



Bridge collision protection ramp Kampen

This paper describes the design and construction of a unique and innovative bridge protection structure: the 'collision protection ramp' that is placed in front of an existing bridge.

This innovative concept combines the capacity of a ridged structure with the benefit of minimal ship damage and limited visual impact on the bridge.

Preface

As part of the project 'Ruimte voor de rivier IJsseldelta' the river IJssel near the city of Kampen is dredged to a depth of NAP -7,20 m (existing

riverbed level is NAP -4,40 m). The bridge and its guiding structure are not able to withstand the loads of a ship collision after the dredging works [1].

Consequently Rijkswaterstaat and the city of Kampen decided to protect the bridge with two collision protection structures on the upstream (south) side of the bridge and three on the downstream side. The difference in the numbers is explained by the fact that ships pass the bridge only through the main channel when sailing downstream and can pass in two shipping lanes when sailing upstream.

The contract of the project was awarded to 'Isaladelta', a joint

venture of Boskalis and VolkerWessels. The design of the protection structures was made by Volker InfraDesign and the construction and installation was done by Van Hattum en Blankevoort.

Requirements and boundary conditions

The main requirements for the design of the five collision protection structures were:

- the structures need to protect the bridge from the frontal impact of a sailing ship of the CEMT Va class at all water levels between low water (NAP -0,35 m) and high water (NAP +1,80 m); the energy of a sailing ship on the upstream side of the bridge is 55 MNm; the energy of a sailing ship on the downstream side of the bridge is 21,6 MNm;
- the structures need to withstand the side impact of a ship colliding at an angle of 10° calculated according to the Dutch design code Richtlijnen Ontwerp Kunstwerken (ROK). The structures are able to withstand the loads of the above side impact at all levels between 4 m below low water and 1 m above high water;
- the structures need to be separated from the bridge, with a maximum distance of 16 m;
- the structures need to be designed as ramps.

Important boundary conditions for the design and construction were:

- passing ships (safety during construction);
- river discharge (governing for foundation installation and diving works);
- bridge structure (fig. 2);
- scour protection (had to be removed and replaced).

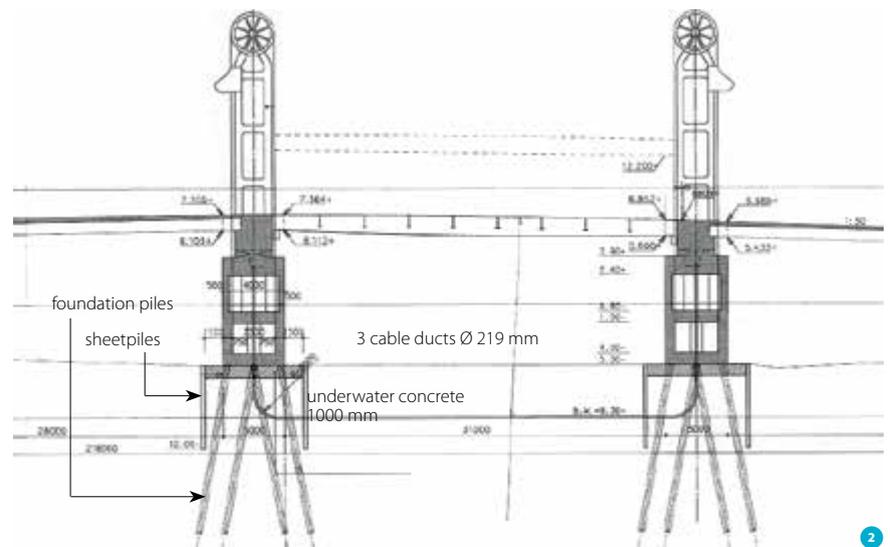
Construction sequence

After studying the requirements and local boundary conditions, different alternative types of structures and construction methods were investigated and compared in a Multi-Criteria Analysis. The structure that was selected is a prefabricated concrete structure that consists of three parts placed underwater on top of six steel foundation piles that are installed at NAP -6 m, just above the dredged riverbed (fig. 3 and 4).

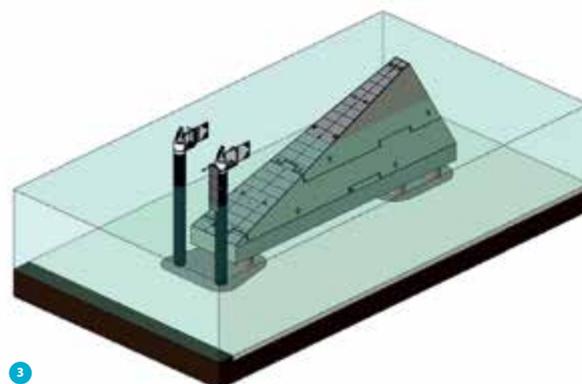
Design

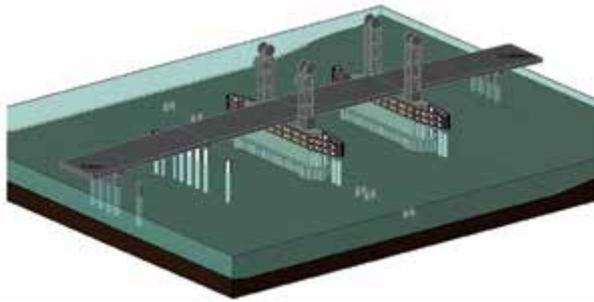
One of the most difficult parts of the design of the collision protection ramps was the calculation of the magnitude of the horizontal and vertical loads on the structure [2]: a colliding ship hits the ramp structure (fig. 5) with a high level of kinetic energy and the front of the ship starts to travel along the surface of the protection structure (the rear of the ship will sink deeper in the water). As a consequence a part of the kinetic energy is converted

- 1 City bridge of Kampen, installation of the sections with a sheerleg
credits: Wagenborg
- 2 As built drawing city bridge
- 3 Collision protection structure



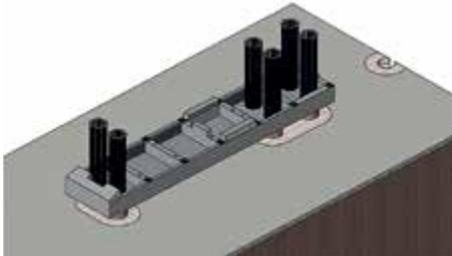
into potential energy and another part is lost as friction (one of the design requirements was to neglect the energy that is lost by deformation of the ship hull). During this conversion the forces on the structure increase and reach a maximum just before the location where, and the moment when, the ship stops. Figures 6, 7 and 8 illustrate the relation between the forces and the conversion of the kinetic energy when a ships sails against the ramp. Important variables in the equations are the angle of the ramp and the coefficient of friction. These have been varied and the design is based on 20°. A steeper slope gives higher horizontal loads (bigger piles) and a more gentle slope gives a longer concrete structure. For the upstream ramp the energy analysis results in loads of 12 270 kN vertical and 9140 kN horizontal caused by the collision. The loads caused by the side impact are 2510 kN perpendicular and 1255 kN parallel. For the loads and dimensions of the downstream ramps one could say that these are a factor 3 smaller.



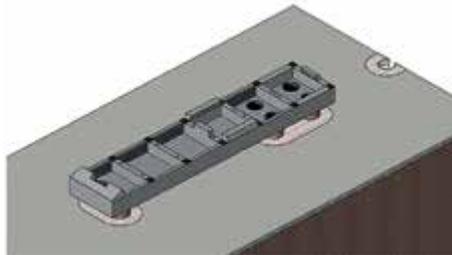


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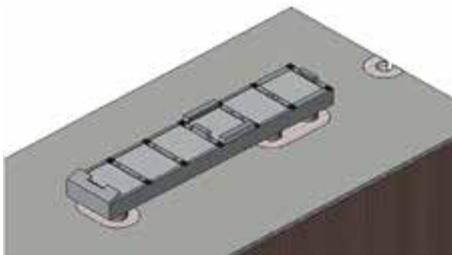
(a) installation of steel foundation piles



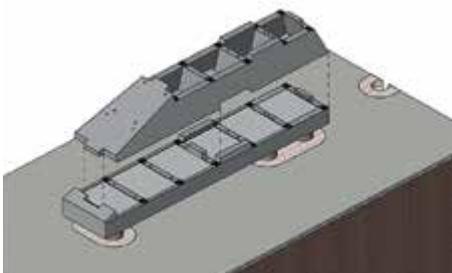
(b) installation of bottom section with rebar cages



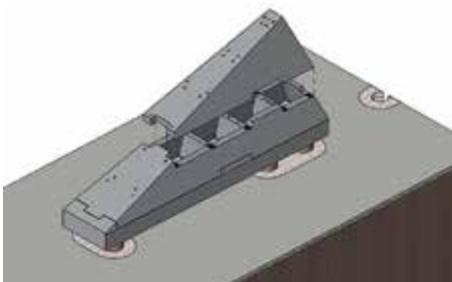
(c) lowering of rebar cages into piles



(d) pouring underwater concrete



(e) installation middle section



(f) installation top section



5

The structural design of the bridge collision protection ramps [3] resulted in:

- five foundations of six steel piles $\text{Ø} 1626 \text{ mm} \times 20 \text{ mm}$ of 20 m S355J2;
- two upstream protection ramps of $(l \times w \times h)$ $24,80 \times 5,00 \times 9,40 \text{ m}^3$ and three downstream - protection ramps of $19,70 \times 5,00 \times 7,80 \text{ m}^3$ concrete C30/37;
- a thickness of the bottom sections of 1450 mm (450 mm prefab + 1000 mm underwater concrete);
- a thickness of the external walls of 600 mm and 500 mm for the internal walls;
- thirty pile connections with rebar cages of 5900 mm length.

The most critical part of the structural design were the connections between the three parts and the load transfer to the foundation piles (see chapter 'details'). Also the fact that the lifting capacity of the sheerleg capable of sailing to the site was limited to 300 tonnes was a challenge during the design (the middle part came close to 285 tonnes).

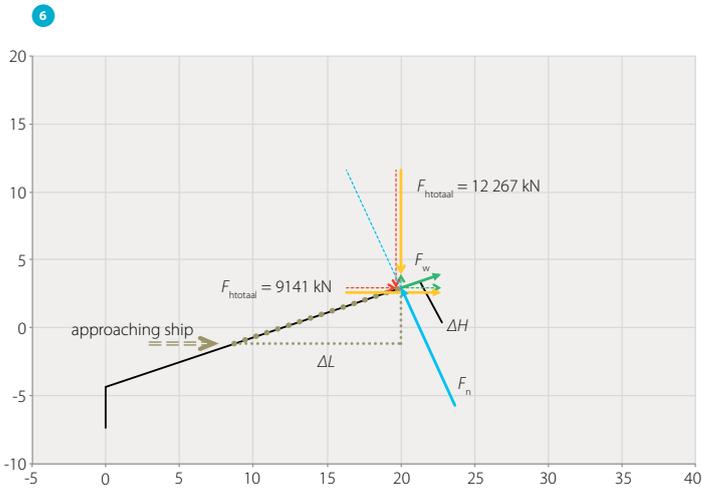
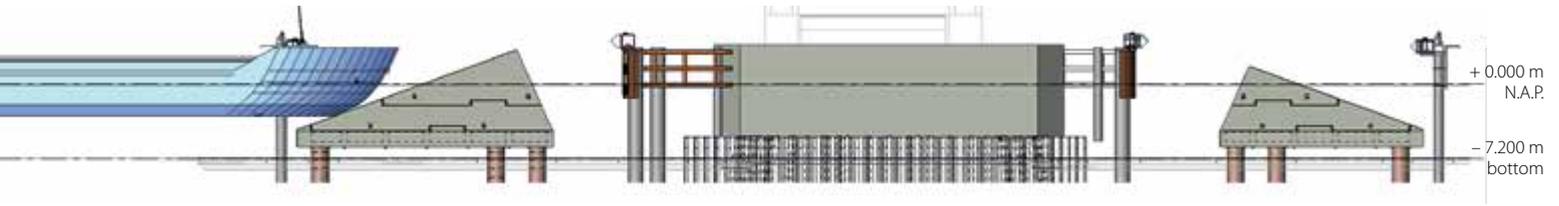
Interfaces

Although deformation of the ship hull is neglected in the energy equation, it is still present in practice. An analysis of the ship damage after a frontal collision on the ramp was made by Marin [4]. Their conclusion is that damage of an unloaded ship is less than that of a loaded ship and therefore the ramps work better for unloaded ships. For loaded ship the ramps perform more like a conventional protection barrier and will damage the ships hull; the damage is limited to the front 10 m (fig. 9) and will therefore not affect the cargo.

Details

The fact that all structural connections had to be made under water (by divers) asked for a set of details that had to be developed specifically for the project. In particular the two details in figure 11 took a lot of engineering before they could be finalised. The lifting points of the bottom section were made of cast in pad-eyes and the lifting points for the middle and top section were openings (panama chock) in the walls. The lifting points have no parts sticking out, to keep the surface of the ramp smooth. The disconnection of the lifting points could be done without divers.

The three concrete parts are coupled by tension bars that are put in vertical ducts in the structure. The bars and bolts fit into recesses in the roof, to keep the surface smooth. Under the bottom section bolts are connected and fastened by divers. The



fact that the openings in the wall are permanent and all tension bars can be removed has the advantage that the two top elements can be lifted of the bottom element after a collision (for repair).

Construction

The thirty foundation piles were installed in November 2015 from a pontoon using both a vibrator and a hydraulic hammer. The installation tolerances for the piles, that were determined in collaboration with the contractor were very strict (x, y +/- 50 mm and z +/- 5 mm). The work sequence and schedule allowed the contractor to adjust the position of the openings for the rebar cages in the bottom section to the as built location of the piles. The concrete sections were casted on a quay in the Zuiderzeehaven in Kampen, relatively close to the bridge. As all sections had to be lifted by the floating sheerleg Triton they all had to be casted close to the waterway. To save room along the quay the middle and top section of the five ramps were cast on top of

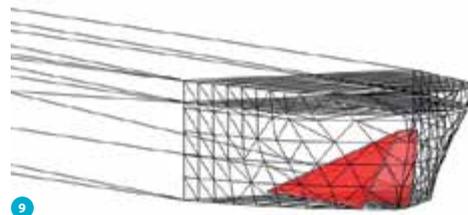
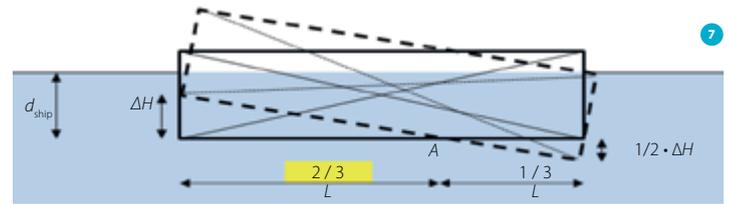
$$E_{kin} = E_{pot} + E_{friction}$$

$$E_{kin} = \frac{m_{ship} \cdot g \cdot \Delta H^2}{8 d_{ship}} + \frac{m_{ship} \cdot g \cdot f \cdot \Delta H^2}{4 d_{ship} \sin 2\alpha} = \frac{m_{ship} \cdot g \cdot \Delta H^2}{8 d_{ship}} + \frac{m_{ship} \cdot g \cdot 2f \cdot \Delta H^2}{8 d_{ship} \sin 2\alpha}$$

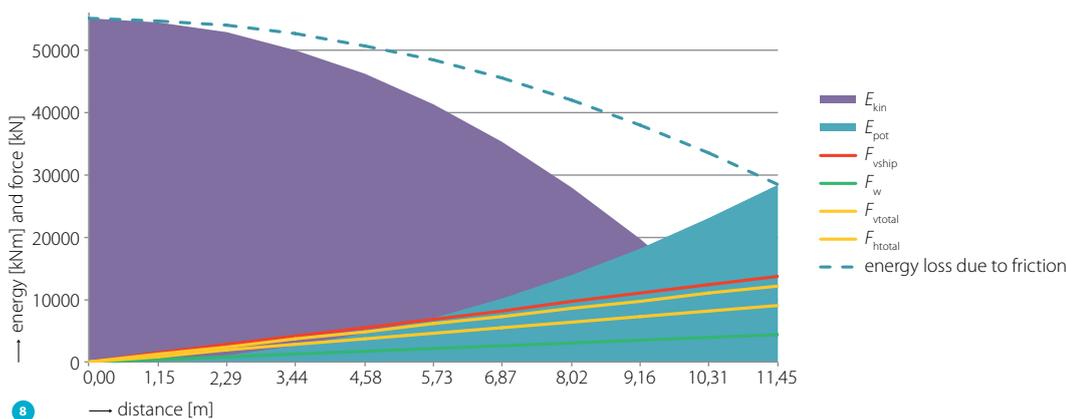
$$E_{kin} = \left(1 + \frac{2f}{\sin 2\alpha}\right) \cdot \frac{m_{ship} \cdot g \cdot \Delta H^2}{8 d_{ship}}$$

It follows that:

$$\Delta H^2 = \frac{8 d_{ship} \cdot E_{kin}}{m_{ship} \cdot g \left(1 + \frac{2f}{\sin 2\alpha}\right)}$$



each other. This casting method also made sure the parts would fit smoothly on top of each other when placed in the river. Between December 2015 and May 2016 the fifteen sections were casted.



- 4 Construction sequence
- 5 Relation between the forces and the conversion of the kinetic energy when a ship sails against the ramp
- 6 Forces on Collision
- Protection Ramp
- 7 Parameters in energy Equation
- 8 Energy conversion
- 9 Calculated ship damage after collision



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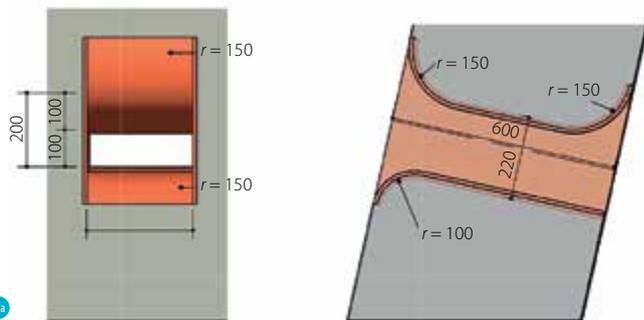
10 City bridge Kampen with the five protection ramps
credits: Maarten van de Biezen

11 Details: (a) lifting point; (b) upper part of tension rod

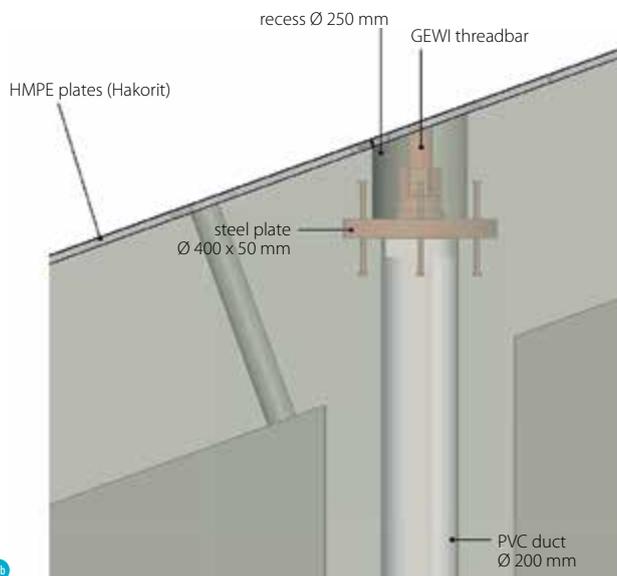
The installation and connection of the sections was planned in two phases: first the bottom sections were placed and poured with underwater concrete and afterwards the middle and top sections were installed and connected (fig. 1). During the works

a delay occurred because of the high river currents in July 2016. Finally all five ramps were placed in August 2016.

After completion of the structures seven steel piles with navigation signs and lights were placed in front of the bridge collision protection ramps (photo 10). The lights are powered by solar panels and battery.



11a



11b

Conclusion

The bridge collision protection ramp is a relatively small structure with the capacity to transfer very large amounts of ship energy to a pile foundation without effect on the structure it is protecting. For the first five structures that are placed in front of the piers of the city bridge in Kampen all technical challenges have been overcome. With this experience it is just a matter of time before other objects in rivers will be protected by ramps like these. ☒

REFERENCES

- 1 Zomerbedverlaging Beneden-IJssel Deelrapport 1B Inventarisatie Constructies en Kunstwerken. LW-AF20120608/RK versie 4.0, RoyalHaskoningDHV, 2013.
- 2 Bergwerf, D. (2015). Addendum Ontwerpbasis Civiel Schanscaissons, IJD-SBK-RAP-1004 revisie 2.0.
- 3 Bergwerf, D. (2015). Berekeningsrapport DO Schanscaissons, IJD-SBK-RAP-2007 revisie 1.0.
- 4 Marin (2013), Review van Schanscaissons voor Stadsbrug Kampen. 27106-001-HSS.
- 5 Schoffelmeer, M. (2015). Geotechnisch ontwerp DO Schanscaissons, IJD-SBK-RAP-2006 revisie 1.0.
- 6 Schoffelmeer, M. (2015). Beoordeling invloed zomerbedverlaging op Stadsbrug Kampen, IJD-OIJ-RAP-2005 revisie 1.0.