SOIL-STRUCTURE INTERACTION ANALYSIS OF A RAILWAY BRIDGE IN ROTTERDAM

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Abstract Theemswegtrace bridge is a double track railway bridge located in Rotterdam, Netherlands. Total length of the bridge is 3.7 km, with a typical span length of 30 meters. For these typical spans, superstructure consists of simply supported precast prestressed I girders and cast in place R/C slab. An assessment study of the original design was performed in a non-linear manner to observe the importance of soft soil conditions on rail-structure interaction. Due to soft-soil conditions, rail-structure interaction analyses according to UIC 774-3 were performed together with inclusion of barrette piles and associated soil-springs. Site specific non-linear p-y curves, t-z curves and q-z curves were developed and used in the analyses. It was found out that soils structure interaction can effect the results significantly and has remarkable importance in rail structure interaction analysis of bridges located on soft soils.

1 Introduction

The viaduct has a total length of 3.7 km, with a typical span length of 30 meters. There are double tracks with normal speed railway traffic. Width of the platform is E=11.5 meters. No rail expansion device for typical spans was selected in the original design. Within the scope of the work, rail-structure-soil interaction analyses for a bridge segment having a total length of 485 meters were performed. Some steel-arc bridge segments are out of scope for this study. Bearing system for the studied segment consists of mobile elastomeric bearings and mobile elastomeric bearing+dowel, providing horizontal fixity for each simply supported segment. The client was Ballast Nedam, Netherlands.

Results for this segment shall be indicative for the rest of the viaduct. Typical cross-sectional view of the superstructure and sub-structure are presented in Figure 1 and Figure 2.

For the superstructure, the system consists of precast girders and the girder depths change from 1.22m to 2.2m. Piers have rectangular shape with dimensions 1.25m x 2.5m, except 3-4 axes with 1.5m x 3m pier dimensions. Within the segment studied, 3 types of barrettes and 2 types of caissons are used. Barrettes types have dimensions of 1m x 7.5m, 1m x 5m, 1m x1 0m and caissons have 5m x 3m and 3.75m x 3m dimensions with 1 meter wall thickness.

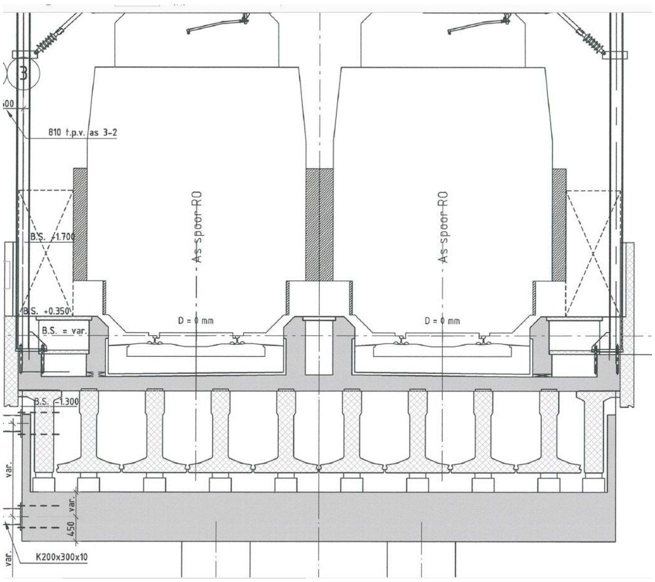

Fig. 1. View of the Superstructure Cross-Section

In the studies, Eurocode 1991-2 [1], UIC 774-3 [2] relevant National Annexes and international codes as well as documents provided by the client [3] are taken as basis. The loads and load combinations as well as other relevant parameters are taken from the above documents to be able to fully check the original design. Larsa 4D [4] software is used for structural analysis.

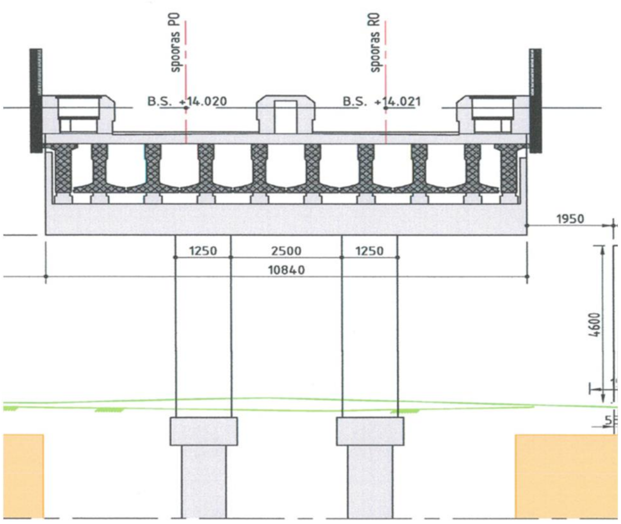

Fig. 2. View of the Superstructure and Sub-Structure

2 Analysis Model and Results

2.1 Substructure With Barrette Piles

In the model, superstructure, rails, piers , barettes and caissons are modeled by using frame elements. Bearings are modeled by using spring elements. Dowels providing fixity is modeled by introducing very high horizontal stiffnesses at those locations although behaviour of dowels is questionable, especially in long term.

The barettes and caissons are included in the model since their flexibility resulted from the loose soil conditions is the dominant factor affecting the rail-structure interaction response of the viaduct. Geotechnical studies performed for this project at Middle East Technical University are taken as basis for non-linear p-y, t-z and q-z spring load-displacement curves. Soil layers at the site consist of loose to medium stiff sand. There is no bedrock at the bottom.

In the analysis model these soil springs as well as springs representing the behaviour of ballasted track are modelled by nonlinear bi-linear springs. A general view of the analysis model is presented in Figure 3.

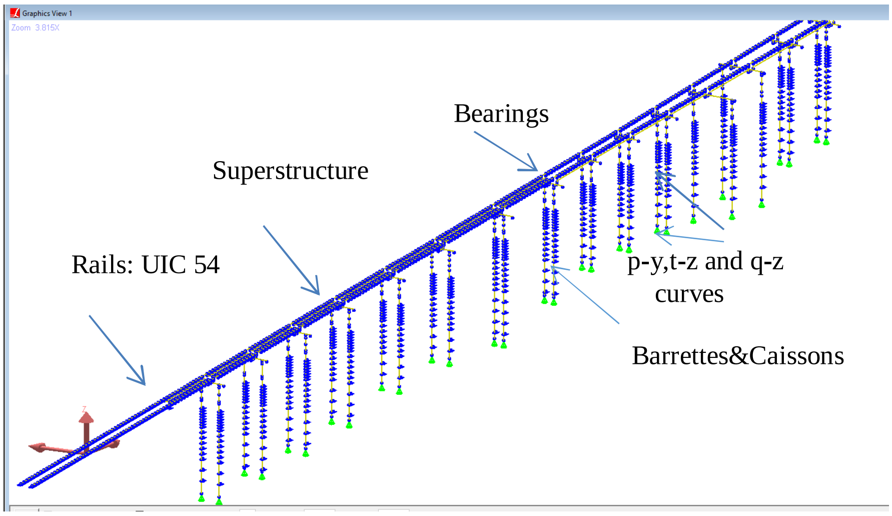

Fig. 3. General View of the Analysis Model

Since no rail expansion device is foreseen in the original document for this segment, rails are considered to be CWR (Continuous Welded Rail) and requiments of EN 1991-2 and UIC 774-3 for CWR are followed. Live load classification factor α is accepted as 1.21.

For braking, acceleration and live load analysis, loaded spring properties are used for the ballast whereas unloaded spring properties are used for modelling thermal behaviour of the track.

Absolute horizontal displacement of the deck under braking+acceleration is about 12 mm which exceeds the upper code limit of 5 mm (EN 1991-2 6.5.4.5.2) significantly. Approximately half of this displacement result from the flexibility of the barrettes&caissons. Relative displacements between the superstructure modules, the basis for evaluation, sometimes exceeds the code specified limit of 5 mm. On the other hand, rail stresses are almost within the code limits. Typical rail axial forces under temperature rise of 35ę is presented in Figure 4.

Settlements at the pile bottoms were checked to observe extent of the settlement. The maximum settlement at the tip of the caissons/barettes under service load combination is 15 mm, which is within the acceptable limit of 25 mm. Therefore, no settlement problem is expected. The axial load distribution in barrettes/caissons under representative service load combination is presented in Figure 5.

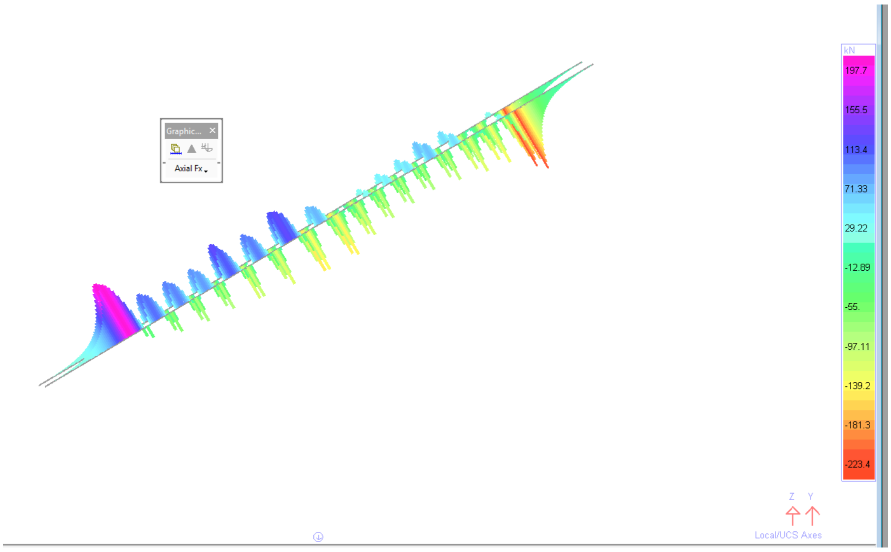

Fig. 4. Rail Forces Under a Temperature Rise of 35 ę

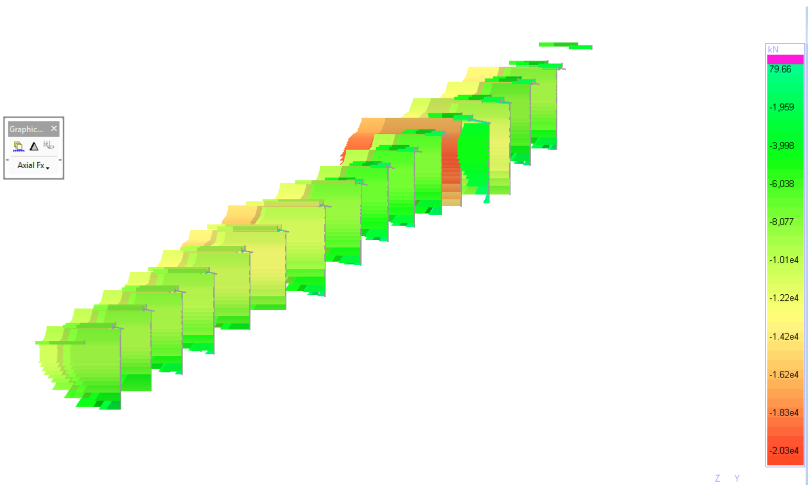

Fig. 5. Axial Load Distribution In Barrettes/Caissons Under Service Load Combination

As seen from the figure, most of the axial load is resisted by skin friction. Contribution of tip resistance to axial load resistance is quite small, as expected. Large perimeter of the barette piles resulted in high total vertical skin friction resistance.

P-y curves behave elastically in their horizontal load displacement curve under braking and acceleration forces.

2.2 Batter Pile Alternative

Tubex type batter pile [5] alternative is studied upon the request of the client in detail by performing incremental pushover analyses. The diameter of the piles is 559 mm with a composite cross-section. The thickness of the outer steel shell is 10 mm, with a concrete fill. The general view of the batter pile model is presented in Figure 6. Soil springs are modeled by using the same p-y curves with consideration of pile dimensions and nodal spacings in the analysis model. There are 7 piles in a pile cap. An alternative with 9 Tubex piles is also studied. The inclination of batter piles is 5:1. The number of battered piles is 2 in 7 pile alternative whereas it is 4 in 9 pile alternative. No batter Tubex pile alternative is also studied.

Analysis is performed by applying incremental horizontal loads at the pile cap level. The horizontal displacement is recorded at the same level.

Batter pile alternative with 7 piles provide almost same horizontal stiffness of the original barette/caisson alternative. The horizontal stiffness provided by 9 pile alternative is higher than all alternatives, as can be observed in Table 1. Therefore, this alternative may be used at locations where higher substructure stiffness is needed and substructure utilities (pipelines etc.) allow.

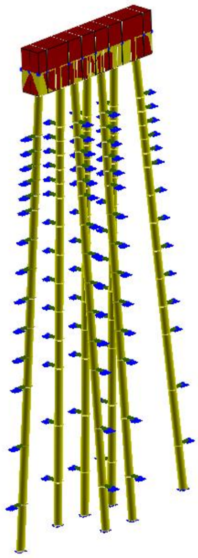

Fig. 6. Batter Pile Alternative With 9 Piles

Table 1: Summary of Pushover Analysis Results

System	Horizontal Load (kN)	Horizontal Pile Cap Displacement (mm)
No Batter- 7 Tubex Piles	1000	6.17
7 Tubex Piles	1000	5.59
Two Supplementary 5:1 Inclined Batter Piles-9 piles	1000	4.20

3 Conclusions

Rail-structure-soil interaction analyses performed on the selected segment segment resulted in horizontal absolute displacements in the order of 12 mm, which is significantly higher than the 5 mm code limit. Since this displacement limit in the codes implies relative displacement between superstructure modules or the displacement between superstructure and abutment, solution of this exceedance may result in addition of supplementary rail expansion devices at bridge abutment transitions and at intermediate positions where there is sharp transitions in substructure stiffnesses resulting from pier heights, pile dimensions, soil conditions etc.

If this alternative is not feasible for a reason, then substructure stiffness can be increased at some certain locations by increasing pier/barette/caisson dimensions. Alternatively, ground improvement methods can be used in between some barettes/pile caps to provide supplementary horizontal stiffness.

The batter pile is a feasible alternative. The horizontal stiffness provided by proposed batter pile system can be significantly increased by adding two more batter piles with 5:1 inclination in the longitudinal bridge direction or by increasing the batter angles of the two 5:1 inclined batter piles in 7 pile alternative. Soil-structure interaction has an important role in rail-structure-interaction analysis of bridges located on soft soils or having foundation systems having low overall horizontal stiffness.

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