Designing a bridge with Plaxis 3D tunnel

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Introduction

The High Speed Line (HSL) between Amsterdam and Brussels is not yet in operation and there are plans to cross this railway track by local roads and motorways. Movares has carried out a global research projects over infrastructures crossing an operational HSL. One of these research projects concerned the crossing the HSL by two large shield tunnels (15 m diameter) without generating any track deformations through tunnelling. An option to achieve this is to construct a “support bridge” i.e. a concerte plate to avoid local settlements of the railway track. The purpose of this support bridge is to carry the HSL track over the route of both shield tunnels free from eventual settlements. Figure 1 gives a 3D-view of the HSL and crossing tunnels. The global dimensions of the support bridge were calculated with the Plaxis 3D tunnel program in an early stage of design.

This article gives a short description of the 3D Plaxis model, the model difficulties and calculation results.

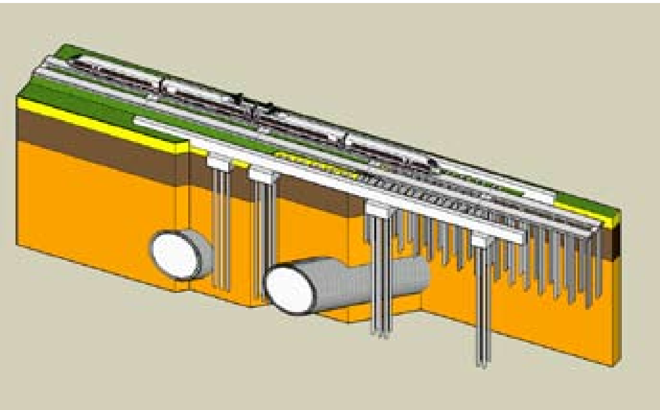


Figure 1: 3D picture of the HSL track, new support bridge and shield tunnels.

Background information HSL

In the Netherlands, the HSL is mainly built on a concrete plate on pile foundation. The bearing piles are driven to a depth of 15 to 20 m below the surface. The bottom of the shield tunnel is situated just under the toe of the piles. The tunnelling process will reduce the bearing capacity of the pile foundation and settlement of railway track is expected. It’s assumed that such a support bridge should prevent (differential) settlement of the railway track.

Why Plaxis 3D Tunnel?

The support bridge is a complex asymmetrical construction. The question asked is: is the bridge capable of meeting the HSL deformation requirements and can this be modelled with Plaxis 3D? Rough calculations by hand do not provide these answers. Plaxis 2D has been used for predictions of settlement caused by the tunnelling process.

The Support Bridge

Figure 1 gives a 3D artist impression of the support bridge, shield tunnels and the HSL. Figure 2 presents the Plaxis 3D model with the main components of the bridge.

Plaxis 3D Model

Solid elements are used for primary, secondary beams and concrete plate. All abutments support the main beams in a vertical and rotational direction. Because of rotation support, every abutment has two fixed-end anchors. The abutment in the middle section supports the main beam also in a horizontal direction; horizontal fixed-end anchors are added in longitudinal direction (acceleration and break forces). One fixed-end anchor is added in transverse direction for numerical integrity.

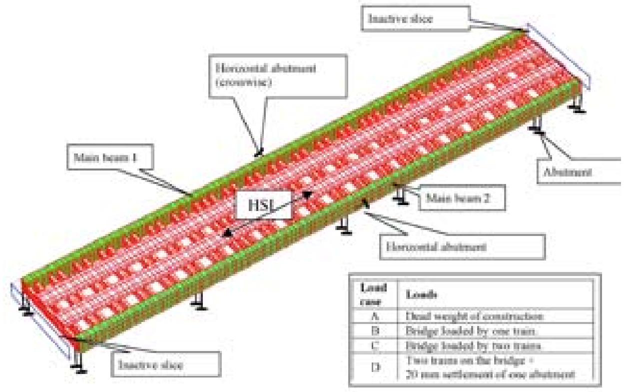


Figure 2: Plaxis 3D model with main parts.

Some special modelling features need to be taken into account, which are indicated in table 1

Do’s
- Add fictitious inactive slices on both ends of the model. Fictitious inactive slices overcome problems with the standard boundary conditions at both ends of the model. - Define separate material data set for each abutment. Separate material sets make it easier to change the vertical stiffness of the abutment during calculation. - Two fixed-end anchors models each abutment, to provide rotation stiffness for the main beams.
Remarks
- It was considered including plate elements in the primary and secondary beams. Plate elements with a fictitious, low bending stiffness, simplifies presentation of bending moments, normal forces etcetera. The use of plate elements was rejected because bending moments occur in diverse directions.

Table 1 special modelling features

Post processing, deformations and reaction forces

During normal train operations, the key element to consider is global deformations and differential deformations. Settlements of track are obtained in Plaxis 3D through generating a cross section at track level. Numerical deformations are thereafter copied into an Excel sheet for further processing. Figure 3 shows the deformed support bridge. Figure 4 shows the settlements of the main beams, the railway tracks and the reaction forces of abutments for load case B (load case B being the situation where one train is on the bridge). Figure 5 shows the bending moments in the main beam for the different load cases.

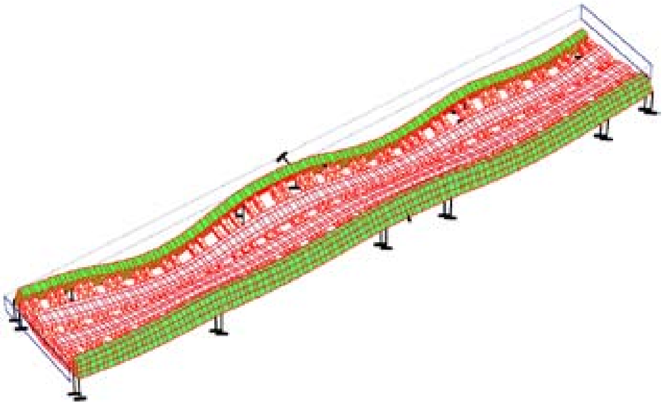


Figure 3: deformed support bridge

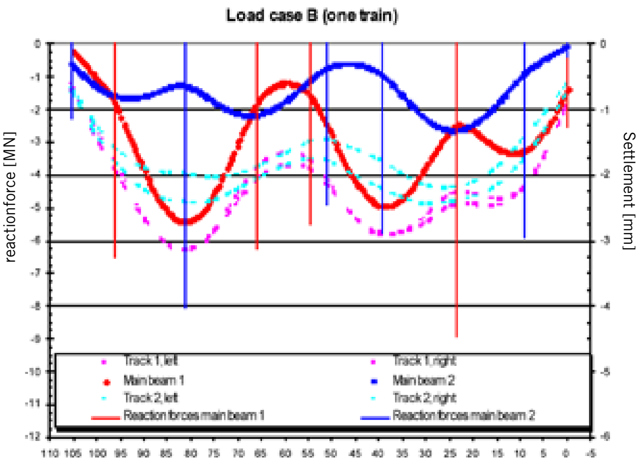


Figure 4: settlements of the main beams

Tunnelling Process

Settlements of the abutments as a result of the tunnelling process were expected for the abutments situated close to the tunnels. Settlements of the abutments caused by the tunnelling process are modelled by reducing the vertical stiffness of the support. The amount of reduction applied is an iterative process. The calculated settlement of the abutment had to comply with the predicted settlement induced by the tunnelling process.

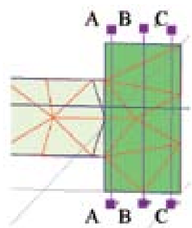
Post processing, bending moment

The plate elements were not included in the model. Bending moments are obtained by integrating the stresses over the height of the main beam.

Calculation of the bending moments

For the cross sections A-A, B-B and C-C

$M_{AA}(z) = \sum \sigma_{zz;i}(z) \cdot A_i \cdot y_i$



Bending moment in Main Beam:

$M(z) = 1/3 \cdot (M_{AA}(z) + M_{BB}(z) + M_{CC}(z))$

M(z)	Bending moment around X-X.
M_{AA}, M_{BB}, M_{CC}	Bending moment cross section A-A respectively B-B and C-C.
A_i	Area for $\sigma zz(y,z)$
$\sigma_{zz}(y,z)$	Stress in longitudinal direction in cross section A-A, B-B and C-C.
y	Distance to X-X
Z	Z-coordinate

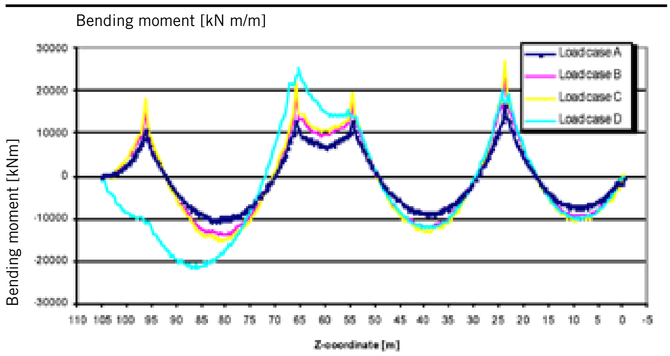


Figure 5: bending moments in the main beam

Conclusions

- The definition of the boundary conditions gave a few difficulties;
- Modelling the support bridge with Plaxis 3D posed no difficulties;
- The post processing of the numerical results is a time consuming process;
- The copy option of slides and planes in the calculation model proved to be a useful timesaver;
- Herewith the structure complies with the deformation requirements;
- There is a good concordance between the results of the Plaxis 3D calculation with other FEM programs such as Ansys (not presented here).