Bridge approach embankments on holocene peat improved with Geosynthetic Encased Columns (GEC) in Northern Germany

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ABSTRACT

Several preloaded embankments and bridges are located over a distance of 5 km within the construction works for a new section of the federal motorway, A26, in Germany. In consideration of the particular construction schedule, whereby the bridges and their piled foundations are built before their approach embankments, in conjunction with a low stiffness and shear resistance of the Holocene subsoil, a special soil improvement technique in the transition zones close to the bridges was required. In order to enhance the embankment stability, the settlement reduction and the acceleration of the consolidation process, the construction methodology, Column Supported Foundation Pad (CFP) was chosen. Thereby Geosynthetic Encased Columns (GEC) reinforced with a horizontally arranged geosynthetic basal reinforcement layer were installed below a soil pad. The extensive geotechnical monitoring program allowed the evaluation of required consolidation ratios during intermediate construction steps, the estimation of the filling schedule and the determination of the appropriate preload removal time.

Keywords: Geosynthetic Encased Columns, Preload, Bridge Abutment, Holocene Peat, Embankment on soft soil

1 INTRODUCTION

Along a 5 km long section the construction methodology of Column Supported Foundation Pads (CFP) was utilized at 10 of the 16 bridges crossing, streets, irrigation ditches and service roads.

Additionally, the preload or consolidation procedure with prefabricated vertical drains (PVD) was used for the road embankments and remaining ramps. The CFP is installed in the transition zones between the piled bridge abutments and the road embankments constructed using the preload procedure.

In order to control the consolidation and deformation behaviour during construction, as well as to schedule the embankment filling works and the consolidation periods, an extensive monitoring system was applied.

From April 2016 to January 2017, in total, 9,000 Geosynthetic Encased Columns (GEC) on an overall area of 37,000 m² were installed using two vibration pile drivers (Fig 1). Over 2.5 mio m³ of embankment fill material (sand) were installed within this period.

2 SUBSOIL

2.1 Geotechnical parameters

Along the new route the subsoil consists of mainly Holocene, low bearing, soft soil layers with high organic content and water content up to w = 1000 %. The severely decomposed peat layer, which was localised below a 0.6 m thick crust of peaty clay and moderate decomposed peat, has a thickness in a range of 4 to 7 m. Beneath that the soil investigation results show bearing Pleistocene sand layers with small admixtures of clayey silts and low organic characteristics.

The geotechnical parameters of the aforementioned soil layers are given in Table 1. These values form the basis for the geotechnical design (see section 5).

Fig. 1. Aerial view of GEC installation

Table 1. Soil Parameters

Soil	Friction angle $\varphi`$ [°]	Cohe-sion $c`$ [kN/m²]	Undrained shear strength s_u [kN/m²]	Stiffness modulus E_s [MN/m²]

Peaty Clay	15	5	4 – 6	0.5 – 0.8
Peat, near surface	15	5	3 – 15	0.4 – 0.6
Peat, > 0.6 m below GL	15	2	3 – 6	0.2 – 0.4
Holocene Sands	30	-	-	10 – 20
Pleistocene Sands	32.5-35	-	-	> 30 – 50

2.2 Ground water

The existing ground water level is highly influenced by the local agricultural irrigation system and can be at ground level depending on the current precipitation. Besides this, a second ground water level in the sand layers was observed which is characterised by artesian confinement. Hence, a bottom sealing of the GEC is required.

3 CONSTRUCTION TECHNIQUES

3.1 Preload or consolidation procedure

The preload or consolidation procedure is described in detail by Blume et al. (2004) and involves the deposition of a preloading embankment made of sand. This pre-loading compresses the subsoil, causing it to settle, and hence provokes a consolidation. Once roughly 90% to 95% of the consolidation is completed, the excess height is removed. No significant settlement is expected to occur after that. The additional preloading height corresponds to the expected settlements of the embankment and has a proven reduction effect on the long-term creep settlements. Generally, the higher the preload the higher the reduction of the creep settlements that can be observed, see Edil et al (2016) or Tinat and Rosenberg (2016).

3.2 Column supported foundation pads (CFP)

The CFP construction methodology comprises GEC below a soil pad reinforced with a horizontally arranged geosynthetic basal reinforcement layer.

GEC are non-cohesive material columns encased by a seamless, tubular geosynthetic sleeve. The columns are typically uniformly arranged in a triangular pattern. The axial spacing varies between 1.7 m and 2.4 m. This arrangement produces a ductile bearing system, which significantly reduces the primary as well as creep settlements. Resulting from load distribution and arching effects in the embankment, stresses concentrate on the GEC, whereas the soft soil is significantly less loaded. Thus, soft soil and GEC settle in equal extent, which is a basic assumption in the GEC design, see Raithel (1999). Additionally, as the columns act as filtration stable large diameter drains, they accelerate the consolidation process.

The overall loads and stress concentrations above the column heads induce outwardly directed radial horizontal stresses in the columns. These stresses affect a lateral expansion of the geosynthetic encasement, which in turn activates the tensile strength in ring direction. A state of equilibrium is reached, ensured by the strength and the stiffness of the non-cohesive column fill, the radial counter-pressure by the soft surrounding soil and the confining tensile strength in the geotextile encasement.

The horizontally arranged geosynthetic reinforcement is used to control the stability of the embankment during the various constructions stages by reducing the introduced shear strain in the subsoil and adding additional restraining forces. Further, this layer takes the spreading forces from the embankment slopes and supports the load distribution and load transmission to the GEC heads.

The major objectives of the construction method are listed below:

- Shortening of construction and consolidation durations for the piled bridge abutments as well as the transition zones between the bridge structures and approach embankments by the excellent drainage capacity of the GEC
- Decrease of long-term deformation in the transition zone between bridges and road embankments, see Alexiew et al. 2016
- Minimisation of embankment foot prints and embankment fill material
- Reduction of horizontal pressure on the piles below the bridge abutments

4 CONSTRUCTION DETAILS

4.1 Bridge BW 8091

The construction details are presented for Bridge BW 8091. Fig. 2 shows the typical section of the single-span bridge (span w = 23 m) and its approach embankment. The abutment is built on driven in-situ concrete piles with a diameter of D = 0.51 m and a pile inclination of 4:1.

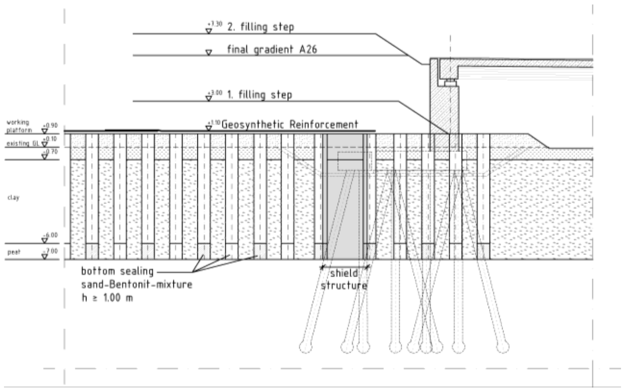

Fig. 2. Typical longitudinal section of a piled bridge abutment with CFP, Bridge BW 8091-West, modified from Ed. Züblin AG

4.2 Construction sequence

Due to technical reasons the bridge foundation had to be built prior to the approach embankment. When the approach embankment is filled on extremely soft subsoil lateral stresses acting on the bridge piles can develop. As the driven in-situ concrete piles have not been designed to withstand lateral loads the CFP as well as a shield structure are incorporated. Both are designed in order to reduce the lateral pressure on the bridge piles resulting from the approach embankment.

The remarkable reduction of lateral loads on bridge piles using CFP has been demonstrated in successfully executed projects, see Alexiew et al. 2016.

4.3 Shield structure

The shield structure is a local soil replacement built in a secant wall method and has a width of b = 3.5 m. Finally, the secant wall, made from sand, is adjacently encircled by GEC. The position and the dimension of the shield structure are presented in Fig. 3. The consideration of both CFP and shield structure within the geotechnical design is presented in section 5.2.

Fig. 3. Site plan of GEC columns and shield structure, Bridge BW 8091-West, modified from Ed. Züblin AG

5 GEOTECHNICAL DESIGN

The broad geotechnical design for this construction section includes many different aspects. Due its limited extent, this paper does not focus on the estimation of settlements (incl. creep settlements), the estimation of the excessive preload height or details information about the overall slope stability analyses for the different design cases.

5.1 GEC design

The analytical GEC design procedure is based on Raithel (1999). Further it is published in the EBGEO (2010) and referenced in DIN 1054 (2009), which acts as the German Annex of the Eurocode 7 (2004). Hence the design falls under the European geotechnical standards. The design was performed using the design software RingtracS. The outcome presents the required area ratio (a = 14%) and the ultimate tensile strength of the geosynthetic encasement (R_{bk0} = 400 kN/m, type Ringtrac® 100/400) as well as the settlements of the GEC improved area after construction.

5.2 Lateral pressure relief of bridge piles

Within the design procedure for piles the consideration of lateral stresses can be omitted when the overall slope stability results in $\mu \leq 0.75$, in accordance with EA-Pfähle (2007). Where μ is defined as the degree of utilization (μ = 1/FOS) acc. to DIN 1054 (2009). The slope stability analyses following DIN 4084 (2009) was performed considering the shield structure by using the shear strength parameter of sand. The improving effect of the GEC is taken into account using an equivalent cohesion. Thus, the GEC is transformed into discrete soil layers with enhanced shear strength parameters estimated in accordance with Raithel (1999). Finally, the ultimate tensile strength of the horizontal basal reinforcement is considered in the calculation. Its strength was increased to R_{bk0} = 1000 kN/m (type Stabilenka® 1000/100) in order to add additional resistance to the slope structure and eventually to fulfil the requirement given above.

For other bridges it was shown, that the improving effect of the CFP was sufficient to fulfil the $\mu \leq 0.75$ requirement. In those cases, the shield structure was not required and consequently not installed on-site.

6 Measurement Results

6.1 Geotechnical monitoring system

Regarding the high degree of complexity for Bridge BW 8091 the so-called Control Method defined in DIN 1054 (2009) had to be adopted. This method is detailed by Blume et al. (2004).

Prior to the GEC installation, gauges measuring excess pore water pressure in varying depths between the GEC were installed. Additionally, load gauges as well as settlements gauges were arranged both on top of the GEC and between them.

6.2 Excess pore water pressure

During the GEC installation the excess pore water pressure (EPWP) increased up to u_1 = 50 kN/m² and dissipated rapidly after the steel pipe (installation aid) was withdrawn (see Fig. 4). With rising embankment fill EPWP increased up to u_1 = 45 kN/m² and after 5 month the required consolidation degree U = 95% was achieved. The transient increase of EPWP in January 2017 was caused by excavation works at the bridge abutment. EPWP gauges installed at the opposite bridge abutment confirmed those findings by evincing similar EPWP developments.

6.3 Settlements

The settlements induced by the installation of the working platform amount to s_1 = 30 cm (see. Fig. 5). After the GEC installation and completing the 1st filling step (level +3.0 mNN) increased settlements of an additional s_2 = 37 cm on and between the columns was measured (please note for Fig. 6: $s_2 = s_{tot} - s_1$, with s_{tot} = 70 cm).

In comparison, at approach ramp K40 which was built using the consolidation procedure on subsoil of similar characteristics the measured settlements were considerably higher (s_3 = 180 cm).

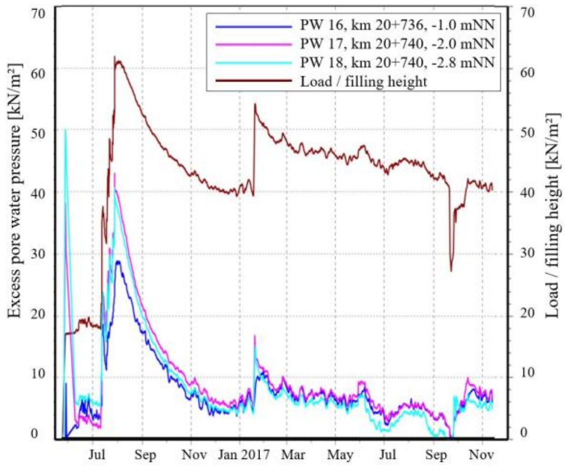

Fig. 4. Time and filling related settlement between columns

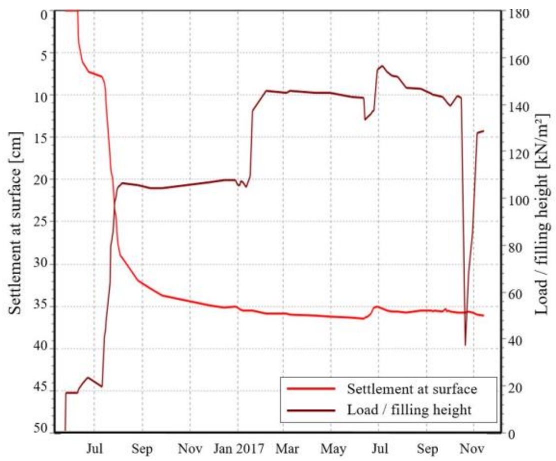

Fig. 5. Time and filling related settlement between columns

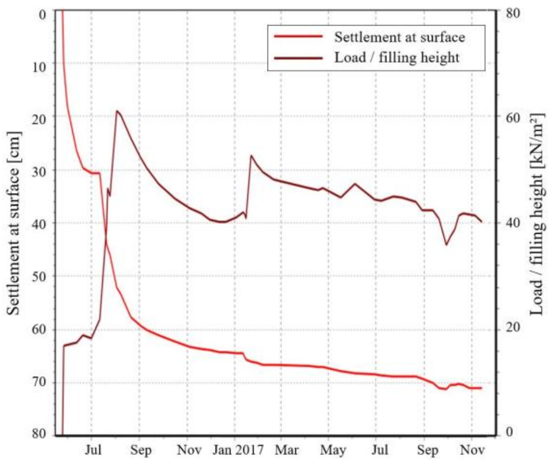

Fig. 6. Time and filling related settlement on column 29

7 CONCLUSION

This paper introduces the Columns Supported Foundation Pad (CFP) construction method using Geosynthetic Encased Columns and horizontally arranged geosynthetic reinforcement by means of a complex bridge structure built on Holocene peaty soft soil.

The measurement results substantiate the main GEC objectives of settlement reduction and settlement equalization as well as their application as appropriate drain elements noticeably accelerating the consolidation process.

From an operational perspective the CFP construction method fulfilled all requirements to ensure a safe construction and an on-time completion of the construction works.

ACKNOWLEDGEMENTS

The authors would like to thank the Regional Authority for Roads Construction and Traffic of Lower Saxonia (Business Segment Stade) for the support of the publication.

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