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Assessment of existing caisson and pile foundation of Van Brienenoordbrug

Vérification de caissons et pieux de pont Van Brienenoord

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ABSTRACT: In the 1960's the first Van Brienenoordbridge was built, an almost 300 m long main span founded on a caisson foundation. In the 1980's, the bridge needed to be widened, and a second bridge deck was designed. In the longitudinal direction the deck spans the same 300 m. In transversal direction was decided to put one of the bearings on the old caisson foundation (by extending the top of the caisson), and build an adjacent foundation on piles to support the other bearing. The two types of foundations were dilated from each other, so the deck was supported by four individual foundations.
Currently the newest deck (west) needs to be retrofitted for fatigue. This article shows the original design and the check of that design against the new increased design loads. Bearing capacity and deformations have been checked both analytical and with FEM, for the deformations also making use of settlement measurements done for the earlier construction works. It can be concluded that the foundation can take the extra load, with minimal additional settlements.

RÉSUMÉ: Dans les années 60, était construit le premier pont Van Brienenoord, ouvrage de 300m de portée, fondé sur caisson en béton armé. Dans les années 80, l'élargissement de la voie était conçu par un second tablier accolé et de même portée. Le nouveau tablier était pour partie supporté par le caisson existant et pour partie par de nouvelles piles fondées sur pieux. Les nouvelles piles et les caissons sont structurellement indépendants.
Le second tablier du pont Van Brienenoord doit être renforcé pour contrecarrer la dégradation par fatigue.
L'article présente la conception d'origine et la vérification de celle-ci sous les charges accrues actuelles. La capacité portante et les déformations ont été vérifiées de façon analytique et par modèle aux éléments finis. Les déformations sont évaluées en prenant en compte les mesures faites dans le cadre des travaux antérieurs. L'étude a pu démontré que la fondation en caisson peut prendre les charges additionnelles avec un tassement additionnel minime.

Keywords: Renovation; caisson; pile foundation; re-assessment

1 HISTORY VAN BRIENENOORD BRIDGE

The Van Brienenoord bridge passes the Nieuwe Maas in Rotterdam, the Netherlands. In 1965, the first bridge was opened, consisting of a main span of 300 m constructed as a steel arch, a bascule bridge of 60 m and approach bridges. The total length is 1320 m. One of the piers of the main span is in the water, the other near the shore. Due

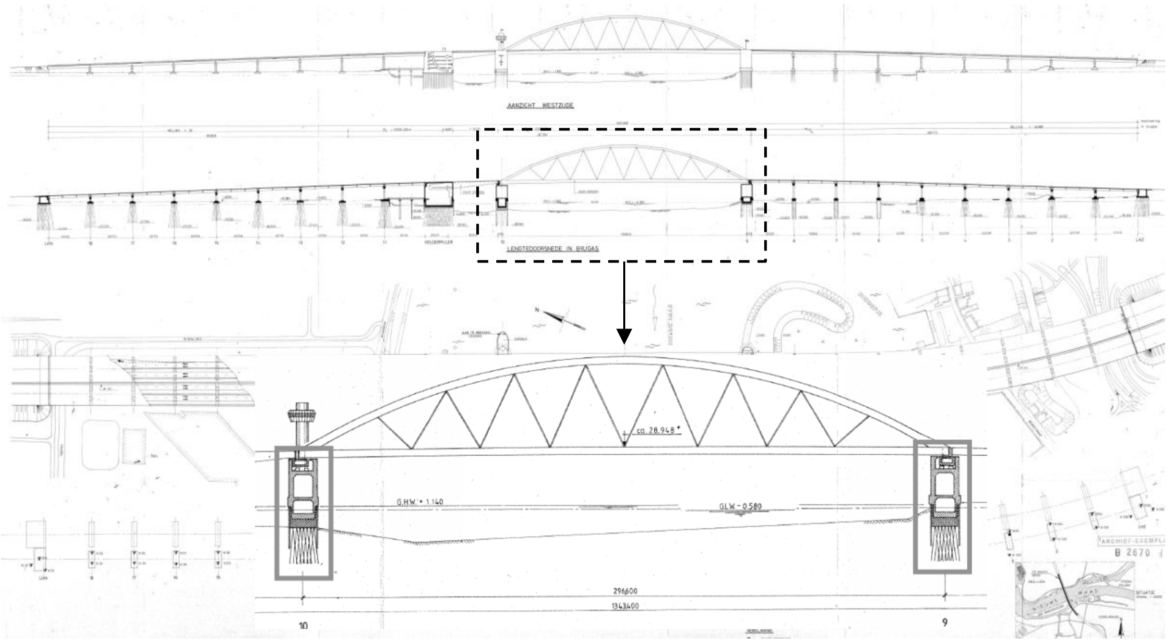

Figure 1. Overview van Brienenoord bridge

to the increase in traffic, the bridge was doubled to the west side between 1988 and 1990. Figure 1 shows a plan view of the west (new) and east (old) bridge. As a result of fatigue issues in the steel deck, the main span of the west bridge needs renovation, which is currently being designed. Renovation of the east bridge is also planned in the near future.

2 SOIL CONDITIONS

The ground level at the north pier is around Dutch reference level NAP -9 m. The soil conditions at the north pier can be described as loose sand over the first meters (down to about NAP -15 m), the formation of Echteld. Below that the Kreftenheye formation, generally loose to dense sand. From about NAP -23 m the formation of Peize and Waalre is found (formerly known as Kedichem), consisting of sand with distinct overconsolidated clay layers at certain depths. A typical CPT at the location of the pier is presented in Figure 2, extending from NAP -9.5 m to NAP -36.5 m. Also boreholes and laboratory tests were available.

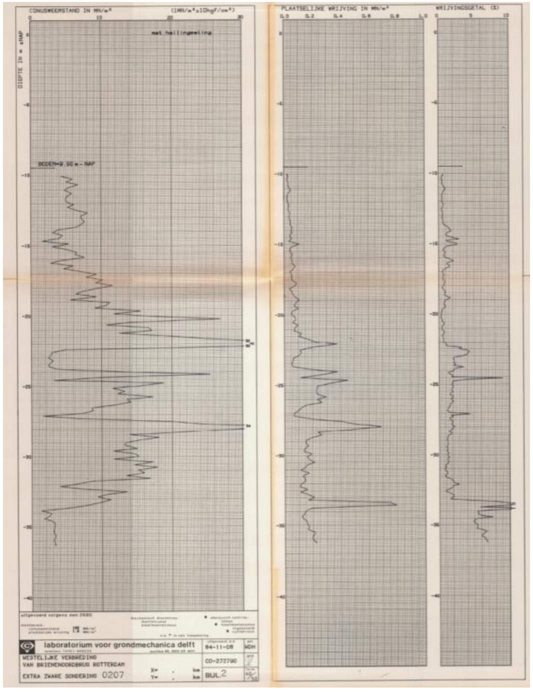

Figure 2. Typical CPT at north pier

For the south pier (on land), the ground level was around NAP -5 m when the east bridge was constructed, and was filled to around NAP + 2.5 m before construction of the west bridge. Stratigraphy is similar to the north pier, with the difference that a clay layer is encountered, from about NAP -9 m down to about NAP -15 m. A typical CPT is presented in Figure 3, extending from NAP +1.5 m to NAP -31.5 m.

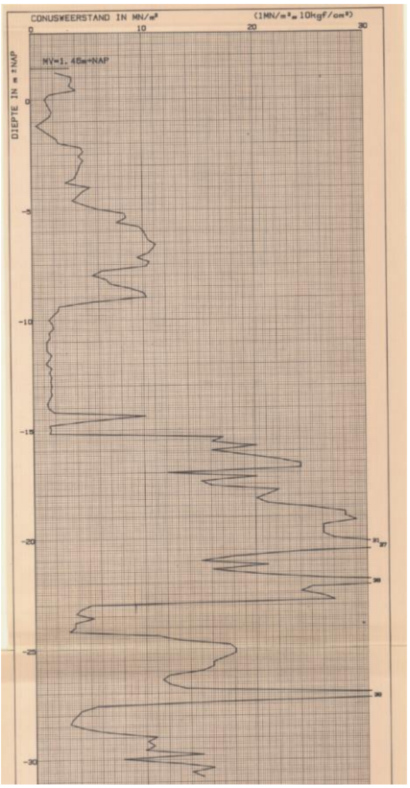

Figure 3. Typical CPT at south pier

The water level in the Nieuwe Maas varies from NAP -2 m to NAP +3,75 m. The groundwater level at the south pier is at about NAP.

3 FOUNDATION DESIGN

3.1 East Bridge

Both supports of the east bridge are caisson foundations. The foundation level of the north support is at NAP -25 m and of the south support at NAP -20 m. The area of the caisson floor is about 1000 m^2, aiming for a pressure not more than 500 kN/m^2 at the time. The prefabricated steel and concrete caissons were shipped to the location that had been prepared to a flat surface. They were brought to depth by excavation in the wet. When the target depth was reached, a floor of underwater concrete was installed with a thickness of about 4 m. To accommodate for tolerances a sheet pile screen was installed around the caisson and the space in between was filled with concrete. See Figure 4 for the caisson foundation structure.

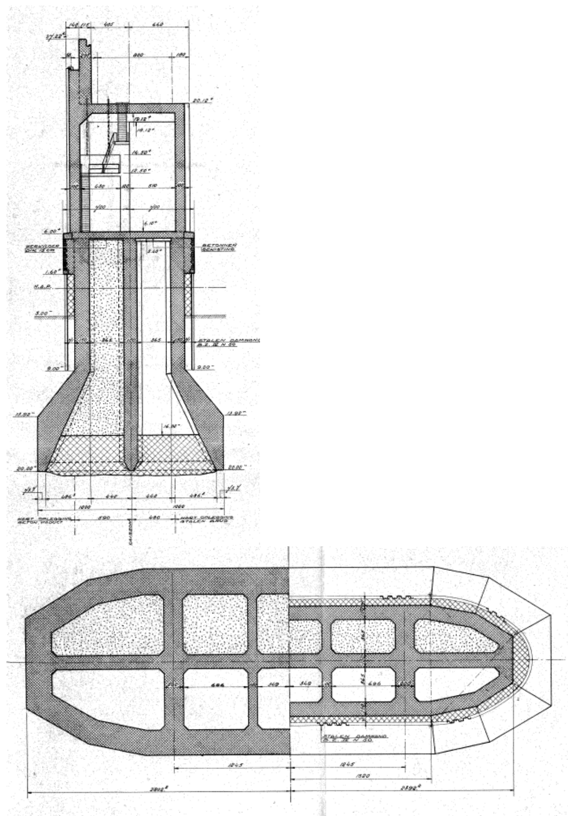
Figure 4. Caisson foundation south side

3.2 West Bridge

For the widening of the bridge to the double width, different alternatives for the foundation were considered. First the option of only using the existing foundation was considered, but in the end not considered to be feasible. Finally was agreed on a pile foundation next to the existing caisson, that would structurally be kept separate from the caisson foundation (full dilatation of the substructure). The new deck would half (west side) be supported by the new pile foundation, and half (east side) by the existing caisson foundation. The caisson needed extension of top of structure to make it work geometrically. The caisson foundation was assessed for the extra load and the resulting eccentricity of the load. The pressure in SLS at foundation level increased from 447 to 571 kN/m^2 for the south caisson and from 436 to 541 kN/m^2 for the north caisson. Figure 5 shows the schematic design.

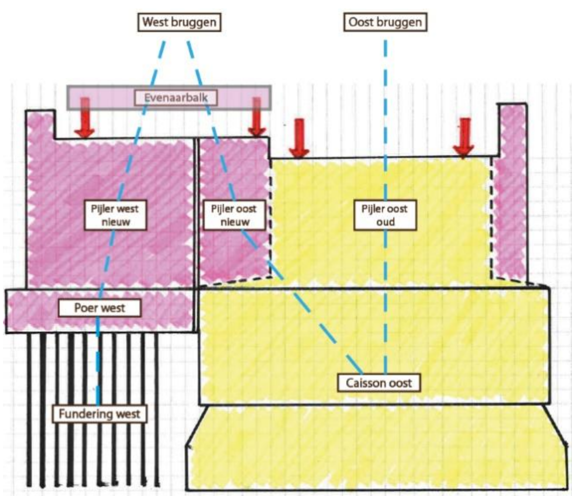

Figure 5. Foundation extension in purple

During and after installation, the caissons were monitored for deformations. These deformations were less than expected based on the calculations.

The pile foundation of the extension of the foundation consisted of a wall of sheetpiles and boxpiles, with prefabricated concrete piles down to NAP -18 m for the south pier and closed-ended steel piles down to NAP -25.5 m for the north pier within the combined wall, with a part of the piles raked. Figure 6 shows the pile foundation.

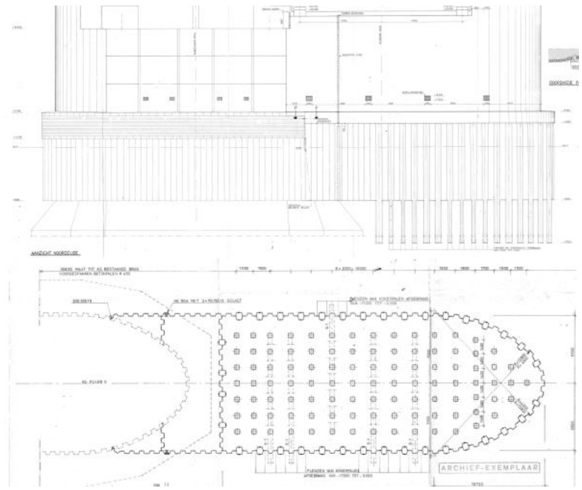

Figure 6. Pile foundation west bridge

4 PLANNED RENOVATION

The deck of the west bridge needs renovation due to fatigue issues. Furthermore traffic loads have increased since the original design. Reassessment of the loads resulted in loads on the caissons that are about 1 % higher than the original loads and loads on the pile foundation of about 3% higher. About half of this is result of the increase of dead weight and half of this of higher traffic loads.

5 ASSESSMENT OF FOUNDATION FOR RENOVATION

As the west bridge is partly supported by the caisson foundation and partially by the pile foundation, both foundations have been assessed. Although the increase in load is small, it was considered appropriate to do an assessment on the foundation.

The results of the original design calculations were available, but the actual calculations itself were not available. The foundations were reassessed based upon the current geotechnical standard, NEN9997-1 with the National Annex, as well as the NEN8707, Geotechnical assessment of existing structures.

For the piles the bearing capacity was calculated taking into account the initial piling factors. In 2017 the piling factors in the Dutch National Annex have been reduced, this reduction was not taken into account for the reassessment, this agrees with NEN8707 because the increase of the load is less than 15%. Negative skin friction was taken into account for the south pier, where the fill had taken place during the widening of the bridge. As this negative skin friction will already have developed, and deformations as a result of this will have taken place, this is a conservative approach.

The bearing capacity of the caissons was recalculated. First an analytical calculation was performed for which the actual shape of the caisson was converted to a rectangle with equivalent section modulus and area. The method as specified in the National Annex of NEN9997-1 lead to a very conservative calculation, as the 1.5 m thick clay layer had to be fictively extended to the end of the influence zone of the footing (about 25 m deep). This punch check has to be performed for the undrained situation. As the majority of the load has already been there for more than 20 years, fully undrained behaviour is not very representative. Therefore an extra check was performed with a 2D finite element calculation (modelling the footing as a strip) in Plaxis. See Figure 7 for the results of the calculation.

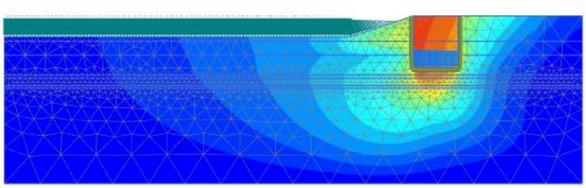

Figure 7 Finite element calculation caisson

As the governing failure direction of the caisson is in the direction of the bridgedeck, and the pile foundations extension is perpendicular to this, no influence of the pile on the caisson foundation was taken into account. An overall safety factor of about 2 was found with the finite element calculation.

For the estimation of the deformations, interaction between the two foundation types was taken into account. The deformation measurements, see Figure 8, were also used to predict the extra settlement. The log in Figure 8 shows about 65 mm of settlement of the caisson from 1962 (start of the construction) and 1982 for the south pier,

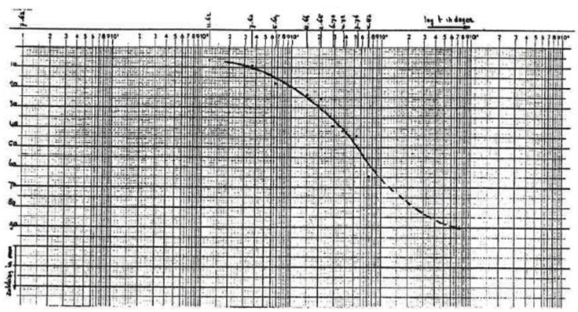

Figure 8. Measured settlement of the south caisson

6 CONCLUSIONS

It can be concluded that the renovation will slightly increase the loads on the foundations. Both the caisson foundation and piled foundation have been assessed for this increase and have sufficient bearing capacity. Expected deformations under the extra loads have been calculated as maximum 2 mm, which is acceptable for the bridge. The differential settlements between the two foundation types are maximum about 1 mm.

7 ACKNOWLEDGEMENTS

Both Rijkswaterstaat and Deltares (at the time Grondmechanica Delft) have kept extensive hardcopy archives of the van Brienenoord project, which made it possible to obtain a lot of information about the actual design as well as the intensive design process that was carried out, especially for the west bridge. This article is meant as an ode to that design.