



3D Finite Element Analyses – Interaction between Abutment and Adjacent Earth Embankment of a Modern Railway Bridge

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The Scherkondetal Bridge in Eastern Germany belongs to a new generation of railway bridges with a semi-integral structure. It is one of the three large bridges of the new high speed railway track Erfurt – Leipzig/Halle currently under construction. The bridge measures 576.5 m in length and the loads are transferred into the subsoil via 13 pillars and two abutments. The advantages of the semi integral structure are its aesthetics and the significantly reduced number of high-maintenance slide bearings.

➤ The foundation pile design of the eastern abutment was influenced by a change of the construction sequence; namely the abutment had to be built prior to the embankment. The correct prediction of the development of consequential settlements due to the construction of the adjacent embankment was crucial for the design.

Figure 1 depicts the construction design of the abutment including the abutment (wing) walls and the adjacent earth embankment, which is supported by hydraulically (cement) stabilised fill. The subsoil consists of the following layers: Slope loam (approx. 2 m), underlain by completely to highly weathered (decomposed) rock (approx. 3 m) underlain by decreasingly weathered rock with depth.

In the area of the abutment the slope loam was exchanged for hydraulically stabilised material. The abutment and the adjacent embankment are designed based on the principles of the observation method with the following main foci:

- Design of a deformation-resistant bored pile foundation, consisting of 14 piles 10 m in length and 1.5 m in diameter
- Deformation prognosis with respect to the settlements due to the construction of the embankment, for the interaction system “abutment – adjacent embankment”.
- Settlement monitoring of the abutment and the embankment during and after construction of the embankment

The allowable settlement for the abutment was set to 5 cm. Settlements up to this value can be compensated later by the abutment structure

within the meaning of the observation method.

Monitoring

Figure 2 shows the layout of measuring points at the abutment, below the footprint of the embankment and on top of the embankment. The settlements at the foundation of the abutment and along the track axis on top of the embankment were measured by means of geodetic leveling. Additionally, one settlement marker was installed at each of the abutment walls. The settlement measurements below the footprint of the embankment were performed by means of two multi-extensometers (E1 and E2, cf. Figure 2) along the track axis, reaching depths down to 20 m. This instrumentation rendered possible the settlement measurement of three different depth

intervals (0 – 5 m, 0 – 10 m and 0 – 20 m).

The relevant settlement measurements together with the calculated values are depicted in Figure 7 and 8 and will be discussed below. The two diagrams also show the relevant construction stages, for each of which measurements were performed. These construction stages were also modeled in the 3D finite element analyses.

3D Finite Element Analyses

The high requirements for the settlement prognosis for the interaction system “abutment – adjacent embankment” necessitated a 3D finite element modeling of the abutment foundation, the embankment and the surrounding subsoil.

The following FE analyses were performed:

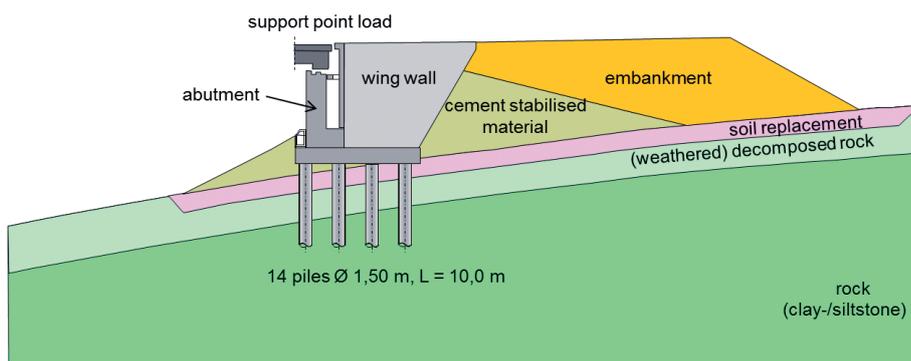


Fig. 1: Cross-section of the abutment with the adjacent embankment



Photo by DB AG

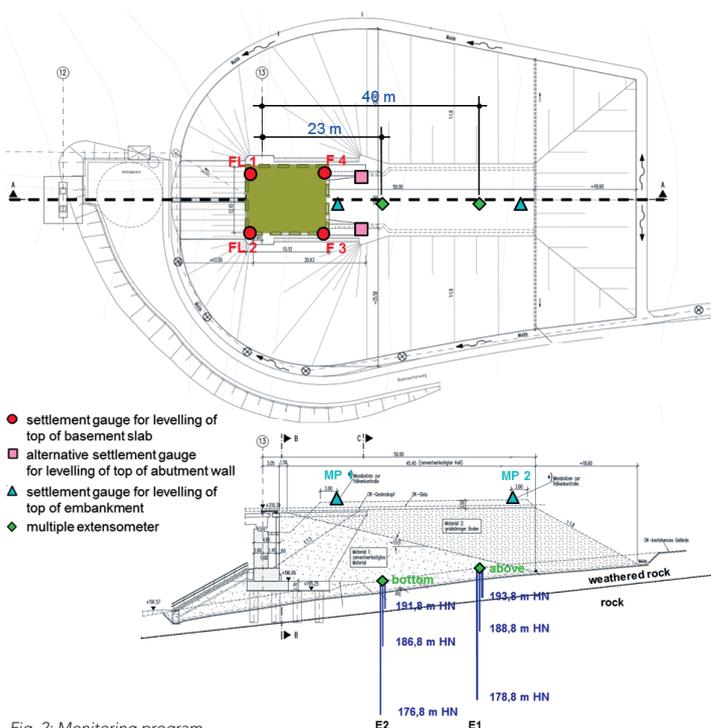


Fig. 2: Monitoring program

HS Small Model		Slope loam	Decomposed rock	Rock
Calculation Type		Drained	Drained	Drained
γ_{unsat}	[kN/m ³]	21,0	21,0	22,0
γ_{sat}	[kN/m ³]	21,0	21,0	22,0
k	[m/day]	8,64E-3	8,64E-5	8,64E-5
E_{50}^{ref}	[kN/m ²]	7.000,0	12.000	55.500
E_{oe}^{chref}	[kN/m ²]	7.000,0	12.000	54.000
power (m)	[-]	0,90	0,60	0,40
c_{ref}	[kN/m ²]	12,5	20,0	50,0
ϕ	[°]	22,5	22,5	45,0
ψ	[°]	0,0	0,0	10,0
E_{ref}	[kN/m ²]	21.000	36.000	166.500
G_0	[kN/m ²]	40.000	70.000	2.080.000
$\gamma_{0,7}$	[-]	2,0E-4	2,0E-4	4,0E-5
ν_{ur}	[-]	0,20	0,20	0,20
p^{ref}	[kN/m ²]	100,0	100,0	100,0
Tensile Strength	[kN/m ²]	0,0	0,0	0,0
R_{inter}	[-]	1,0	1,0	1,0

Table 1: Material parameters of the HSsmall constitutive model of the slope loam

- Class A prediction with 3DFoundation (PLAXIS 3D was not yet available) in the framework of the observation method
 - Subsequent analysis with PLAXIS 3D 2012 to allow for a more realistic model geometry
- The symmetry of the abutment geometry is incorporated in both FE models in terms of a vertical symmetry plain along the track axis (cf. Figure 3 and 4).

Class A prediction with 3DFoundation

Due to the limitations of 3DFoundation with respect to the generation of complex 3D

geometries, the following simplifications were made:

- horizontal surface and layering of the subsoil
- modeling of the foundation slab with 2D plate elements
- modeling of the abutment by means of vertical surface loads
- modeling of the superstructure of the bridge by means of vertical point loads

Using the symmetry of the system a FE mesh consisting of 6690 15-node 3D wedge continuum elements was generated.

Subsequent analyses with PLAXIS 3D 2012

The subsequent analyses with PLAXIS 3D 2012 aimed at

- modeling of the complex geometry of the abutment including the abutment walls and especially of the adjacent embankment supported by a hydraulically stabilised wedge as well as the inclined ground surface
 - and comparing the results with those obtained from the simplified 3DFoundation model.
- In analogy to the 3DFoundation model, the superstructure of the bridge was modeled by means of vertical point loads. The FE mesh of the

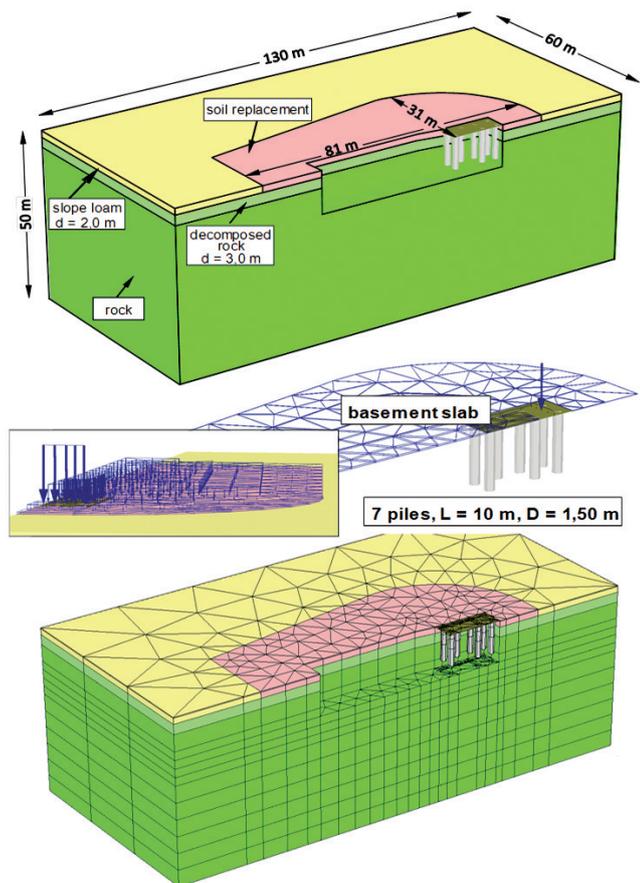


Fig. 3: FE model – 3D Foundation

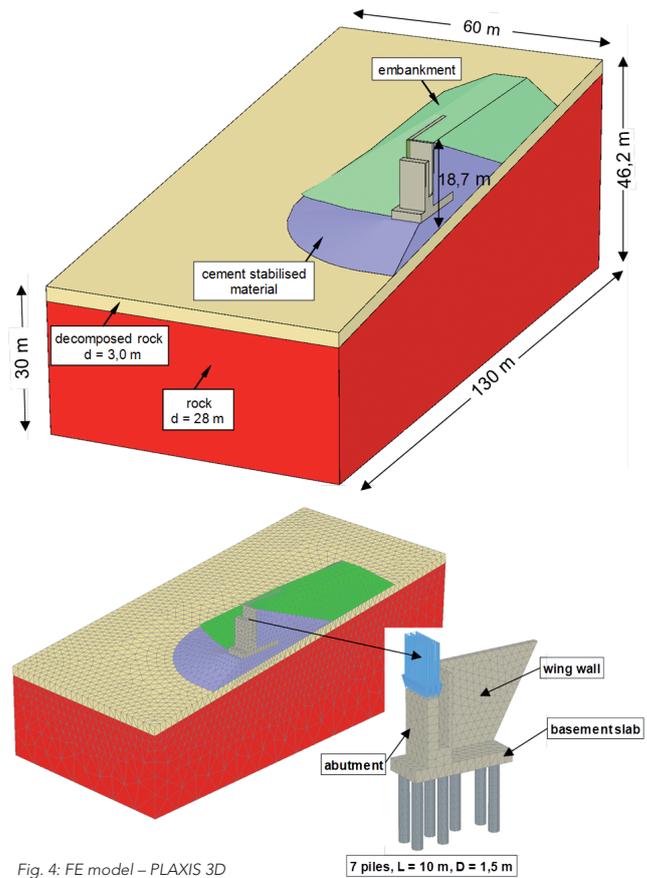


Fig. 4: FE model – PLAXIS 3D

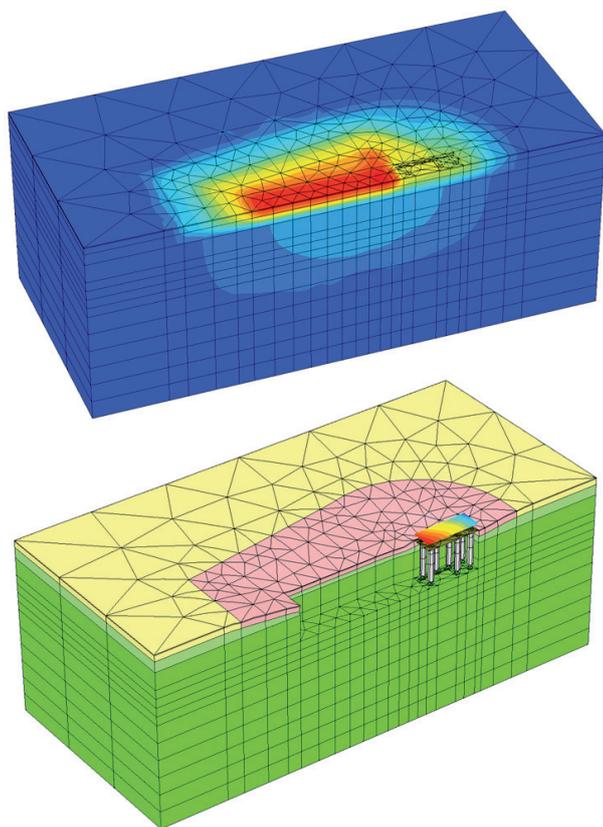


Fig. 5: 3DFoundation analysis – Settlements of embankment base and abutment

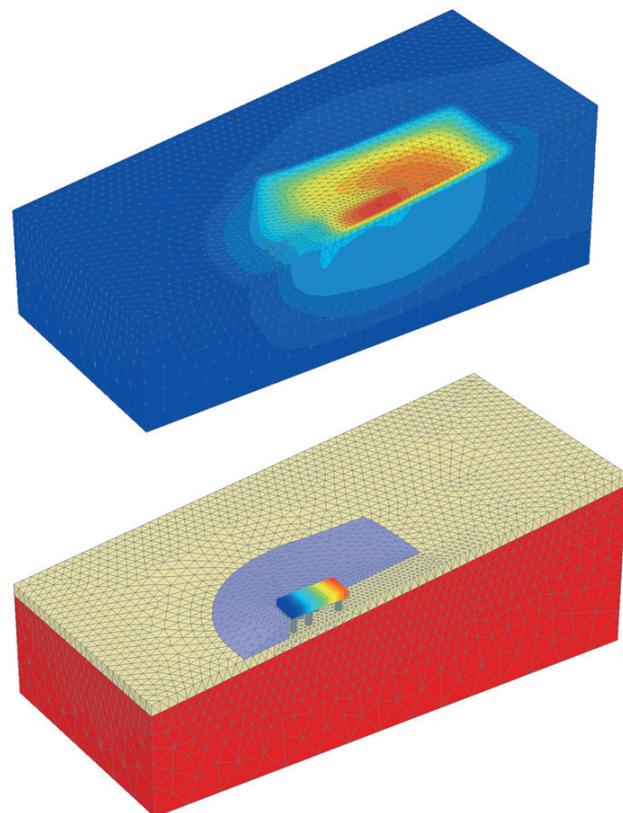


Fig. 6: PLAXIS 3D analysis – Settlements of embankment base and abutment

model depicted in figure 4 consists of 108784 10-node 3D tetrahedral continuum elements, with a total of 150790 nodes.

Constitutive models of soils and structural members

In both FE models the following constitutive equations were used:

- linear elasticity for the abutment, modeled with continuum elements in PLAXIS 3D and with plate elements (foundation slab) in 3DFoundation, respectively and for the bored piles.
- linear-elastic perfectly plastic model with Mohr-Coulomb failure criterion for the hydraulically stabilised material
- Hardening Soil Small Strain Model (HSsmall model) for the soils/rock

Stiffness values according to the concrete strength class C35/45 were assigned to the structural members. A cohesion of 15 kPa with tension cut off was assigned to the hydraulically stabilised material. The applied material parameters for the structural members and the hydraulically stabilised layer, were determined based on relevant codes and experience, respectively.

The HSsmall model was not only used for modeling the behaviour of the slope loam and weathered rock, but also for the only slightly weathered to fresh (solid) rock. Especially with respect to the two parameters governing the small strain behaviour, namely G_0 and $\gamma_{0.7}$, there is only limited experience for rocks. Table 1 summarises the sets of material parameters of the HSsmall constitutive model of the slope loam, weathered rock and rock.

The less pronounced pressure dependence of the stiffness of the rock is reflected in the low value of the exponent ($m = 0.4$) of the stiffness-pressure relation according to OHDE or JANBU, respectively. The stiffness for small strains of the solid rock, which lies in the range of the values of concretes, was determined based on data sets given by BENZ (2007) for solid rock and the relation between the “static” and “dynamic” stiffness according to ALPAN (1970) (cf. PLAXIS material models manual, Figure 6.7). The very high small strain stiffness of the rock means only the stiffness of the compact rock is relevant. Hence, that the influence of joints is irrelevant.

Calculation Phases

In both FE analyses the construction stages “installation of the pile foundation” and “construction of the abutment” were modeled (calculation type: plastic) after the initial phase (calculation type: gravity loading). Performing the Class A prediction with 3DFoundation, the construction of the embankment was modeled in one step only, since a work schedule was not available. The calculation phase “embankment construction” was carried out as a consolidation analysis to obtain the development of settlements with time (Figures 7 and 8).

In the subsequent analysis with PLAXIS 3D the “construction of the embankment” is divided into three phases, according to the by then known work schedule. These calculation phases were carried out as plastic analyses.

Results

Figure 7 depicts the measured settlements due to the construction of the embankment together

with the results of the Class A prediction and the subsequent analysis. The agreement between the measurements and the numerical results is good, with the results of the class A prediction representing a lower bound and the ones of the subsequent analysis an upper bound of the measurement results.

Figure 8 shows the development of the settlements measured in the observed soil layers by means of the multi-extensiometers together with the results of the two FE analyses. For the extensiometer E1 (Figure 8a and b), the corresponding numerical results exceed the measured values. Whereas the calculated values for the extensiometer E2 closer to the abutment lie in the same range as the measurements.

In the face of the principal lack of information with respect to the subsoil, the agreement between the measured and calculated development of settlements is satisfactory. The measured developments of settlements differ more significantly for the different depth intervals (0 – 5 m, 0 – 10 m and 0 – 20 m) than the calculated values, which yield more or less the same value for all intervals. The main reason for this is the rock layer was assumed to be homogeneous. With the

rock layer divided into sublayers with increasing stiffness and strength characteristics with depth and related to the degree of weathering (decomposition) one can expect more realistic results. However, especially in case of the rock a reliable base of investigation data is missing.

Conclusions

The two different FE analyses yielded the following conclusions:

1. The HSsmall model is applicable not only for soils but also for (weathered) rock. The results show only little lateral spreading of the settlement troughs as well as a small range of influence of settlements with respect to depth. The settlements mainly occur in the upper part of the weathered/decomposed rock layer.
2. Complex model geometries can be generated and imported from CAD data with PLAXIS 3D. However, the expenditure of human labour should not be underestimated.
3. It is not always necessary to model geometries as realistic as possible. It is of much more importance, that the modeling engineer makes adequate simplifications where applicable.

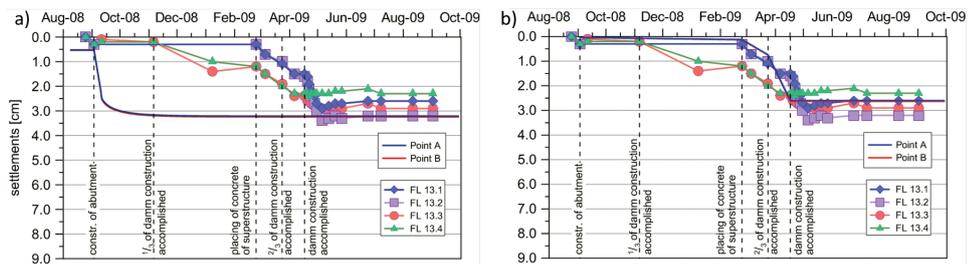


Fig. 7: Measured and calculated development of settlements of the abutment, a) 3DFoundation, b) PLAXIS 3D

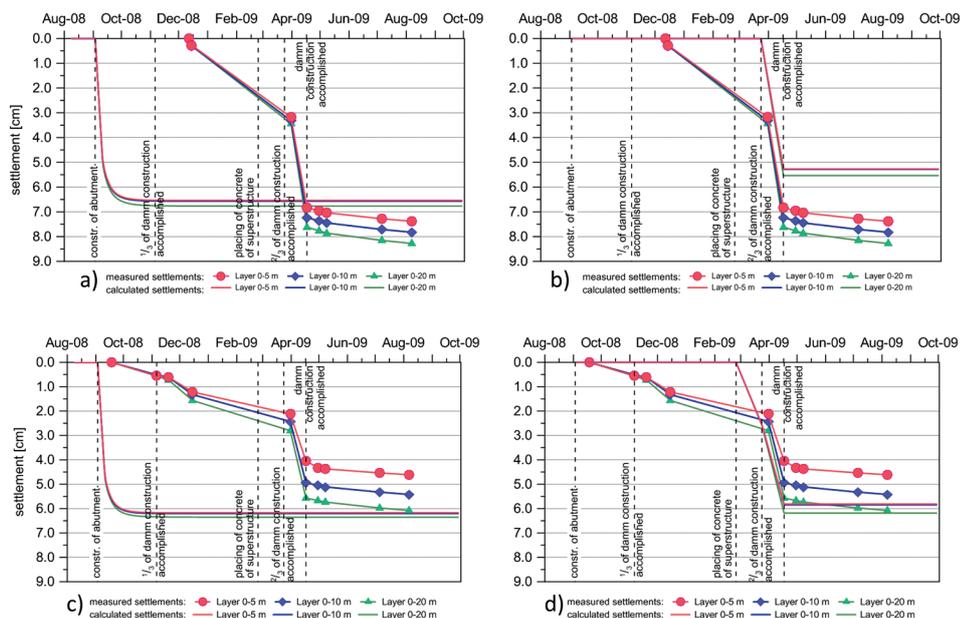


Fig. 8: Measured and calculated development of settlements (extensiometers E1 (a+b), extensiometers E2 (c+d)), a)+c) 3DFoundation, b)+d) PLAXIS 3D