Abstract

The first quay walls were constructed in 2400 BC and were constructed with bricks. Since then, the quay walls have developed a lot. The quay walls nowadays are constructed out of steel, concrete or a combination of both materials. An upcoming material in the field of hydraulic engineering is fibre reinforced polymer (FRP). FRP has several advantages such as the low weight to strength ratio. Bridges and lock gates have already been constructed out of FRP.

This thesis is a feasibility study to an FRP quay wall. An FRP quay wall is designed based on a reference project provided by the engineering bureau of Gemeente Rotterdam. CUR96 has been applied as a design guideline. The focus of this feasibility study is the retaining wall. The anchors and superstructure are not included in this study.

A variant study has been conducted concerning 4 types of quay walls. The cantilever quay wall, an anchored quay wall, an L-wall and a caisson. For each of the variants a preliminary design has been made. As a result of the variant study the anchored quay wall is proven to be the most suitable type of quay wall. This recommendation is based on the forces and moments on the structures as well as the amount of required material.

The maximum allowable deformation is based on the heeling angle and draught of the governing vessel as well as the distance between the moored vessel and quay wall. The quay wall from the case study has been modelled with the program 'D sheet Piling'. The stiffness of the quay wall has been lowered until the deformation of the quay wall was more or less equal to the maximum deformation.

The Young's modulus of FRP is a static variable while the moment of inertia is a dynamic variable. The moment of inertia depends on the cross section of the quay wall profile. The cross section of the FRP quay wall is similar to Z-profiles used for steel sheet piling. The FRP quay wall consists out of 2 skin laminates, web laminates which connect the skin laminates with one another and foam that fills the space between the skins when no web is present. The foam has no significant mechanical properties and will therefore be neglected.

The skin laminate has been designed as an anisotropic laminate while the web laminate has been designed as a quasi-isotropic laminate. The laminates are designed with the programs 'eLamX^2' and 'Kolibri'. According to CUR96 the strain in the laminates may not be higher than 0,27%. With a hand calculation, a 2D model in 'SCIA' and a 3D FEM model in 'SCIA' the strains in the laminates have been calculated for the governing loading combination.

A Z-profile with a skin thickness of 50 millimetres, a web thickness of 20 millimetres, a width equal to 650 millimetres, the height equal to 725 millimetres and a spacing equal to 200 millimetres between the skin laminates remains below the strain criteria as given by CUR96.

The skin and web laminates have been checked for the following failure mechanisms: buckling, interlaminar shear stress, wrinkling and shear stress between the laminates. From these checks it can be concluded that neither the skin nor the web laminate is sensitive to these failure mechanisms.

Common checks related to quay walls have been performed as well. The anchor capacity, overall stability, bearing capacity and deadweight of the quay wall have been checked.

The joints of the FRP quay wall have been discussed quantitatively. This concerns the joints between 2 Z-profiles as well as the connection between the skin and web laminate. It is stated in design guidelines that the design of the joint between the skin and web laminate has to be verified with testing and a numerical calculation with a FEM. Literature shows that FRP is already being applied as shoring equipment but with a limited retaining height. The type of connection used in the shoring equipment is similar to the connections used with steel sheet piling.

The required installation technique for a FRP quay wall has been researched as well. Driving, vibrating and pressing the FRP quay wall to the required depth is not feasible. A diaphragm wall installation technique is therefore assumed to be the best alternative.

An LCA has been performed for the steel combi wall from the case study as well as for the FRP quay wall. The carbon footprint and environmental impact has been calculated for both quay walls and are compared to one another. The results are the same, the impact of the FRP quay wall is way bigger than the impact of the steel combi wall. The LCA has been performed for a running meter quay wall.

The FRP quay wall has been compared to the steel combi wall based on the LCA. Both structures have also been compared to one another based on a cost estimation for a running meter quay wall. The result of this estimation is that the FRP quay wall is far more expensive than the steel combi wall.

The conclusion of this feasibility study is that an FRP quay wall is technically feasible. However, the environmental impact as well as the cost estimation shows that a steel combi wall still is a better alternative.

It is recommend to perform more feasibility studies to FRP in large hydraulic structures to see whether the material is a suitable alternative for steel and concrete.