Analysis and Design of Ship Collision Barriers on a Submerged Floating Tunnel subjected to Large Ship Collisions

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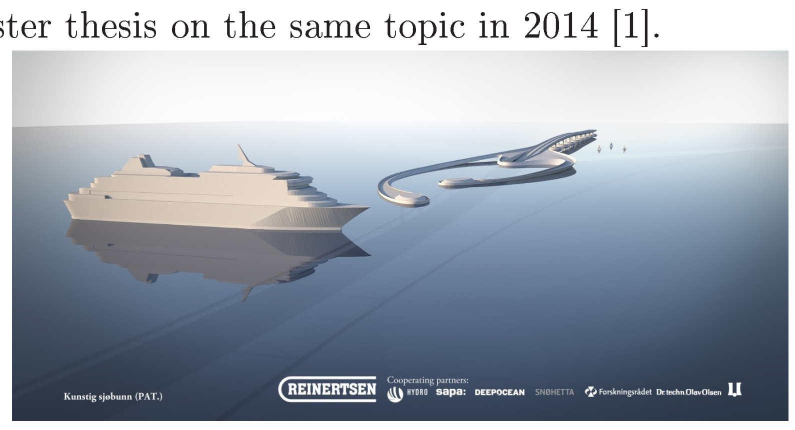
Introduction

The Norwegian Public Roads Administration (NPRA) is running the project "Ferry free coastal route E39". One of the main challenges are regarding how to cross the wide and deep fjord on the west coast of Norway.

In 2012 NPRA initiated a study to investigate the feasibility for crossing the wide and deep fjords on the west coast of Norway, focussed on Sognefjorden. Different solution was considered and the conclusion was that the crossing was technically feasible.

This master thesis is focusing on the ship collision barrier. The purpose of the ship collision barrier is to protect the transition zone between the floating bridge and the submerged floating tunnel. The concept is shown in the Figure below, where the ship collision barrier is shown at the port side of the ship. It was written a master thesis on the same topic in 2014 [1].



Basic theory

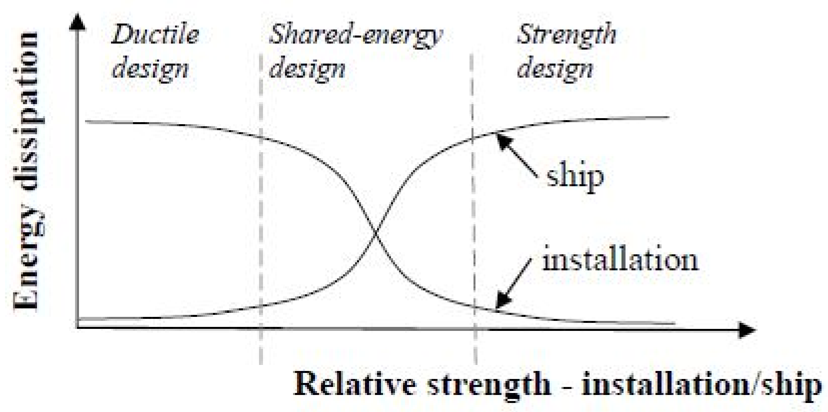
The characteristic value related to ship collision is kinetic energy.

$$E_{kin} = \frac{1}{2} \cdot (m + a) \cdot v^2 \quad (1)$$

- m: Mass
- a: Added mass
- v: Velocity
- E_{kin}: Kinetic energy

In addition to this equation the simplified calculation methods are based on two fundamental concepts, conservation of momentum and conservation of energy.

It is common to distinguish between three different design principles related to ship collisions. The Figure below is adopted from [2].



Strength design implies that the installation is rigid and major part of the energy is to be taken as deformation in the ship. **Ductility design** implies the opposite, major part of the energy is to be taken as deformation in the installation. In the middle a **shared-energy design** should be applied, which means that both the ship and the installation undergo some deformation. Hence this case is more complicated and complex than the other two design principle.

References

[1] Ørjan Konstali. Analysis and Design of Ship Collision Barriers on a Submerged Floating Tunnel Subjected to Large Ship Collisions. (Master Thesis NTNU), 2014.

[2] NORSOK N-004. Design of Steel Structures NORSOK N-004 Rev. 2. 2004.

Acknowledgements

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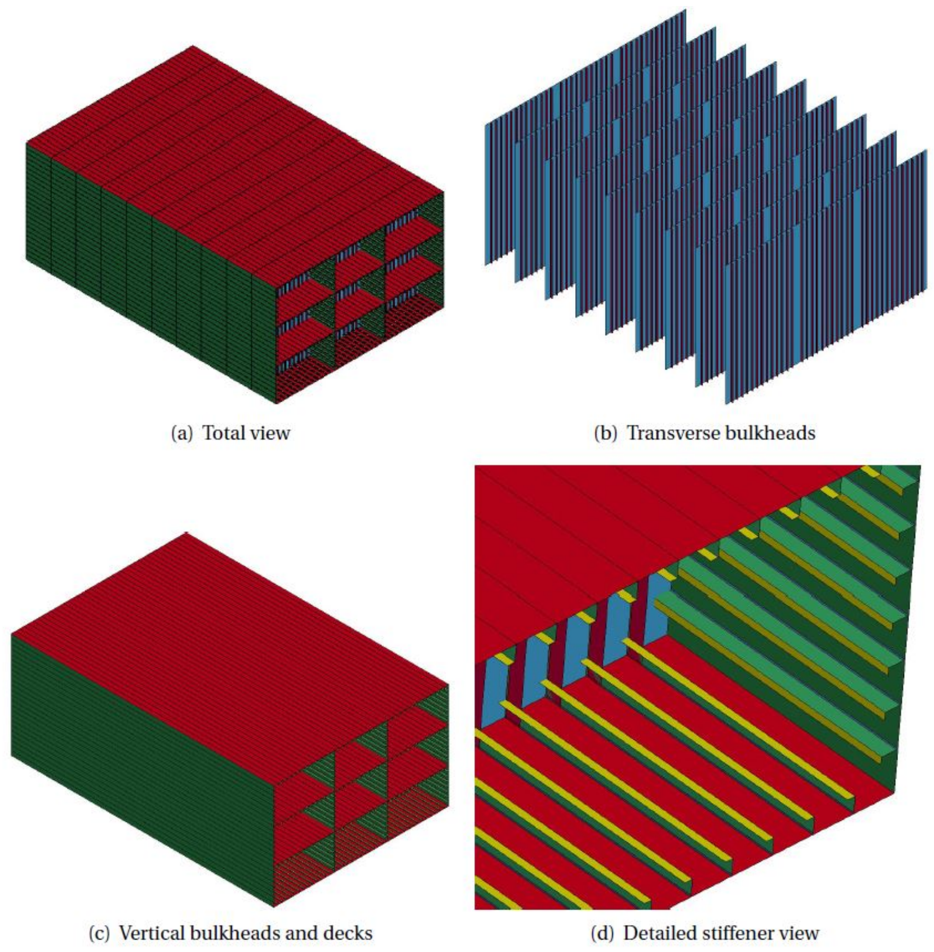
Concept and modelling

Ship impact is to be taken as an accidental action, this means that the design condition should be taken according to the condition which has a probability of occurrence of less or equal to 10^{-4}. The design ship according to this probability have a kinetic energy equal to about $1500MNm$. This energy needs to be dissipated as strain energy in the ship and in the barrier. In addition some energy will remain as kinetic energy after the impact and this energy needs to be taken by the boundary conditions.

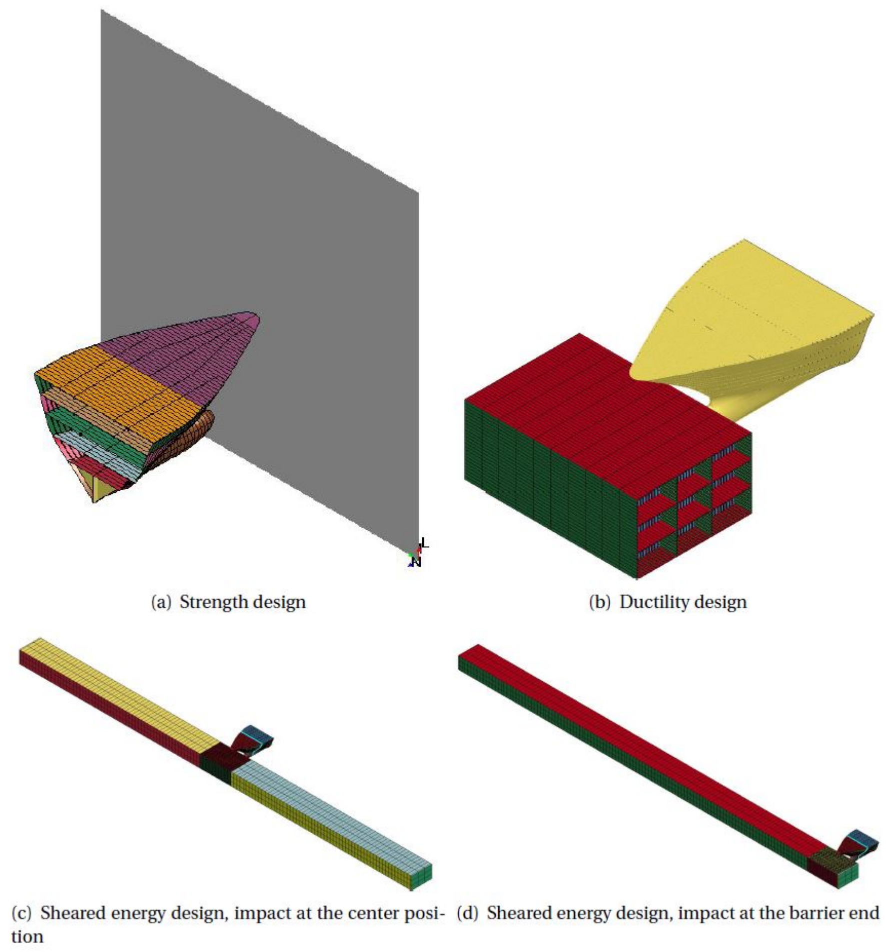
The barrier is assumed to be a freely floating structure which only is supported by inertia and drag forces. The barrier needs to be designed for dissipation of a large amount of energy. By those reasons it was decided to make the barrier cross section similar to a ship structure with bulkheads, decks and stiffeners.

Models to conduct all the three design principles have been created. For the sheared energy design both collision at the center of the barrier and at the barrier end needs to be investigated.

The ship collision barrier is made by aluminium alloys and is a relative light structure. Therefore it needs to be ballasted down to the desired design draft. For a design draft equal to $8m$ the height of the ballast water inside the cross section will be about $7.9m$. Hence the center of buoyancy and the center of gravity will be placed close to each other, which means that the intact stability is mainly given by the waterline stiffness.



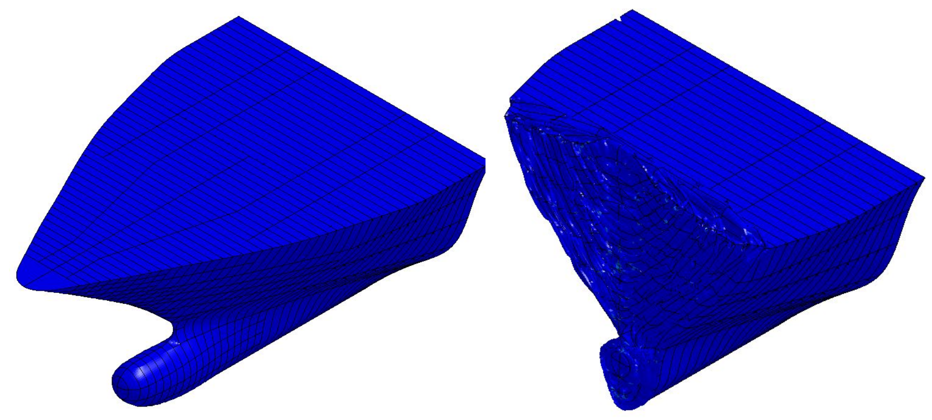
(a) Total view (b) Transverse bulkheads (c) Vertical bulkheads and decks (d) Detailed stiffener view



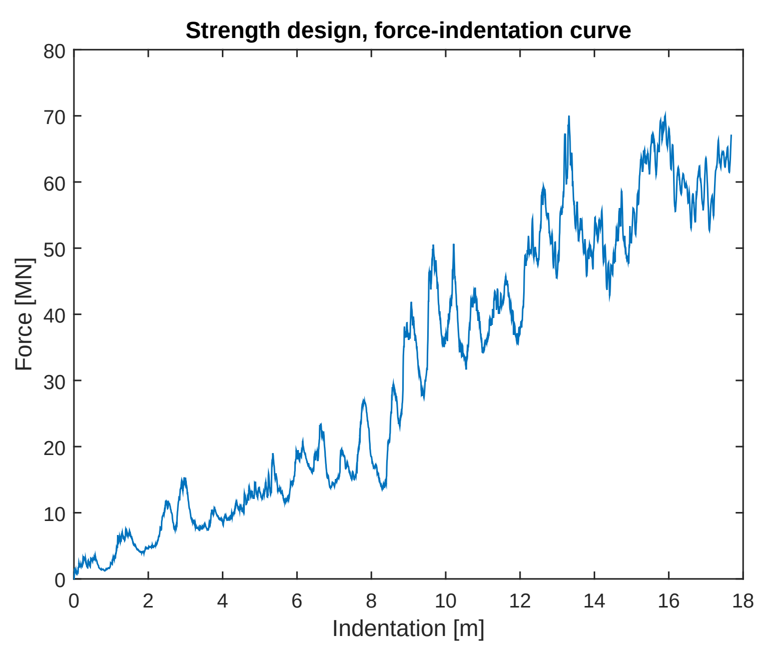
(a) Strength design (b) Ductility design (c) Sheared energy design, impact at the center position (d) Sheared energy design, impact at the barrier end

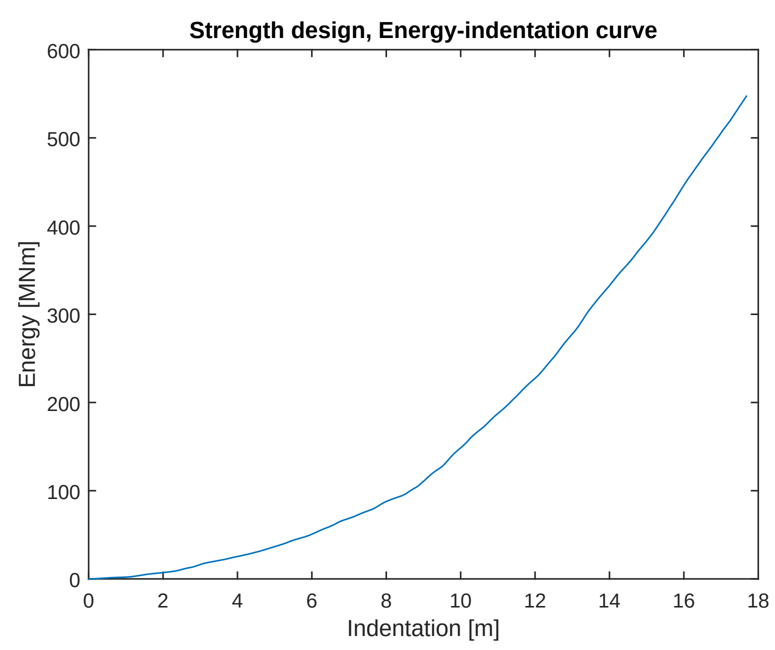
Results

The strength design approach where the bow in front of the collision bulkhead is crushed into a rigid wall is shown below.



The force-indentation and the energy-indentation curve for the strength design approach are shown bellow. The curve indicate that the bow can dissipate about $500MNm$ before it reach the collision bulkhead.





The figures below shows an illustration of how the ductility design have been conducted. The bow is assumed rigid and the energy dissipated in the barrier could be measured.