The design challenges of the new movable bascule bridge 'Parallelstructuur A12 Gouda'

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Abstract

The Parallel Structure (or ‘parallelstructuur’ in Dutch) for the A12 motorway near Gouda in the Netherlands is designed to relieve the weaving traffic on the A12/A20 interchange by creating a direct connection to bypass the interchange. The project consists of two components. The first component is the Extra Gouwe Crossing parallel to the A12 between the Gouda and Gouda-West off-ramps. The other component is the Moordrechtboog which will connect the A12 and A20 motorways. In the Extra Gouwe Crossing there will be a movable bridge to cross the river Gouwe. The bridge will be a balanced bascule bridge, with a total weight of 900 metric tons. The total length is 41 m and the width is 23,5 m. The span between main center of rotation and it’s front supports is 30 m. This paper is about the design challenges of this movable bridge.

Keywords: Movable bridge, steel orthotropic deck, electro mechanical operating mechanism, panama wheel, fatigue life, stability.

1 Introduction

Contractor Heijmans is expanding the road network around the Dutch city of Gouda, in a project commissioned by the province South Holland. Engineering firm Movares provided the necessary designing and engineering of the bridge. The two new roads will relieve the A12 motorway and give more capacity on this route. The big movable bridge is located at the crossing of the Gouwe, see Figure 1.

Building the bridge on this location is a complex puzzle, with a lot of effort during the design process. The bridge is built directly next to the Gouwe-aqueduct, which is built is 1981. Damage to the existing aqueduct is the risk with the biggest impact in the project, which could compromise traffic flow and safety on the A12 motorway. This should be avoided at all cost. Under the bridge there is a existing space which houses the traffic management systems of the A12 from The Hague till Utrecht. Failure of this system may result in a traffic hazard or non-availability of the A12. Directly next to the bridge there is a production facility which uses very sensitive equipment, which cannot be disturbed. This meant building the entire foundation in a two week cleaning break in the production facility. In short, a large amount of interfaces in a complex environment with many stakeholders and requirements.

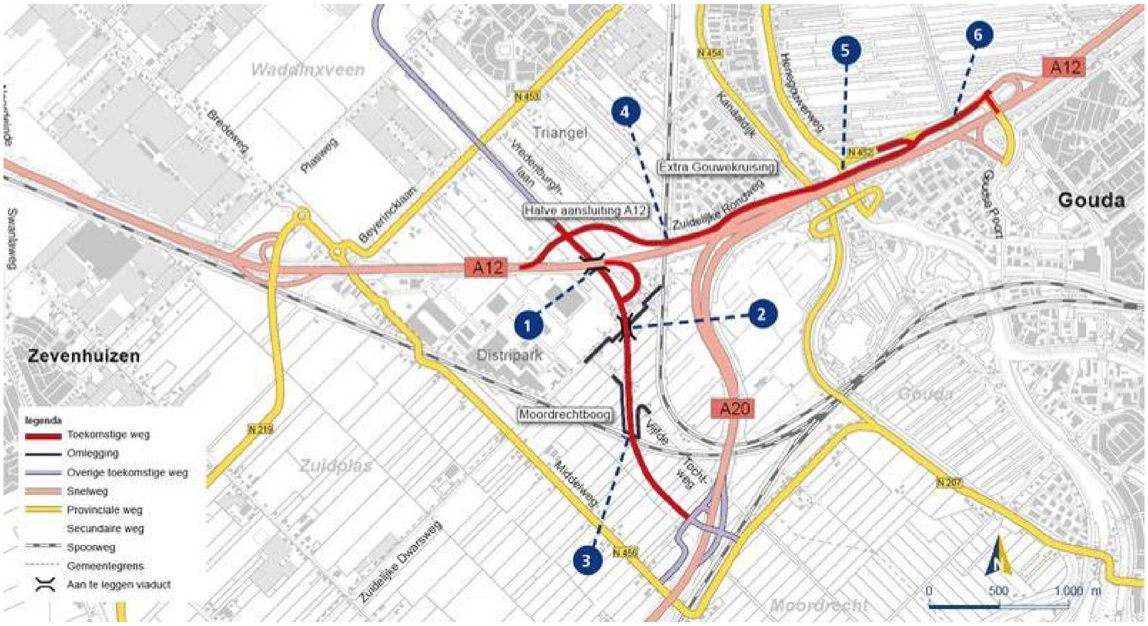

Figure 1. Map of the project; no 5: location of new bascule bridge

2 The design

By the requirements put by the province, the movable bridge had to be of the bascule bridge type. In the first dialogue phase many design choices were made to get an as optimal as possible design for the bridge. Trade-off matrices were made of for instance bridge type, type of deck construction and type of operating mechanism.

The deck construction chosen is a traditional grid of two main beams and multiple crossbeams with a deck plate and longitudinal stiffeners. In the study of alternatives the most narrow and short concrete engine room, which also houses the counterweight, gave the most cost effective design. The size of the concrete engine room is 19x17x13 m. The bridge has an available width for ship traffic of 25 meters in closed position with an available height of 7 meters. In open position there is an unlimited height over a width of 22,5 meters.

The structural elements of the movable bridge are made completely out of steel. The orthotropic deck has a deck plate of 20 mm, with longitudinal stiffeners of 6 mm plate thickness. The stiffeners carry the traffic load to the cross beams, which in turn carry the load to the main beams. The deck plate also functions as upper flange of the main and crossbeams. The span between main axis of rotation and front supports is 29,75 m, of a total bridge length of 41 m, the maximum width of the bridge is 23 m. The counterweight (4,0x2,75x2,5 m) is completely filled with heavy concrete weighing 44 kN/m^3 which almost completely balances the bridge. This of course limits the forces on the operating mechanism of the bridge greatly, as opposed to an unbalanced bridge. The support reaction on the front support is only 3 metric tons, on a total bridge weight of 900 tons. The bridge is fitted with FRP side elements, in which lighting for ship traffic is incorporated.

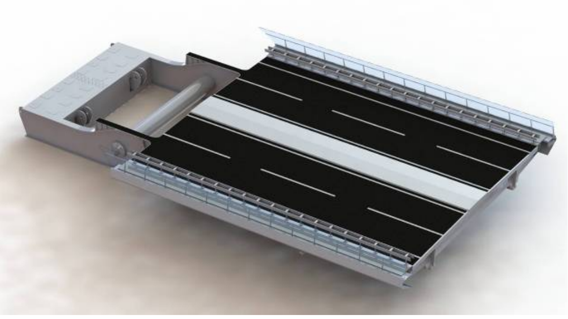

Figure 2. Steel bascule bridge

Figure 3. Artist impression of the bridge

3 Operating mechanism

A big challenge was found in the very short time (a little over a minute) in which the bridge had to fully open. An electro mechanical operating mechanism was required, which resulted in a double set of panama wheels. These were mainly designed according the Dutch standard for movable bridges, but due to the large size of the bridge not all design rules could be followed. Therefore some extra research has been done to prove the design was reliable and equivalent to a code-designed bridge.

The bascule bridge is one of the larger movable bridges in the Netherlands. The size of the bridge, in combination with its short time for opening and closing, resulted in high loads on operating mechanism despite the balancing of the bridge. The relative small size of the concrete housing made it a big puzzle to design an operating mechanism that not only would fit in the engine room, but also was strong enough to carry the loads. Because of the demands for safe machine operation in the Netherlands, the engine room is designed in such a what that the operating mechanism is safely accessible for inspection and maintenance, at each possible bridge position.

The operation of the bridge is done with an electro mechanical operating mechanism, consisting of two large panama wheels, a single gear box and a main engine of 160 kW. In case of a failure the mechanism is also equipped with an electrical and manual override. The crank of the panama wheel is connected to the front of the counterweight via a rod. When the engine drives the panama wheel this rod will pull the bridge into its opened position.

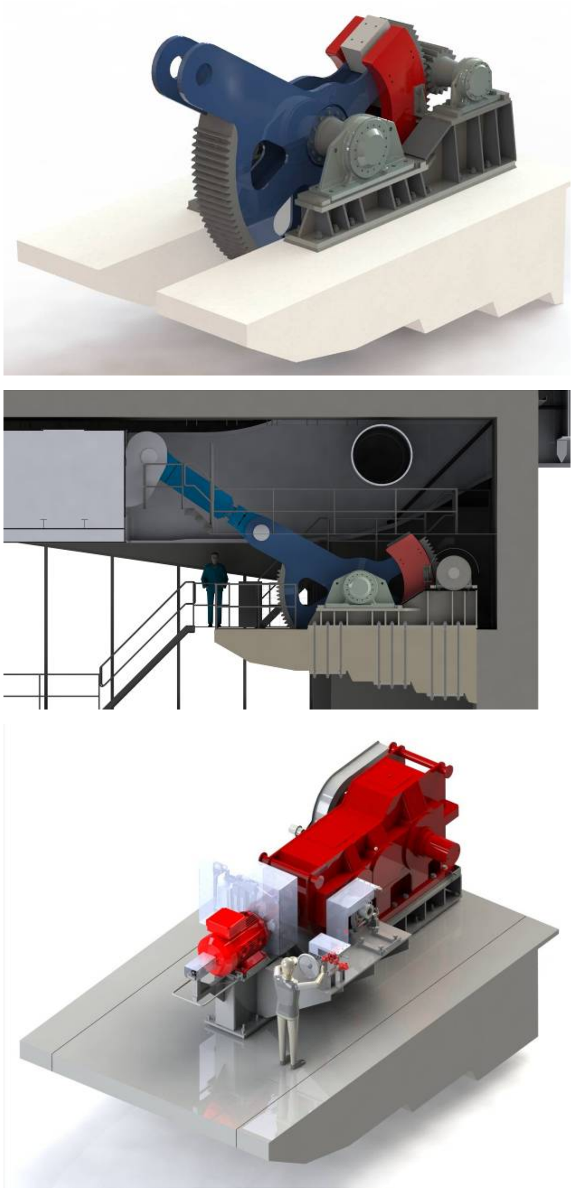

Figure 4. Panama wheel and central gear box

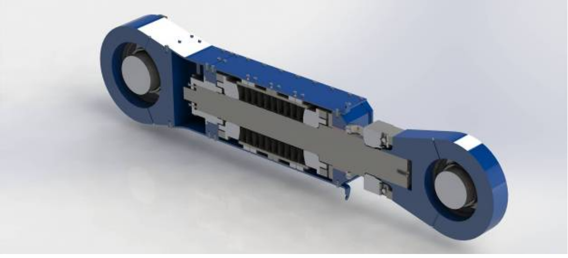

Figure 5. Push-pull rod

The rods have been fitted with large disc springs, so after closing the bridge can be pushed firmly on the front supports. This is needed to secure a safe position of the bridge, so it won't accidentally open under any circumstance, for instance under high wind loads.

The combination of a large bridge and short opening time resulted in high loads. Using a standard layout the forces on the bridge, concrete foundation and operation mechanism would have been too high. Making the various parts stronger was not an economical solution, which made is necessary to reduce the loads. Many technical solutions have been explored. The solution was found in a extraordinary design of the pre-tensioned disc springs in the push-pull rod between the bridge and panama wheel.

For opening and closing of the bridge two sets of panama wheels are used. But how would you know if the loads are equally distributed between the two? After making extra calculations it was found that this is not automatically the case. Some extra measures were put into place to ensure a even enough distribution of forces.

The stiffness of the spring in the push-pull rod has a large influence on the natural frequency of the bridge in open position. Therefore extra calculations have been carried out into the wind resonance which may occur. These calculations showed that the expected resonance will not exceed the dynamic wind factor which is taken into account according the design code.

In the operating mechanism of the bridge multiple technical measures have been taken to improve safety and reduce damage in case of an emergency. The panama wheels for instance are balanced themselves, so that if unintentionally the brakes are lifted, the bridge will not open automatically. The end stops of the panama wheels are produced using buffers. This will greatly reduce the damage in the structure in case of an accident.

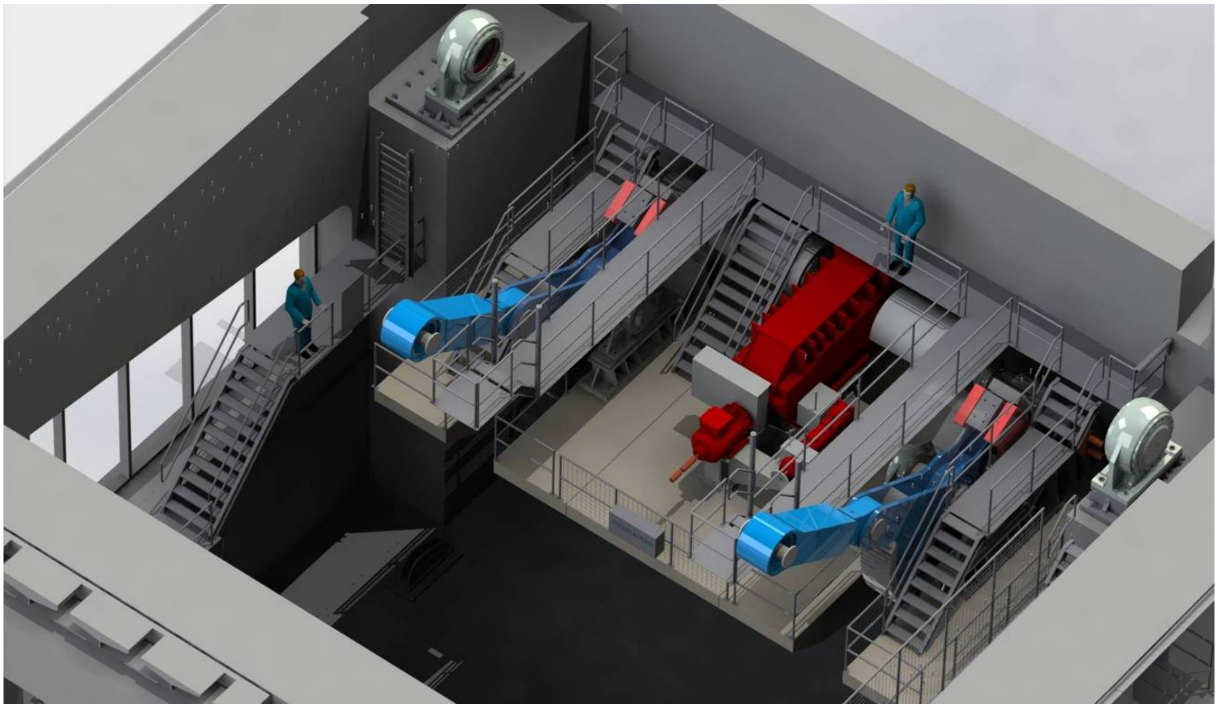

Figure 6. Layout of engine room

4 Engineering of steel deck

Because of the high traffic volume expected on the bridge and the number of expected opening and closing cycles, detailed fatigue calculations have been carried out. A base finite element model of the bridge has been made using shell elements, except for the longitudinal stiffeners. These are modeled as beam elements with the right eccentricity to the deck plate. With this model all verifications for strength, stability and fatigue life of the main girders has been done. The bridge is also modeled in its open position, which is important for the stress range due to opening and closing and the natural frequency in open position.

For the more elaborate fatigue verifications of the orthotropic steel deck the entire bridge, including its steel orthotropic deck, is modeled completely in shell elements. This is to ensure an accurate insight in the stresses for the fatigue and strength verifications. To combine accuracy with a useable and efficient model the mesh has been divided in zones. The heaviest loaded longitudinal stiffeners have the finest element size. The mesh gradually becomes more coarse, until it reaches its base value in the main girders.

Figure 7. Steel deck in Inventor

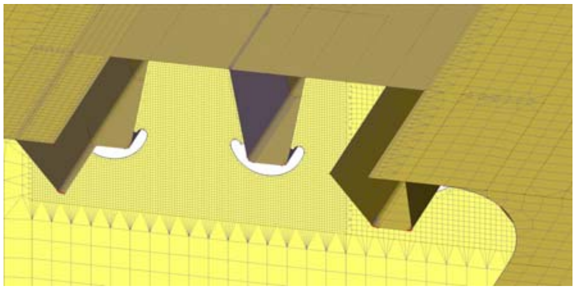

Figure 8. Detailed FEM mesh

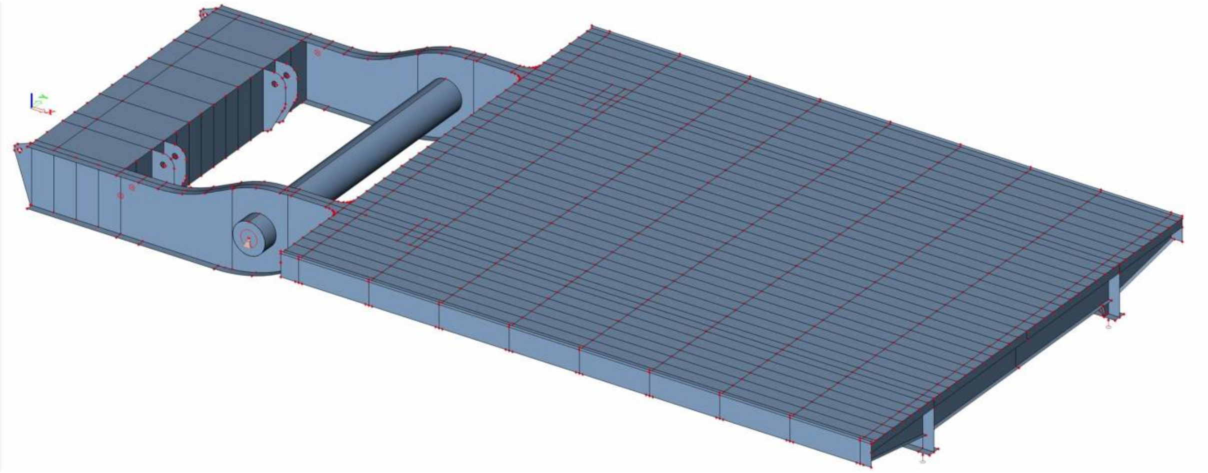

Figure 9. FEM model steel deck

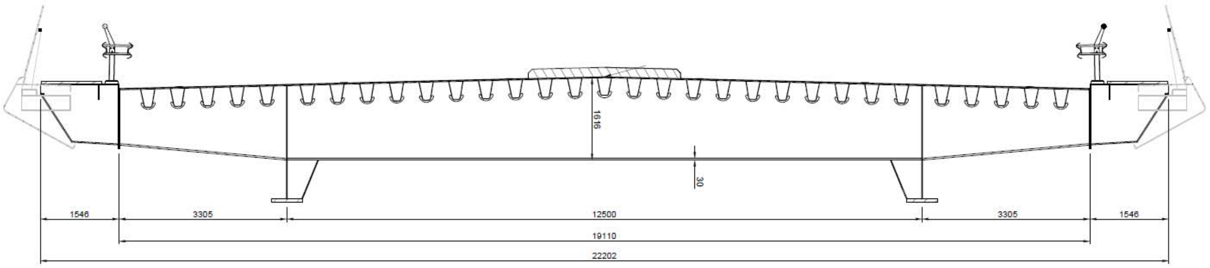

Figure 10. Cross section steel deck

5 Fatigue analysis

For the analysis of the fatigue life the load spectrum according FLM4 of NEN-EN-1991-2 is used. This spectrum consists of several types of lorries, which represent the real traffic loads. Because the bridge is placed in a new road with a very high expected traffic volume, the actual amount of traffic is deducted from the traffic models used in the earlier stages of the project. On these numbers the expected growth according to the Eurocode is added.

For an accurate verification of the fatigue life detailed influence lines are required for each critical detail. These are made using the detailed FEM model with only shell elements, by placing a single axle load of 1 kN on the model. This load is moved over the model with a step size of 10 cm. For details with sharp changes in stresses (like the crossbeam to deck plate detail) this is absolutely necessary for an accurate influence line.

The influence lines are exported out of the FEM model and reworked in a spreadsheet to the correct lorries according the Eurocode. In this process the lines are first multiplied with the correct axle load and dynamic factor. Next the axle spacing is added by shifting the axles to the right position. Adding the lines for the individual axles gives the influence line for an entire truck.

Mainly around the centre of rotation the stress range due to opening and closing of the bridge and taking into account a vibrating counterweight is much bigger than the stress range due to traffic. These stress ranges have also been added to the spreadsheet.

The influence lines are translated to single stress cycles using the rainflow method (a way to count random occurring stress cycles). With a Miner summation the actual fatigue damage is determined. If the total calculated damage is smaller than 1.0 the required fatigue life is verified. For this project a fatigue life of 100 years is required.

6 Coupling tube

Between the two main bearings a large tube (diameter = 1500 mm, t = 40mm) couples the main girders. This way the entire bridge rests on two main bearings, instead of a regular four. This greatly decreases the width of the engine room by saving the space needed for two main bearings.

One of the requirements of the province was that no stiffeners may be used around the main centre of rotation. This resulted in an un-stiffened steel web plate which distributes the support reaction of 8000 kN in the 3.5 m high main girder. Many buckling shapes can occur in this web plate, local, global, or any of their interactions. Because the verification rules in the Eurocode do not match up with the geometry of this detail, a FEM calculation was made for the capacity of this joint.

7 3D-modeling

In this project all the different disciplines were working in 3D. The movable bridge is modeled in 3D in Inventor, while the engine room is designed in Revit. In Navisworks a integral 3D model is compiled of all sub-models, this way the interfaces could be checked in an early stage. The 3D models have been delivered to sub-contractors to minimize the changes of unforeseen errors.

8 Production

The transport of the steel bridge from workshop to final location has a size 41x19x4,5 m and total weight of 390 tons. The bridge is build in four separate sections, due to limitations in the coating hall. After coating the bridge is welded together in the assembly hall in Middelburg. The total width of the bridge is adjusted to the size of the assembly hall of 19.3 meters. By making the bridge al little bit narrower (and subsequently widening the side elements) the total costs have been greatly reduced. This is a direct result of inviting tenders using design and construct, while also having subcontractors on board in an early stage of the project.

The panama wheels are cast in a single piece. They have a diameter of 4.1 meters and weigh including the axles and bearings a mighty 30 tons each. Nice detail is that the wheels will always be visible for the general public, since a part of the engine room is fitted with large glass windows.

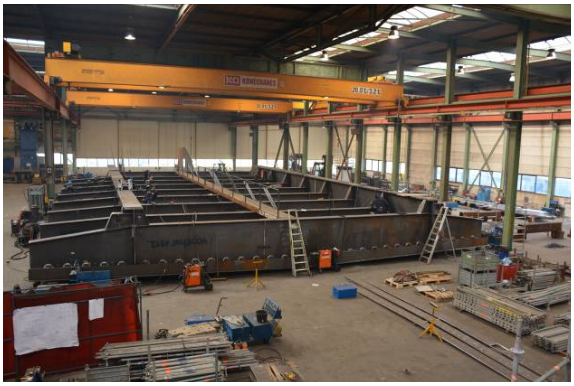

Figure 11. Production of steel deck

Figure 12. Steel deck after coating

9 Transport

The bridge is transported in a single piece using SPMT's (Self Propelled Modular Transporters) and driven onto a pontoon in Middelburg. Once arrived in Schiedam the bridge is placed in a steep angle to reduce the width of the transport, since some narrow bridges and locks need to be passed.

10 Final assembly

At the final destination the bridge is placed in positions using big sheerlegs. After the bridge reached its final position the counterweight is filled with the heavy concrete. During the curing the operating mechanism is attached and directly afterwards the bridge is placed in its opened position. This entire operation is done in a single weekend with a minimal stoppage of traffic. After finishing the bridge it will be taken into use near the end of 2016.

Figure 13. Artist impression of end result