Independent Check Activities at the New Storstrøm Bridge (Denmark)

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ABSTRACT

The New Storstrøm Bridge will connect the Danish regions of Zealand and Falster via Masnedø. The project forms part of the railway line upgrading between Copenhagen and Rødby, and on to the Fehmarnbelt Tunnel, which will link Denmark and Germany. The existing bridge is in poor condition and forms a bottleneck in the transport corridor to Germany. Arenas & Asociados, teaming with German specialists schlaich bergermann partner and Moormann Geotechnik Consult, is responsible for the independent check of the detailed design.

KEYWORDS: Independent check, detailed design, cable-stayed, concrete, prefabrication, Storstrøm

1. Independent Design Check. General aspects

The aim of the independent design check is to ensure a level of quality of the project by gaining confidence and reducing the risks through a sufficiently competent reviewing process.

It is a responsibility of Civil Engineering to guarantee public safety by preventing not only the risks of collapse but also the consequences of a design error. The costs of a mistake would extent from additional time and money expenses to fatal effects caused by the failure of the structure. The four-eye-principle constitutes a basic procedure to ensure the accuracy of calculations and technical decisions that will warranty a correct design, which will not lead to accidents or damages.

A truly independent review is essential to allow the detection of errors and to provide confident results.

Figure 1. Chirajara Bridge collapse.

The origin of the independent checking is the collapse of the steel box girders bridges in Milford Haven in 1970 when the Merrison Committee of Inquiry started a new design rule for steel box girders which soon resulted in include all major bridges and those of unusual or complex behavior [1].

Figure 2. Milford Haven Bridge, Wales.

The extent of the independent check process could comprise a full numerical calculation of the structure or just a check carried out by another member of the design team, as a typical quality control system of a design office.

According to BS 5975:2008, depending on the category of the structure, different levels of independence of checkers are required, as can be seen in Figure 3.

The independent check process, besides providing improvements to the design itself, is positive both for designers and checkers. Lessons learned through sharing experiences and opinions between expert engineers, on their own interest, allow to improve their present and future designs and, as a consequence, global knowledge about structures design.

According to the International Federation of Consultant Engineers (FIDIC), the reviewer, having a general view of the project, should objectively advise the designer, who is further involved in the development of details. Being this collaborative work a consequence of the engagement of both subjects.

BS 5975:2008

Table 1 – Categories of Design Check

Category	Scope	Comment	Independence of Checker
0	Restricted to standard solutions only, to ensure the site conditions do not conflict with the scope or limitations of the chosen standard solution.	This applies to the use of standard solutions and **not** the original design, which will require both structural calculation and checking to category 1,2 or 3, as appropriate.	Because this is a site issue, the check may be carried out by another member of the site or design team.
1	For simple designs. These may include: formwork; falsework (where top restraint is not assumed); needling and propping to brickwork openings in single storey construction	Such designs would be undertaken using simple methods of analysis and be in accordance with the relevant standards, supplier's technical literature or other reference publications.	The check may be carried out by another member of the design team.
2	On more complex or involved designs. Designs for excavations, for foundations, for structural steelwork connections, for reinforced concrete.	Category 2 checks would include designs where a considerable degree of interpretation of loading of soils' information is required before the design of the foundation or excavation support or slope.	The check should be carried out by an individual not involved in the design and not consulted by the designer.
3	For complex or innovative designs, which result in complex sequences of moving and/or construction of either the temporary works or permanent works.	These designs include unusual designs or where significant departures from standards, novel methods of analysis or considerable exercise of engineering judgement are involved.	The check should be carried out by another organization.

Figure 3. BS 5975:2008 Categories of Design Check.

The typical scope of an independent checker is to certify the scope of work of contractor with the client's requirements, to ensure the compliance of the design and construction techniques and procedures with contractual standards and regulations and to warranty the correctness and completeness of the final design.

So as to make certain the independence of the checking process, two types of independence must be guaranteed: technical and commercial [1].

Technical independence implies that the independent checker does not have access to the designer's calculations. Verifications should be performed following their own hypothesis, calculations, software, spreadsheets, … so no concatenated errors occur.

Through this procedure, verification of the design is made if equivalent results are obtained.

Commercial independence should ensure that no conflicts of interest influence the process. The checker should not depend on the designer so as not to be influenced by the designer's interests. It is preferable that the checker is independent of the designer and depends directly on the client [1].

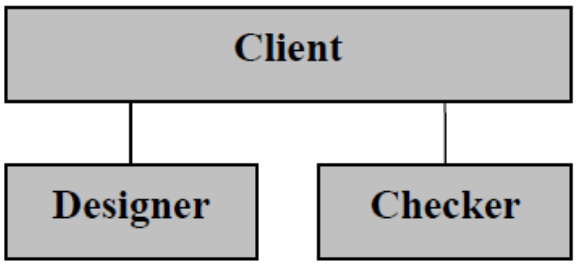

Figure 4. Checker's independence chart.

In a design and build contract, the checker could also be employed by the contractor. However, depending directly on the employer, would guarantee the complete independent checking and will allow the employer to profit directly from the checker expertise.

2. Independent Design Check of Storstrøm Bridge

2.1 New Storstrøm Bridge

The New Storstrøm bridge will replace the existing bridge in connecting the small island of Masnedø with the greater island of Falster.

Figure 5. The existing bridge was erected in 1937.

The new bridge follows a gently curved alignment west of the old bridge and the very small island of Masnedø Kalv. It will be approximately 4 km long from the northern abutment on Masnedø to the southern abutment, located at the end of an embankment protruding some 430 m into the sea from the coast of Falster.

Figure 6. Storstrøm Bridge location.

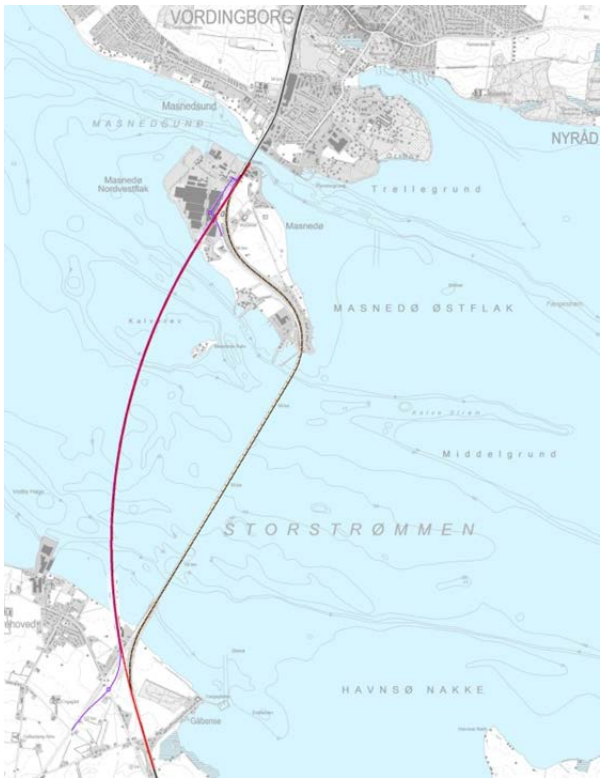

Figure 7. New Storstrøm Bridge vs. existing bridge.

The new "Storstrømsbroen" will carry a double-track electrified railway (200 km/h for passenger trains, a two-lane road (80 km/h), a combined (two-way) bicycle lane and sidewalk.

Figure 8. Typical cross section.

The bridge is, for all of the viaduct spans, a girder bridge with typical span lengths of 80 m. The central part of the bridge comprises two cable-stayed span lengths of 160 m, on either side of a central pylon pier, marking the separation between the East and Westbound main shipping lanes.

Figure 9. Storstrøm Bridge general view.

Other main dimensions are:

- Maximum height of top of deck from sea-level: 32.412 m;
- Deck girder structural depth at center-line: 5.62 m;
- Deck girder typical width: 24.82 m;
- Deck girder maximum width: 27.15m;
- Pylon height from sea level: 102.04m;

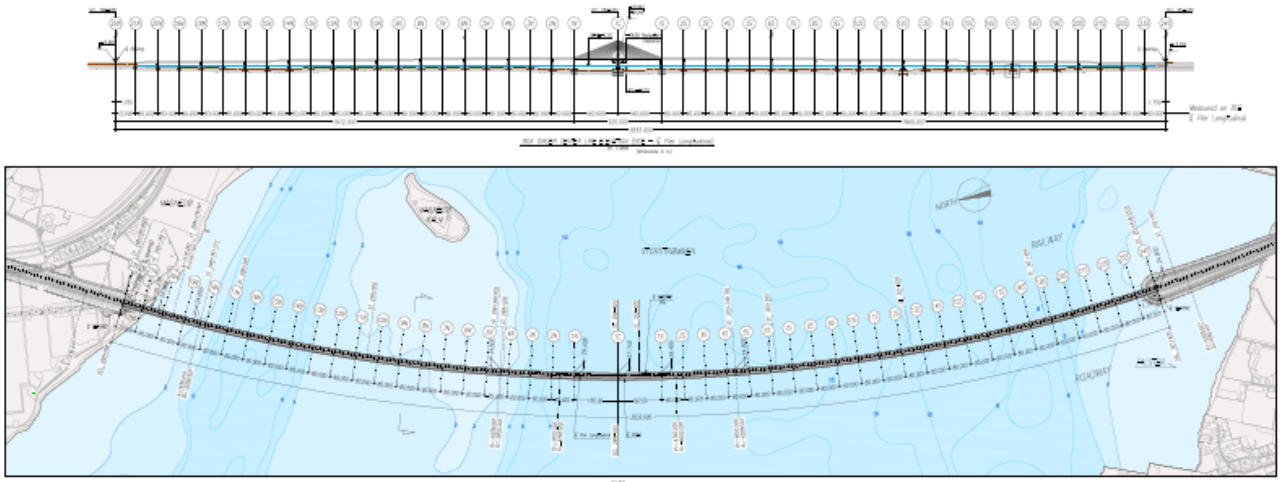

Figure 10. Storstrøm Bridge plan view and elevation.

2.2 Independent Design Check of New Storstrøm Bridge

2.2.1. Client Organization

The Storstrøm bridge contract has been developed under the figure of Design and Build Contract.

As part of the Client Organization, the Independent Checkers shall respond directly to the Design Manager.

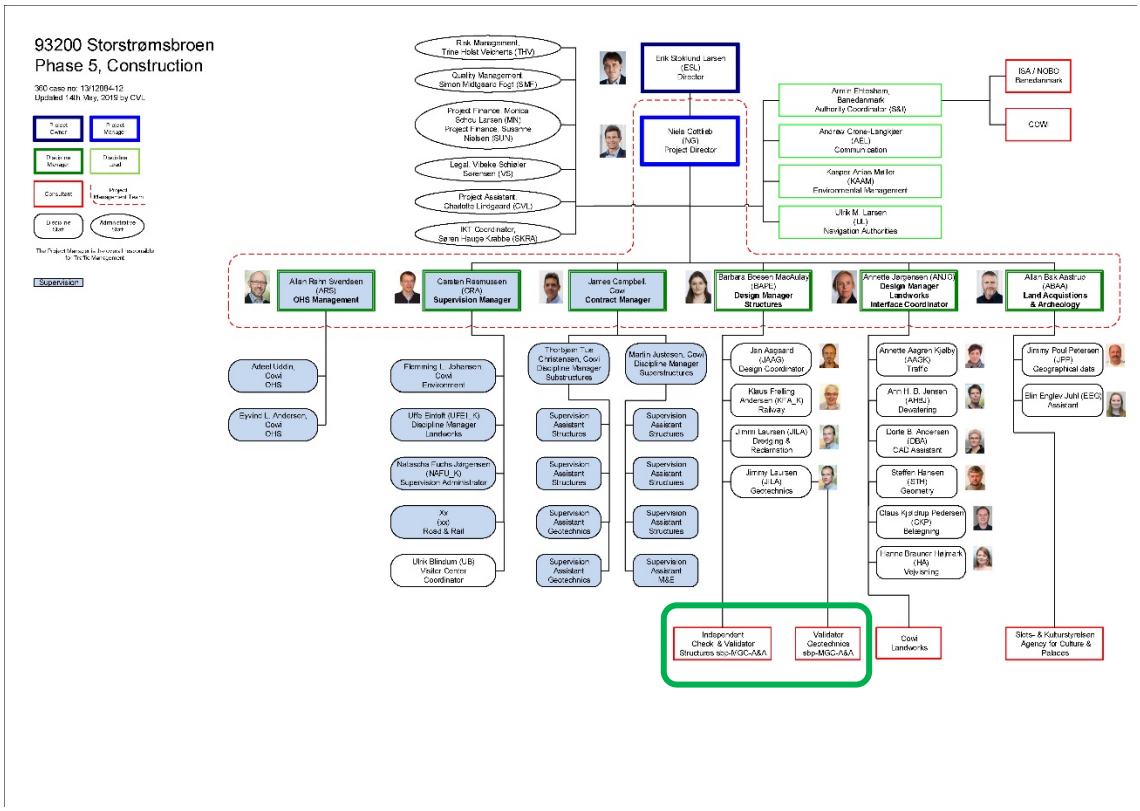

Figure 11. Client organizational chart.

2.2.2 Checking team

The great extension of the project requires a complete checking team covering a great number of disciplines:

Structures:

- Structural Bridge Design (including Cable Stay Bridges).
- Foundation Design.
- Construction Methods.
- Driving Comfort, as well as dynamic conditions of the railway section by design speed.
- Dynamic behavior and conditions of the bridge during ship impact.
- Mechanical & Electrical Installations.
- Operation & Maintenance and Access facilities.
- Bridge Deck Waterproofing Systems.
- Bridge Deck Surfacing.
- Bridge Parapets & Guardrails.
- Scaffolding & Formwork.
- Bridge Bearings.
- Road Expansion Joints.
- Structural Health Monitoring Systems.
- Corrosion Protection.
- Temporary Structures.

Technical Rail:

- Slab-track systems.
- Rail expansion devices.
- Rail fastening and rail expansion during ship impact.

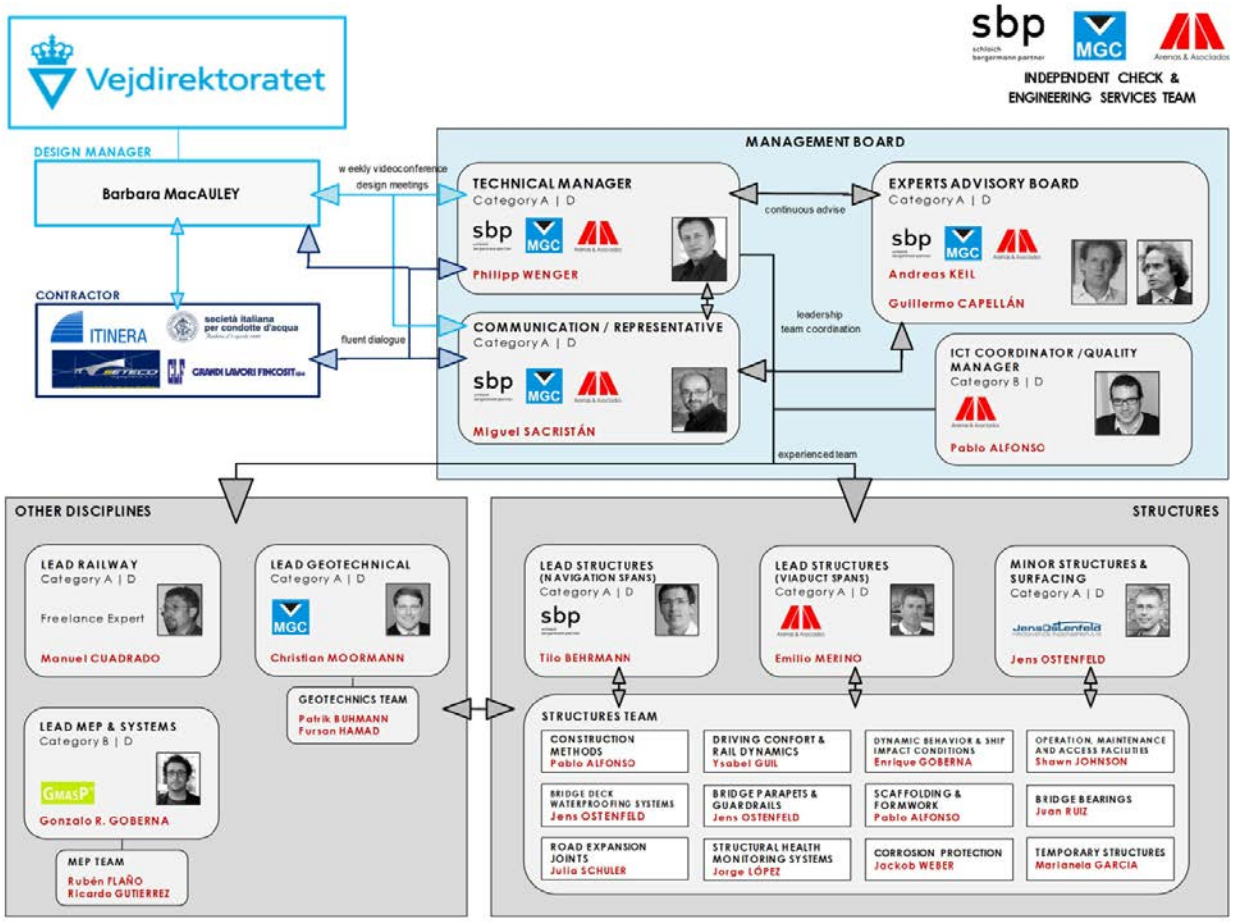

Figure 12. Independent Check organizational chart.

2.2.3. Design Stages

The design of the New Storstrøm Bridge has been divided by the Client into three consecutive stages:

1) Tender Design

   It is the first stage of the design and part of the documents to be provided as part of the tender documentation

   The main objective of this stage is to demonstrate the Contractor's understanding of the Employer's requirements.

2) Basic Design

   It is to be developed by the "chosen" Contractor. The objectives to be achieved in this stage are:

   - Confirmation of all visible dimensions of the bridge according to the Tender Design or proposed changes thereto.
   - Achieving an agreement on the analysis methods to be used in the Detailed Design
   - Providing detailed design analyses and preliminary drawings for the most relevant structural elements: typical pier, typical foundation, pylon, shortest and longest stay cables, and some girder sections.
   - Providing a schedule for the submission of Detailed Design packages
   - Allow the Employer to initiate the Independent Design Check and Validator's check.

   In accordance with the Employer's Design Basis [2], the Basic Design may be submitted as one package for the bridge (or another component under consideration) in its entirety or subdivided into packages, for example, main bridge, viaduct bridges, abutments, ancillary works…

   The solution adopted by the Contractor (SBJV, i.e., Storstrøm Bridge Joint Venture) has consisted of dividing the Basic Design into 34 Design Packages; the first one was submitted on 31st May 2018 and final approval for Basic Design was got on 7th August 2019.

3) Detailed Design

   As per the Employer's requirements, the Detailed Design may be submitted in the following Design Packages:

   - Two packages for each substructure, one for foundation plus pier shaft up the top of splash zone and one for remaining pier shaft including bearings.
   - One package for the bridge superstructure in each span.
   - One package for the pylon plus stay cables.
   - A number of packages for ancillary works.
   - A number of packages for major temporary works.

   However, the list provided by the Employer is to be considered a general reference and the Contractor (Designer) may combine a number of these packages by analyzing the worst case for a number of similar structures.

The expected number of Detailed Design Packages for the bridge is around 200 and by the date of writing this paper, 42 have already been submitted.

2.2.4. The approval process

The Contractor's designs are subject to scrutiny by four entities, which are:

- Independent Checker (Danish Road Directorate - VD). Which was selected through a public tender process and awarded by the JV sbp-MGC-A&A.
- Validator (appointed by Rail Net Denmark – BDK)
- Notified Body (verifying interoperability - TSI-compliance)
- Independent Safety Assessor (assessing railway safety)

The communication flow between these entities, their tasks, and associated key documents are shown in the following figure:

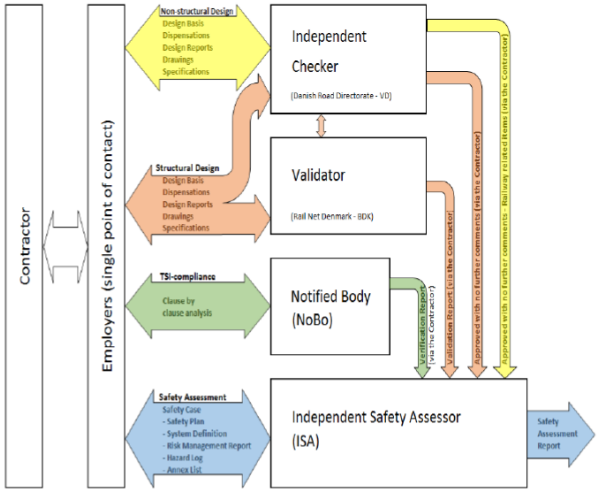

Figure 13. Communication flow chart.

2.2.5. Independent check analysis

Arenas & Asociados (A&A), as part of the Joint Venture sbp-MGC-A&A, is developing the Independent Check Analysis activities from December 2017. This independent check is to be understood as a Category 3 Check as defined in BD 02/12 of the British Design Manual for Roads and Bridges (see figure 3).

A complete general independent calculation model has been developed, based on the drawings and design basis provided by the Employer and the Contractor.

The bridge has been modeled with the software Midas Civil, different from the software used by the designers, which supposes an additional "independency" of the calculations.

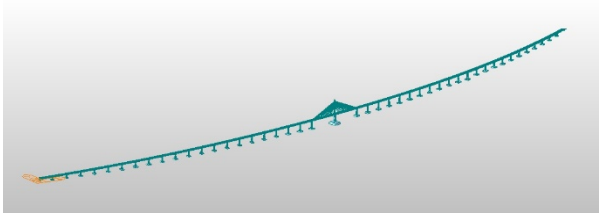

Figure 14. General view of bridge model.

This model includes the whole erection process, the real tendon layout, moving loads.

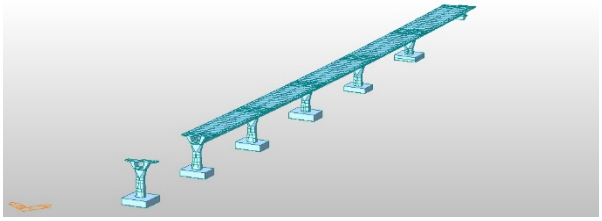

Figure 15. Construction stage of bridge model.

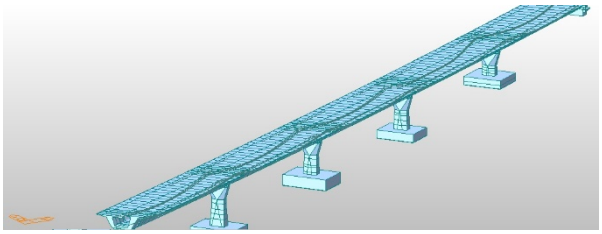

Figure 16. Tendon layout view of bridge model.

Different boundary conditions are to be considered for slow and fast loads due to the presence of STU's. All loads all included in the same calculation model, which simplifies the combination process.

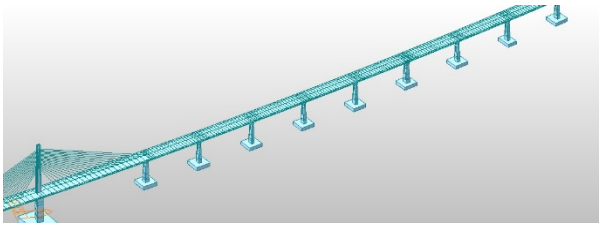

Figure 17. Connection between Cable Stay Bridge and Viaduct Spans.

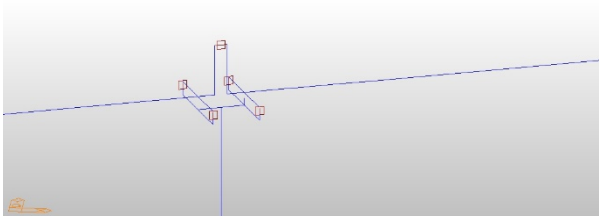

Figure 18. Detail of connection between Cable Stay Bridge and Viaduct Spans.

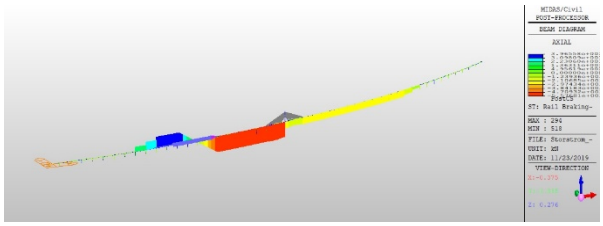

Figure 19. Axial efforts for rail braking load.

In addition to the global model, some local models have been developed for ship impact analysis.

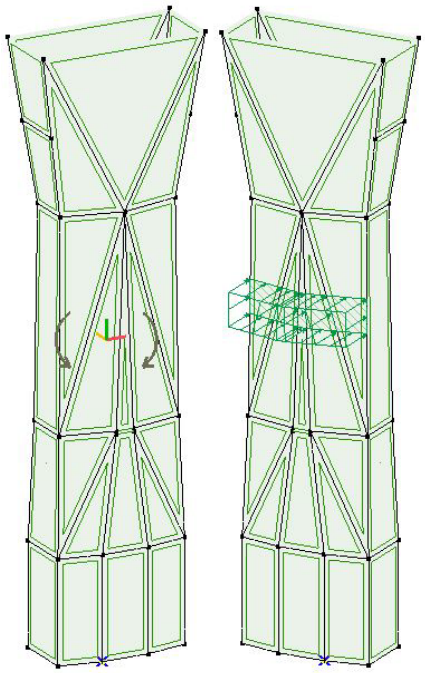

Figure 20. Local model for ship impact analysis (1).

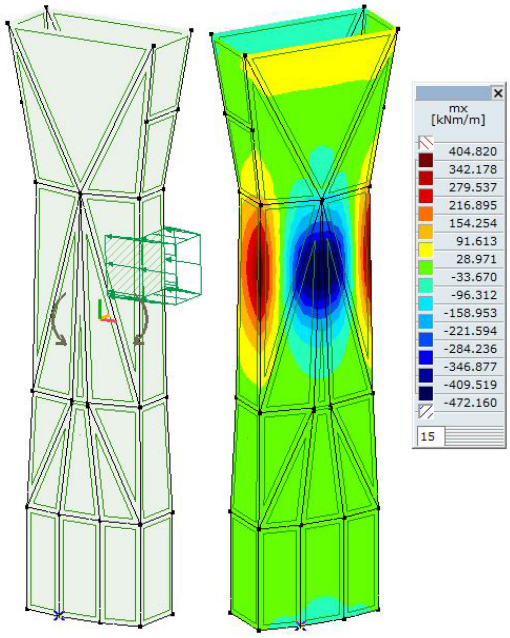

Figure 21. Local model for ship impact analysis (2).

For the so far Detailed Design Packages submitted (pier and foundations for South Viaduct), we have performed an independent sectional analysis that confirms the adequacy of the geometry and reinforcement drawings provided by the Contractor.

However, Independent Checkers work is not limited to the check of the provided documents; there is a fluent relation with the Client who can discuss any other relevant topic for the bridge: we are involved in the check of documentation and testing of the six different concrete mixes; all RFI submissions (Request for Information) related with the bridge are also discussed internally IC-DRD; assistance to the meetings…

2.3. Engineering services of New Strostrøm Bridge

As part of the signed contract for consultancy services, Arenas & Asociados will be part of the Joint Venture that carries out the engineering services: ad hoc technical assistance during construction and commissioning including review of "as-built" documentation.

By the date of this article is being written, no Detailed Design Package has been approved and construction activities have not started, therefore no engineering services have been required yet.

References

[1] "Adding confidence and reducing risk-the role of independent design checking in major projects." Ian Firth, IABSE Symposium, Weimar 2007.

[2] "Design Basis Storstrømbroen", Vejdirektoratet, 2017.