations of Eurocode 7. Along the south bank beneath artificial fillings, alluvial clays are underlain by “Danube” gravels with good bearing capacity. Along the north bank the embankment is located in a former dock, which was refilled with soft, cohesive soils in the 60ies. In this area the stable gravels were found 10 to 11 m below ground level and the free groundwater was found 4 to 5 m below ground level. Outside the former dock vibro replacement was carried out, which was not possible in the former dock due to different reasons. In this area the embankment was founded on a geogrid reinforced soil exchange. Additionally the embankments were pre-loaded with a 3m-high ballast to speed up the consolidation. An intensive monitoring concept was realised. Ongoing measurements show good accordance to the predicted values.

1. Preface

1.1 Introduction

Before 1873, the Danube in Vienna was a widely ramified river with many meanders. In the 1870ies River regulations were carried out. Since then in addition to the Danube, the “Donaukanal” has been one of the most important channels in Vienna – together with the “Entlastungsgerinne” in the north of the Danube, which is very important for flood control. After a big economic boom of the Vienna harbour in the last years, which is located close to the estuary of the “Donaukanal” into the Danube, an improvement of the connection of this area to the transport network was necessary. Therefore the relocation of the existing federal road “B14” was projected, which lead to an additional bridge over the “Donaukanal”, providing a crossing for road traffic, cyclists and pedestrians.

The main goal of the awarding authority - the “Magistratsabteilung 29 – Brückenbau und Grundbau, Stadt Wien” – was the optimal integration of the new bridge into the surrounding area (river on the one hand, industrial area on the other hand) from the technical and architectural point of view. (Kleiser, 2010)
1.2 The Project – Relocation of the Seitenhafenstraße

Figure 1 shows, that the existing road (in black) separates the harbour as transshipment centre from the railway. This fact causes an insufficient capacity of the road for the terminating traffic and transit traffic. Additionally the connection of the area to the next highway – the highway A4 – crosses a residential area. To improve these out-dated circumstances, a new alignment of the road was projected. This new layout was approved after an environmental impact assessment.

The project “B14 – Seitenhafenstraße neu” consists of the reconstruction and improvement of the existing road, the existing parallel railway, the construction of the necessary embankments on both sides of the “Donaukanal” and finally the bridge over the “Donaukanal”. The new road has a length of approx. 2 km, the bridge of approx. 130 m, and the embankments of 150 and 110 m. The total costs of the project will be approx. 26 million Euros. Design and approval took place in the years 2006 to 2009, the construction is going to be finished till the end of the year 2011.

1.3 The „Seitenhafenbrücke“ – an integral bridge

To meet the demand of bringing the economic and technical solution in line with architectural visions a special construction method was chosen. With the integral bridge it was possible to activate all bearing capacities and to allow a very slim construction.

Additionally the advantages for the owner of the bridge are that expensive bridge bearings and expansion joints, which have to be maintained intensively, are not necessary. Considering the length of the bridge of approx. 130 m, this structure is a novelty of bridge engineering.
This construction caused numerous challenges for the structural and geotechnical engineers. One requirement was that the deformations of the structure had to be strongly limited. In addition the load transfer from the structure into the underground had to be ensured. During and after construction singular deformations occurred, but there are still alternating deformations going on caused by changes of temperature and different traffic loads. To avoid a direct load transfer from the bridge into the embankment and vice versa, the bridge was separated from the embankment. To supply this structural function for the service life of the bridge, an elastic and soft interlayer of expanded polystyrol (EPS) was installed between the embankment and the abutment (Pötzl, 2005). The embankment was designed that no earth pressure influences the abutment.

The foundation piles (d = 120 cm) of the bridge have maximum deformations and bending moments on the first 4 m of their length. To allow these piles the horizontal deformation in their upper part, a special soft casing was installed. It was built out of a 3 mm casing pipe with a bonded and curved soft interlayer of EPS, which was put around the bore hole casing.

Fig 2: Placing the interlayer of soft EPS around the bore hole casing

2. Geological situation – underground conditions

The underground conditions, which are typical for this area of Vienna close to the Danube, where investigated by numerous investigation bore holes, dynamic probing and test pits (MA 29 der Stadt Wien, Brückenbau und Grundbau, 2009). Mainly four different layers were found. Below a thin layer of organic top soil, heterogeneous artificial fillings consisting of sands, silts, gravels, bricks, concrete etc. were found. While the regular depth of the fillings was 0.5 to 2.5 m below ground surface, north of the “Donaukanal”, where a dock had been located until the 1960ies, the depth of the fillings was up to 11 m. Especially in the former dock, the fillings mainly consist of soft cohesive soils. This dock can be seen in figure 3.

Fig. 3: Map from 1849 with the Danube before regulation
Outside the dock below the fillings sandy silts and silty sands were found up to a depth of 4 m below ground surface. These alluvial sands and clays, so-called “Ausande” and Aulehme”, have mainly a loose to medium density or a soft to firm consistence and are sensitive to settlements especially when influenced by water.

Underneath these top layers up to a depth of 16 to 20 m below ground surface, rounded sandy gravels (“Donauschotter”) were investigated. These gravels have mainly a medium to dense density, but especially on top of the layer sometimes a loose density.

The underlying stratums are miocene sediments with alternating layers of stiff to firm clays and dense sands. These alternating layers can change on short distances – both vertical and horizontal.

The aquifers of the first ground-water storey are the sandy gravels (“Donauschotter”), which are underlain by the Miocene silts as an aquiclude. In the Miocene sands also confined groundwater were investigated, which corresponds to the upper ground water. The groundwater level is mainly between 4 to 6 m below ground surface. It has seasonal fluctuations and is strongly influenced by the water level of the “Donaukanal” and the “Winterhafenbecken”, a harbour that is still in use.

3. Planning phase of the road embankments

In the run-up to the environmental impact assessment an economic comparison for different solutions was made. Under the local circumstances for the embankments, a geogrid reinforced embankment with less required space compared to a conventional embankment, was found as optimal solution due to environmental and economic reasons.

So the city of Vienna decided to build the 110 m and 150 m long and up to 8 m high embankments as geogrid reinforced constructions. The inclination of the slope was fixed with 70°, the width on top with 16 m. The embankment was intended to be built on an improved soil.

Another difficulty for the design of the embankment was the former harbour on the north side of the “Donaukanal”. This harbour was filled just 50 years ago with excavation materials from the surrounding areas and was used as industrial area.

As the harbour was bombed several times during World War II, it was possible, that there are still warfare agents 10 to 12 m below ground level on the former bottom of the harbour and approx. 5 to 6 m below groundwater level. To avoid high costs for a thorough investigation for warfare agents and even higher costs for a recovery of potential warfare agents, the concept for the foundation of the embankment in the former harbour had to be adapted.

3.1 Concept for the foundation and construction of the embankment

To ensure compatible deformations of the embankments, especially close to the new bridge, a ground improvement with vibro replacement was carried out. The stone columns were designed with a diameter of 60 cm, the grid varied corresponding to the height of the embankment from 2.0 x 1.5 m up to 3.0 x 2.5 m. The columns had to go through the artificial fillings, the sandy silts and silty sands, which are sensitive to settlements, and also had to improve the loose gravels. This improvement was carried out in the areas close to the bridge abutments and in the whole area south of the “Donaukanal” (11th district).
North of the “Donaukanal” (2nd district) on a length of about 130 m a vibro replacement was not possible in the former dock because of a very high cost risk caused by potential warfare agents. Considering economic reasons, the embankment was founded in the soft, cohesive fillings on a geogrid reinforced soil exchange.

Based on the improved ground or the reinforced soil exchange, the geogrid reinforced embankment was built in layers of 30 cm, where every 60 cm a layer of geogrid was installed. As filling material mainly sandy gravels (“Donauschotter”) were used.

To reduce differential settlements and to improve the stability, in the area of the former harbour one or two layers of the geogrid were performed through the whole embankment. Additionally the embankments were pre-loaded with up to a 3m-high ballast to...
speed up the consolidation. Although the total settlements are higher compared to a ground improvement with vibro replacement, the final settlements should be in a tolerable range.

Fig. 6: Typical Cross Section harbour (2nd district)

3.4 Design approaches

The design of the embankments was considering the philosophy of Eurocode 7, which is published in Austria as ÖNORM EN 1997-1-1 (ÖNORM EN 1997-1, 2009). According to the national annex ÖNORM B 1997-1-1 (ÖNORM B 1997-1, 2010) for the determination of the partial safety factors the embankments were in agreement with the awarding authority classified as consequence class CC2. In the area of the former harbour due to the heterogeneous and soft underground conditions and the areal situation, the partial safety factors were slightly increased to $\gamma' = \gamma_c' = 1.20$. For the sensible areas close to the abutments of the integral bridge the safety factors for consequence class CC3 were chosen.


Additionally the recommendations of the concept of EBGEO 02/2009 (Deutsche Gesellschaft für Geotechnik, 2009) were taken into account, as the final EBGEO 2010 was not published at the time of the calculations. The reducing factors A1 to A4 were chosen according to information by the producer of the geogrids Huesker (Huesker Synthetic GmbH, 2010). Huesker has carried out several investigations and tests to confirm that these reducing factors were lower compared to the general values in the EBGEO (Deutsche Gesellschaft für Geotechnik, 2009). To consider the dynamic loads of the geogrids, the factor A5 was determined according to EBGEO (Deutsche Gesellschaft für Geotechnik, 2009).

The design calculations for the slope stability were carried out with polygonal and cylindrical slip surfaces, using the program „Stability“ (Prof. Dr. Ing. Johann Buß, 2010).
Especially in the area of the former harbour, the additional calculations for embankments on soft soil according to EBGEO (Deutsche Gesellschaft für Geotechnik, 2009) were carried out. Additionally as information for the monitoring concept, the allowable pore water pressure in reference to the actual height of the dam was calculated.

In addition to the calculations to secure stability, extensive calculations to predict the settlements were carried out. Considering the very soft fillings in the former harbour, calculated settlements reached up to 20 to 25 cm. To predict the effect of the pre-loading, based on the results of laboratory tests, calculations of the time dependent settlements were done. As result of these calculations, a time span of one year was taken into the general schedule for the pre-loading. The maximum height of the pre-loading was fixed with up to 3 m.

The dimensioning of the vibro replacement outside the former harbour was done according to Priebi (Priebe, 1995).

### 3.5 Structural Design

For the construction geogrids of the types Fortrac 55/30, 80/30 and 110/30 of Huesker (Huesker Synthetic GmbH, 2010) were used. The type and the length of the geogrids were carried out considering the design calculation. To allow the desired greening of the embankment, a mixture of sandy gravels and humus was placed in the facing behind special anti-erosion grids. To ensure an optimal long-time stability of the facing, the geogrids were reverted. To avoid damages caused by vandalism and to reduce dependency on the UV stability of the geogrids, facing elements designed as zincked reinforcement mesh were used.

The elements have a height of 60 cm, where the elements of the different layers were placed with a parallel offset of 10 cm to allow water not to run down too quickly and can be absorbed by the greening (3P Geotechnik ZT GmbH, 2009).
3.6 Special Solution for the abutment of the integral bridge

Close to both abutments a vibro replacement was carried out with a raster of 2.0 x 1.5 m. The geogrid reinforced embankment was carried out before concreting the abutment. Between finishing the reinforced embankment and concreting the abutment, a time of four weeks was integrated in the project schedule.

Significant parts of the settlements and deformations of the embankment took place before concreting the embankment wall. As a result the embankment wall is much less affected by embankment settlements and deformations. The designer of the integral bridge already intended to place a soft layer of expanded polystyrol between the embankment and the abutment. To consider the unavoidable long-term deformations of the geogrid reinforced construction, the thickness of this soft layer was fixed with 20 cm.
3.7 Monitoring concept

To verify the design approaches and to identify critical states of construction accurately timed, an extensive monitoring concept was implemented. Therefore several measuring sections with the following measuring equipment were installed:

- Settlement levels for geodetic control of the settlements in the middle of the embankment
- Measuring points on the facing to measure settlements and horizontal deformations of the embankment
- Horizontal inclinometers to measure the settlements under the embankment
- Vertical inclinometer close to the facing to measure the long-term deformations of the reinforced embankment
- Horizontal extensometers with length of 4 m and 8 m to measure the relative deformations between the facing and the inner area of the embankment
- Additionally pore water sensors in the area of the former harbour to detect critical pore water pressures in order to avoid critical construction phases

Fig. 10: Measuring section

Fig. 11a: Horizontal inclinometer

Fig. 11b: Extensometers
4. Construction phase

4.1 Construction of the embankment

After soil improvement and constructing the geogrid reinforced soil exchange, the geogrid reinforced embankments were carried out with extensive quality control within approx. 3 months. Since October 2010 the pre-loading has been added and it will be removed in the summer of 2011.

Fig. 12: Almost finished embankment with pre-loading on top

Fig. 13: Finished embankment with pre-loading on top
4.2 Results of monitoring

The measurements of the measuring points, the settlement levels and the horizontal inclinometers show good accordance. So far the measurements of the settlements show maximum settlements of about 15 cm in the area of the former harbour, which are a little bit less than predicted. Last measurements already show that the increase of the settlements is decreasing, but settlements are still going on. Some long-time settlements are still expected and were considered in the project from the beginning.

![Fig. 14: Results of horizontal inclinometer measurements in section 67](image)

The measuring points on the facings show horizontal deformation in a range of 1 to 2 cm, whereas the first surveys were carried out immediately after installation. Additionally the relative deformations between the facing and the inner part of the embankment were measured by the horizontal extensometers with up to 7 mm. Figure 16 shows, that these deformations are directly influenced by the height of the embankment.
The sensors for the pore water pressure showed no critical increase during the earthworks. Therefore it was not necessary to limit the speed of the earthworks.

5. Conclusion

The construction of the embankments as geogrid reinforced embankments turned out to be the optimal solution considering the given circumstances both of the technical and the economic point of view. The relatively soft construction was able to take the relatively high and expected deformations in the area of the former harbour without any damages.

After removing the pre-loading in the summer of 2011, the final road surface and road equipment will be installed. The new road will be opened for traffic by the end of 2011.

6. References