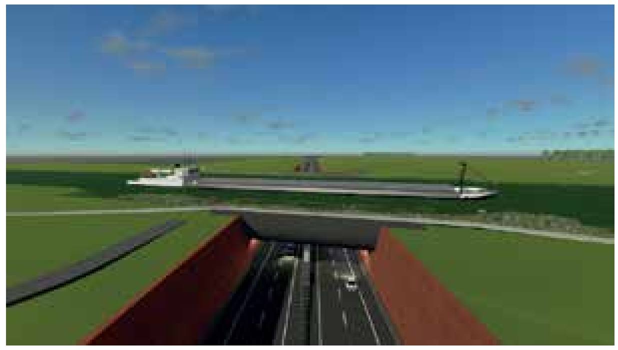
Hendrik Bulthuis Aqueduct Burgum

Across the Princess Margriet Canal in the province Friesland (The Netherlands) a new aqueduct is built. The Hendrik Bulthuis Aqueduct is part of the project De Centrale As, situated in the region of Dongeradeel, Dantumadiel, Tytsjerksteradiel and Smallingerland. De Centrale As will be the main access route to the northern part of the Netherlands and will improve the accessibility, safety, quality of life and the spatial and socio-economic structure of the region.

Sander van het Erve
Mobilis TBI

1 The Hendrik Bulthuis Aqueduct under construction
2 Artist's impressions of the finished aqueduct
3 Longitudinal section over closed part of aqueduct

The Hendrik Bulthuis Aqueduct crosses the Princess Margriet Canal at an angle of 76° (fig. 2). The aqueduct provides a highway with 2×2 lanes crossing underneath the Princess Margriet Canal (class Va vessels with maximum length 110 m). The aqueduct was realised by consortium Nije Daam (Mobilis TBI, Van Gelder and Friso Civiel) and opened for traffic on October 7 2016.
The structure of the Hendrik Bulthuis Aqueduct consists of open and closed parts (fig. 2). The closed part consists of sections 5 to 8 with marsh zones and an water cellar (fig. 3 and 4). The open, lower parts of the ramps consist of sections 1 to 4 and sections 9 to 13, and are built with steel sheet piles, concrete floors and pile foundations. The upper part of the open ramps are made using foil structures for a better integration in the area with green slopes.



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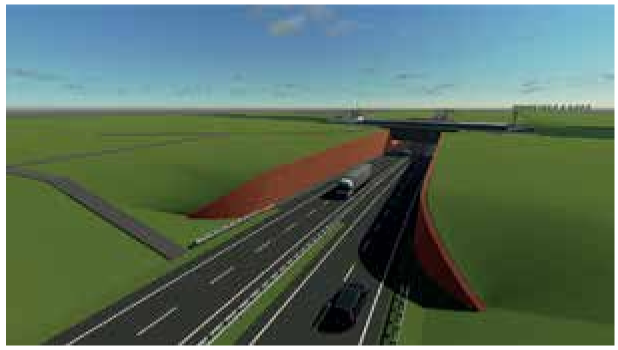


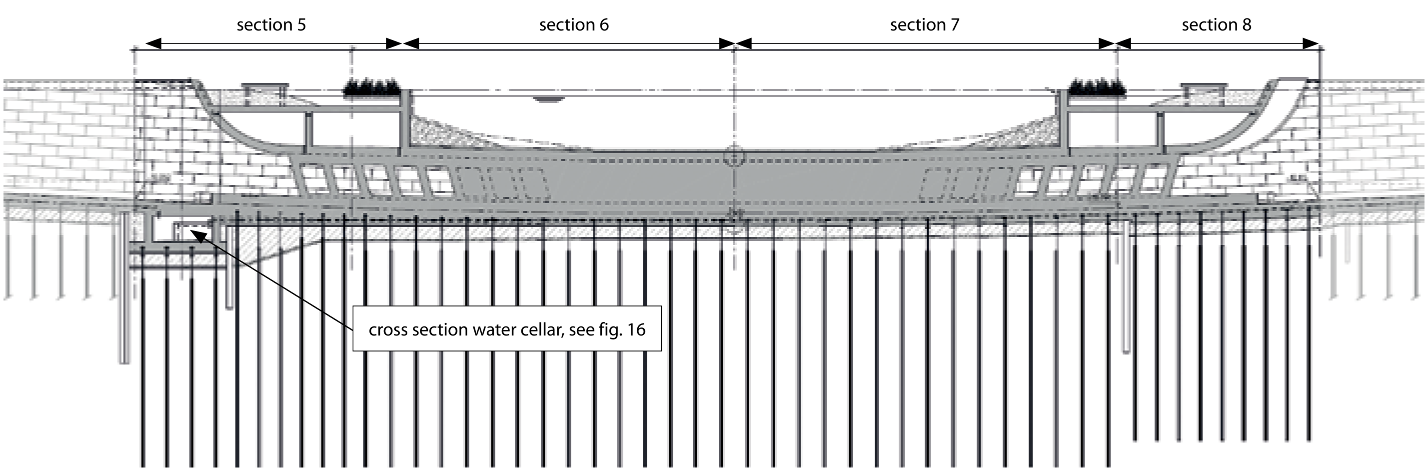
Modelling closed section for construction and operating phase

When the Princess Margriet Canal was opened over the new aqueduct, section 6 and 7 were finished. Sections 5 and 8 were built while vessels were already passing. Section 5 is monolithically connected to section 6 and section 8 is monolithically connected to section 7. An expansion joint (fig. 5) was installed between section 6 and 7, largely to prevent imposed deformations.

A distinction was made between different subsystems according to construction type:
a. Pile foundation
b. Underwater concrete floor C20/25
c. Final concrete construction C30/37

During the construction phase particular attention was given to the exceptional load acting on these sections due to possible collision by passing vessels. An underwater riprap slope at the front of the 800 mm vertical wall was installed before the waterway opened to reduce this load.

A structural 3D model was made for section 6 (fig. 6). Because of equal dimensions, the section 6 calculation in this phase is the same as the one for section 7. In this building phase, the foundations of section 6 and 7 were already laid on anchor piles; these piles, modelled as springs, can transfer both compressive and tensile loads to the substrate.



4 Cross section over the closed sections 6 and 7
5 Expansion joint
6 3D model section 6
7 3D model sections 5 and 6
8 3D model sections 7 and 8

In the operational phase calculations, section 5, 6, 7 and 8 are modelled in their entirety. The normative distribution of forces between construction and operational phase determines the dimensions and amount of reinforcement.

Attention was given to the curved ridge structures under the marsh zones at sections 5 and 8 (fig. 7, 8 and photo 9). Additionally, account had to be taken of the water cellar with access shaft at section 5 (fig. 3, 7 and 10). The dimensions of this were chosen in order to make sufficient water storage and pumping capacity available.

The marsh zones situated on top consist of a dry and wet zone and are necessary to maintain the ecology between the surroundings on either side of De Centrale As. A path at the marsh zone was created for a cycling and walking connection. Also attention was given to the specially shaped intermediate support between the driving lanes (fig. 10). For aesthetic reasons, visible ground-retaining walls were equipped with Corten Steel cladding (photo 11).

Loads

The loads used to design the structure comply with the standards and guidelines, and are introduced in the various models as described earlier. The SLS and ULS load combinations concern linear loads. A non-linear substrate bedding is not included. Only some typical loads are mentioned that were special for this project.

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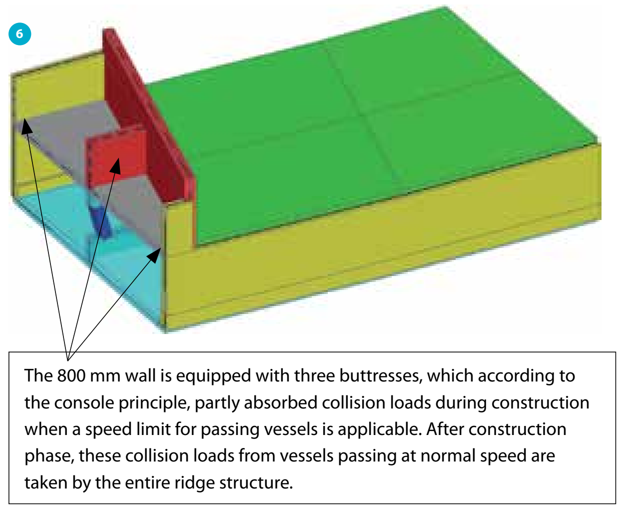

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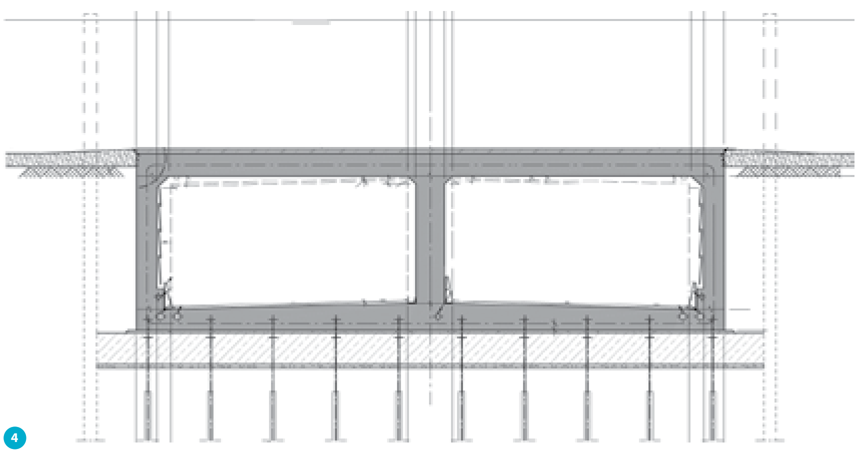

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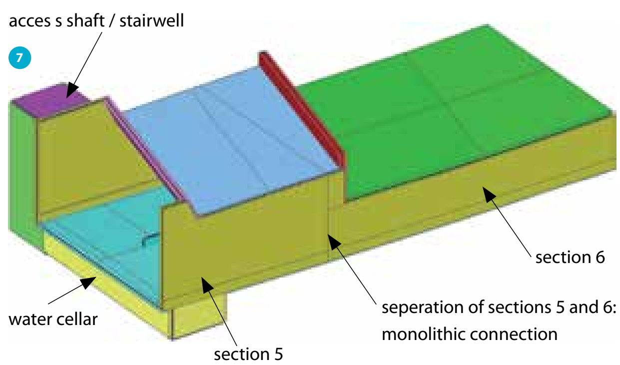

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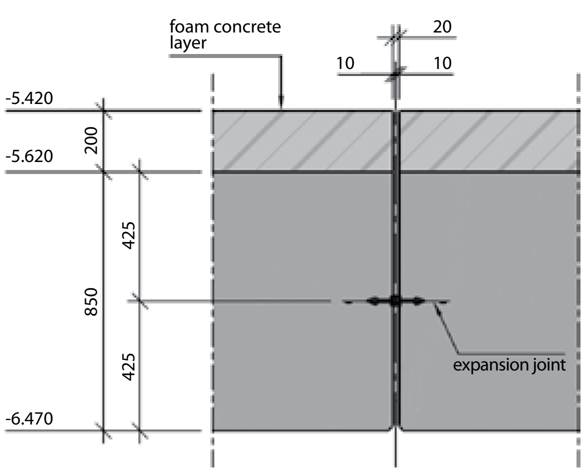

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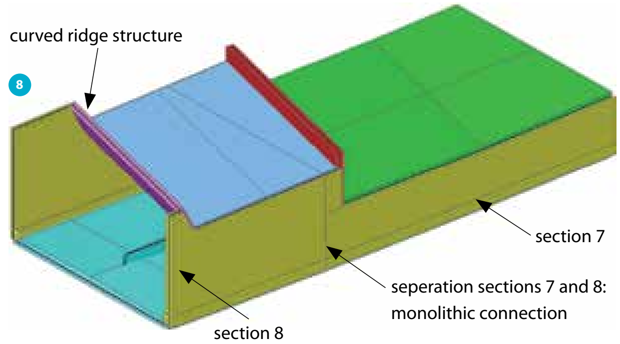

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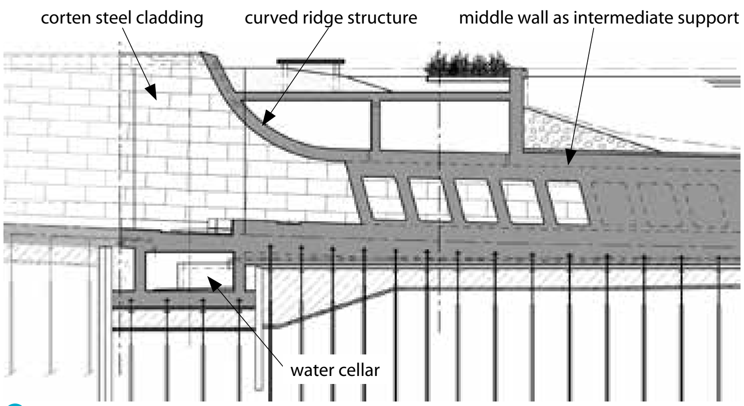

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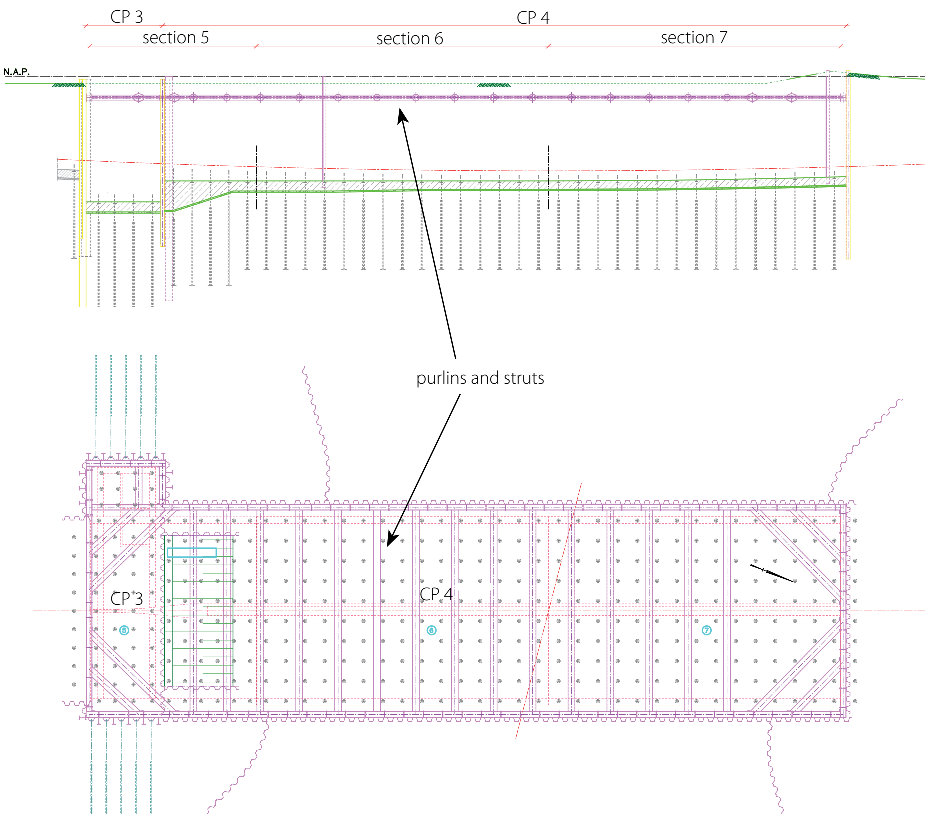
Ground pressure resulting in strut force during construction phase

During the engineering phase, the decision was taken to execute the compartments CP3 and CP4 simultaneously, being as a traditional cofferdam for building section 5 to 7 (fig. 12). The cofferdam is made with sheet piles, underwater concrete, purlins and struts. Purlins and struts are positioned at the top of the cofferdam and the underwater concrete floor is at the bottom.

To build concrete section 8, horizontal forces caused by difference in horizontal ground pressure in longitudinal direction had to be taken with struts. The horizontal forces of approximately 35 000 to 40 000 kN had to be taken up for the horizontal balance. This large horizontal force is transferred on the concrete deck of section 6 and section 7 (photo 13).



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9 Building the curved ridge structures under the marsh
10 Cross-section marsh zone situated on top and middle wall, with columns, as intermediate support between the driving lanes
11 Entrance of the aqueduct with Corten Steel cladding
12 Is a longitudinal section of the entire CP3 and CP4 construction and layout

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Loads during operational phase

Considered loads during operational phase were:

- *Calamity through fire*
- *Calamity through sinking vessel*
- *Calamity through falling anchor*
  For a falling anchor with a mass of 1600 kg a protective layer is required as absorption zone. This protection also prevents the deck from being affected by wear from vessels. For the shipping class within this project, class Va, a solution was chosen in which a 200 mm foam concrete layer is applied to the deck (fig. 5). A point load of 500 kN is calculated as load from a falling anchor.
- *Calamity through collisions*
  Cruising speed of a vessel relative to the water (and vice versa) depends on:
  - vessel type
  - waterway type (width and depth)
  - loading degree (loaded vessels are indicative)

  An underwater slope, installed to counteract colission from a the vessel, protects the concrete construction.
- *Calamity through ice load*
- *Calamity through vessel's dragged anchor*
  A vessel's dragged anchor can hook onto a construction. The anchor force maintained must correspond with the fracture strength of the chain/cable of the normative anchor, in this case 1540 kN. Protection against dragging anchors is provided by mounting a steel plate at the end of the water container floor.

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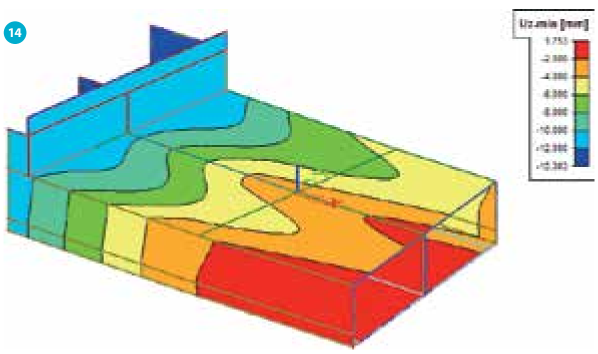

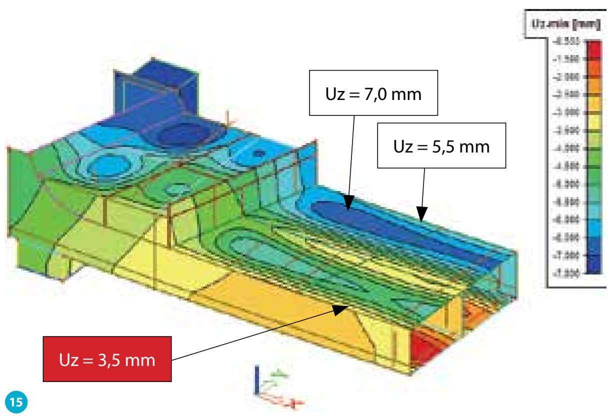

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13 Struts providing horizontal equilibrium during building section 8
14 Deformations section 6 during construction
15 Deformations sections 5 and 6 during operational phase
16 Distribution of forces in section 5
17 Sketch of the connection of wall to floor at section 8

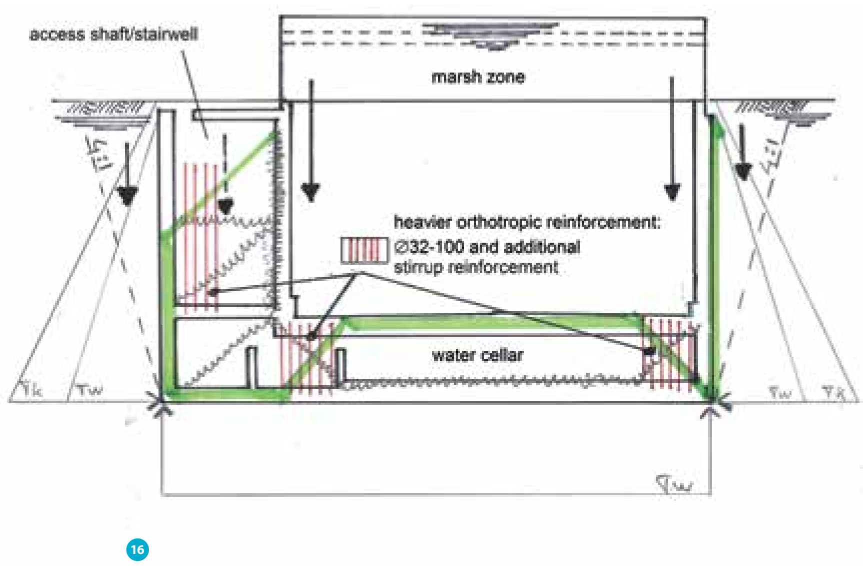
Deformation in construction and operational phases

Deformations during construction and operational phases are determined on the basis of SLS combinations (fig. 14 and 15).

Maximum deformation in the middle of the deck is 7 mm. Maximum deformation of the wall is 5.5 mm. Relative distortion of the deck is therefore 1.5 mm at an un cracked section in the model. In reality the deck will become partly cracked so that the deformation of the deck hatch will increase by the ration of bending stiffness to - 4.68 × 1.5 mm = 7.0 mm. This is lower than the maximum allowed deformation of 10.85 mm, prescribed as 1/1000 of the span between the outer wall and intermediate wall.
It can be seen from the model that when load acts eccentrically the western outer wall deflects about 5.5 mm, and the eastern wall 3.5 mm. Only a very small misalignment occurs with an order of magnitude of 0.1 per mil in transverse direction.
In the longitudinal direction, the misalignment is even smaller.

Force distribution and reinforcement

Distribution of forces in section 5, including water cellar, access shaft/stairwell and marsh zone, is sketched (fig. 16). The location of this cross section is given in figure 3. Large downward vertical loads are acting on the outer walls. These loads are mainly caused by a ground wedge, dead weight of the walls and slabs and piled marsh zone, grain and water pressure on the piled marsh zone and grain and water pressure at the waterway location. The pile foundations under the flooring provide reactions for the vertical balance.
A strut and tie model is drawn in figure 16, the green lines and pencil lines respectively represent the tensile and the compressive forces. Total interaction of forces must be externally balanced. So vertical loads are absorbed by vertical pile reactions. Horizontal ground pressures will also be balanced together. There must also be internal balance. The finite element package shows how the normal and shearing stresses run in various parts of the construction. This serves as a tool for determining the strut and tie model.
If an orthotropic reinforcement mesh is used, tensile and compressive forces can be converted to vertical and horizontal directions. Consequently, llarger quantities of reinforcement are required than when reinforcement is applied in the direction of the tensile forces. This is logical because the reinforcement is no longer placed perpendicular to the crack direction and is therefore less effective. After consulting the executing body, it was concluded that orthotropic reinforcement should be used in certain areas. Therefore heavier reinforcement was installed in the areas with red vertical shading.



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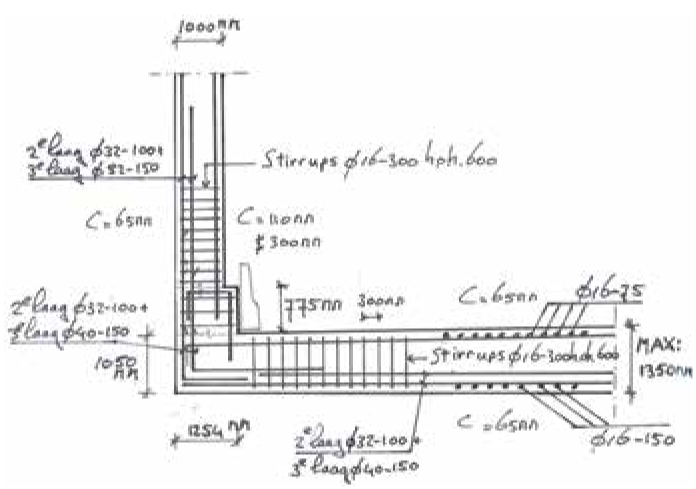

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At section 8, one wall is both vertically a considerable overhang as well as horizontally. There is also no access shaft with water cellar (fig. 7 and 8). In relation to the maximum reinforcement percentage, floor and wall have acquired greater thickness. Floor thickness at section 8 increased from 800 to 1050 mm at the outside and from 1100 to 1350 mm in the middle. Wall thickness increased from 800 to 1000 mm (fig. 17).

Experience within the project

The very important challenge in the project was to achieve good balance between design, planning and construction team. The most challenging part was the curved ridge structure due to the phasing and the various loads that had to be taken into account. ☒