COMPARISON OF INFRASTRUCTURE DESIGNS FOR QUAY WALL AND SMALL BRIDGES IN CONCRETE, STEEL, WOOD AND COMPOSITES WITH REGARD TO THE CO_2-EMISSION AND THE LIFE CYCLE ANALYSIS

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David DUDOK VAN HEEL[2], Trude MAAS[1,2], Jarit DE GIJT[1,2*], and Mozafar SAID[2]

[1] *Delft University of Technology*
[2] *Public Works Rotterdam*
[*] *e-mail of corresponding author: J.G.deGijt@tudelft.nl*

ABSTRACT

This paper describes quay wall and bridge designs in different materials, which are compared with regard to the CO_2-emission and the Life Cycle Analysis (LCA). For this study the requirements and boundary conditions from the Euromax Terminal quay wall, in the Port of Rotterdam, have been used. The preliminary designs of this quay wall (made during the tender phase) are presented. They consist of a concrete diaphragm wall and a steel combi wall. New designs have been proposed for the materials wood and composites. These designs resulted in a retaining wall of Azobé and a sandwich panel of Fiber Reinforced Polymers. For these four quay wall designs cost estimations were made. For the bridge comparisons four structures, all built in the city of Rotterdam, have been considered. After completing the designs, the CO_2-emission during the lifetime of these structures was calculated. In addition several other impact categories have been determined with help of an LCA.

Keywords: Quay wall, bridge concrete, steel, wood, fiber reinforced polymer, CO_2-emission, life cycle analysis.

1. INTRODUCTION

This paper is the result of a master thesis for the specialization Hydraulic Structures at Delft University of Technology. It involves a comparison of quay wall designs in different materials with regard to the CO_2-emission and the Life Cycle Analysis. Traditional materials like wood have been replaced over time by concrete and steel. A relatively new material in civil engineering is the use of composites, which result in fiber reinforced polymer structures. Next to that climate change is a hot topic nowadays. The building sector is one of the sectors which have a large impact on the environment. Constructing durable and sustainable throughout the entire life cycle is becoming more and more important. CO_2-emission is a widely excepted parameter to estimate sustainability. Besides CO_2 many other environmental effects, so called impact categories, have an impact on air, water and soil. These impacts can be shown with help of a Life Cycle Analysis (LCA).

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2. CONCRETE

The first design that is used in the LCA is the design as shown in Figure 1.

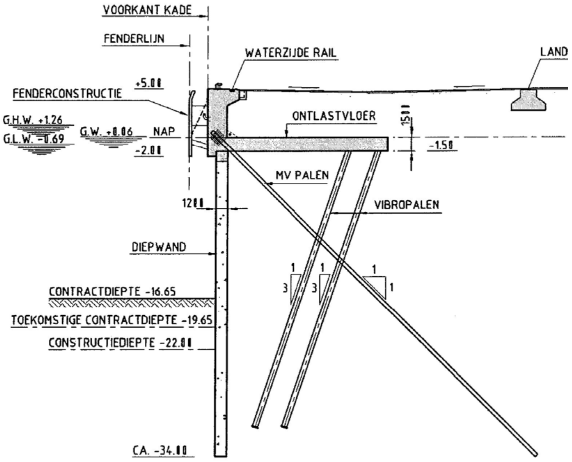

Figure 1. Cross-section concrete quay wall

It presents an overview of the preliminary design of the structure that is in reality designed and constructed. The quay wall consists of a concrete diaphragm wall of 1200 mm with a length of 32.0 meters. On top of that a concrete L-shaped relieving structure is constructed. The stability of the total structure is guaranteed by a combination of mv-piles for tension and vibro-piles for compression.

3. STEEL

The second design is shown in.Figure 2.

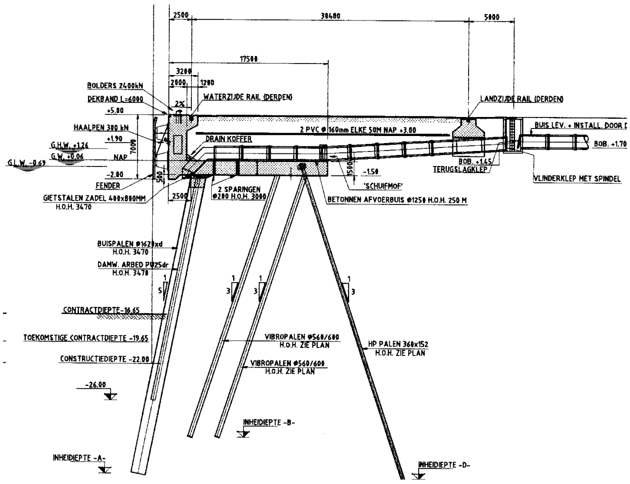

Figure 2. Cross-section steel retaining wall

The retaining wall consists of a combi wall with steel tubes of circa 35 meters and sheet piles with a length of 32 meters.

Furthermore, this design makes use of the same relieving structure as the design shown in Fig 1. The only difference is the position of the mv-piles.

4. WOOD

The third design makes use of wood as the main building material. Since there is no design of the Euromax terminal using wood, a new design was made. The durability of wood species is an important matter. Structures are classified in hazard classes depending on the loads and environmental exposure. Besides that, wood species are assigned to durability classes. When combining these two, it follows that for the design of the quay wall structure only several hardwood species are suitable "(CUR 2003)". Their chemical composition and density are able to withstand fungus and marine bores.

As stated previously, sustainability is an important subject in this research. Forestry is considered sustainable when the ecosystem of the forest is being preserved over time. The Forest Stewardship Council (FSC) has a certification system for sustainable produced wood.

Several types of quay walls have been discussed. Designs have been proposed for a wooden retaining wall with a relieving structure and furthermore a wharf "(NEN committee 2007)". These designs have been compared to each other with respect to several criteria: use of material, durability, construction techniques, etc. The wooden wall combined with a relieving structure appeared to be the best design. This was mainly because the material use in this design is less than the wharf. A cross-section of the wooden wall is shown in Figure 3.

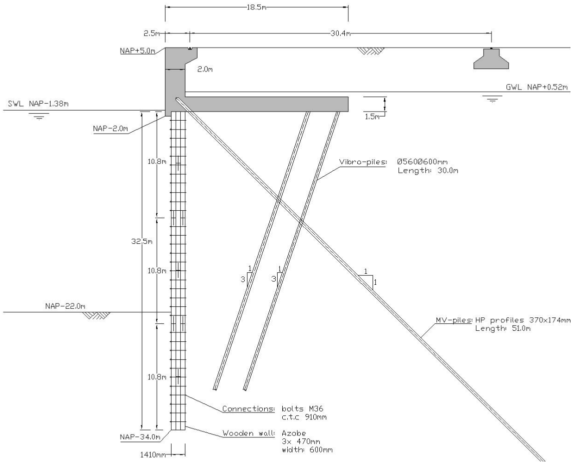

Figure 3. Cross-section wooden wall

The wooden wall has a thickness of 1400 mm and the concrete relieving structure has the same dimensions as shown in Figure 1. Large Azobé elements must be connected with help of bolts creating larger elements. These can be lowered in a trench supported by bentonite slurry.

5. FIBER REINFORCED POLYMER

The fourth design is made with composites, resulting in the use of Fiber Reinforced Polymers (FRP). The use of this material in civil engineering is relatively new, especially for large hydraulic structures.

Since all three foregoing designs make use of the L-shaped relieving structure combined with a retaining wall, decided was to use an FRP sandwich panel as a retaining wall.

FRP consists of a polymer matrix reinforced by fibers. Mostly used fibers are glass fibers and carbon fibers. The properties of carbon fibers with respect to glass fiber are much better, but the costs are approximately 25 times higher. Common resins for this purpose are polyester, vinyl ester and epoxy. A vinyl ester resin reinforced with glass fibers has the best mechanical properties in relation to the costs for this purpose. The choice of the fiber configuration determines the strength of the composite. Both isotropic and anisotropic materials can be obtained.

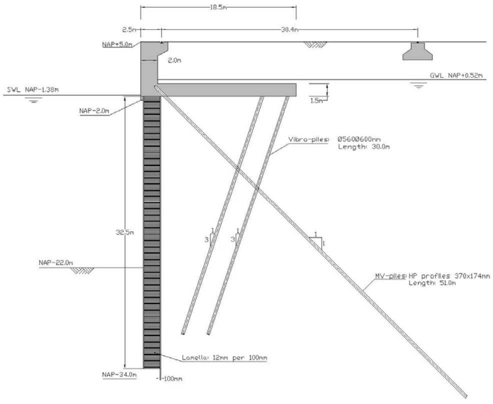

Figure 4. Cross-section FRP sandwich panel

The maximum allowable strain (0.27%) in the outer fibers was normative for the design of the sandwich panel “(CUR Committee 2003)”. This strain must be limited, since the diffusion of water rapidly destroys the bond between resin and glass fibers. The dimensions of the sandwich panel resulted in a total thickness of 2.08 meters. A cross section of the design is shown in Figure 4.

This maximum allowable strain is subject to discussion, a new CUR publication (CUR 96) is dedicated to this phenomenon.

6. COSTS

After completing the designs, cost estimations were made for 1.0 m quay wall (see in Figure 5).

From this it can be seen that the traditional building methods have the lowest costs. The Azobé design is circa twice as expensive and the costs for the quay wall with the FRP retaining wall are circa 7-10 times higher.

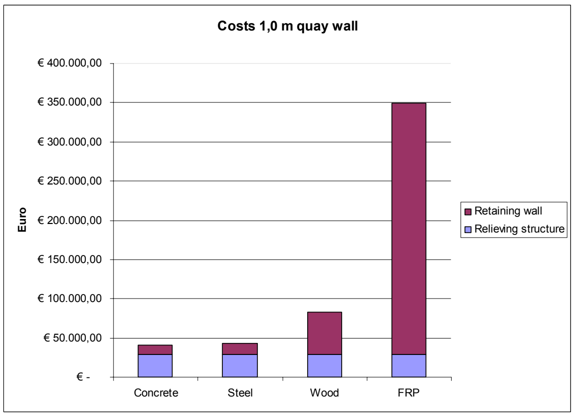

Figure 5. Cost estimation per 1.0 m quay wall

7. CO_2 EMISSION AND LIFE CYCLE ANALYSIS QUAY WALL

Finally the CO_2-emission of each structure was calculated. The generic accepted idea is that global warming is induced by the green house effect, although sceptics do not agree with this opinion.

The six most important greenhouse gases include CO_2, CH_4, N_2O, HFC’s, PFC’s and SF_6. For each of these gases their potential contribution to global warming relative to CO_2 can be determined.

The contribution of all these greenhouse gasses have been expressed in CO_2-equivalents.

Furthermore the emissions of several other impact categories have been determined with help of a Life Cycle Analysis (LCA). They represent emissions causing pollution to air, water and soil, depletion and land use.

An LCA can be performed, following several steps:

Step 1: Goal and scope definition

The functional unit expresses the unit that shall be compared. In the concerning research this is 1.0 meter quay wall. The effects that are taken into account are: Global warming potential, Ozone, Energy, Abiotic / Biotic depletion potential, Human toxicity potential, Fresh and Salt water ,Terrestrial, Aaquatic ecotoxicity potential, Photochemical oxidant creation potential, Acidification, Eutrophication potential,

These effects will be taken into account over a time horizon of 50 years, since this is set to be the lifetime of the structures.

Step 2: Inventory analysis

The impacts during all phases of the life cycle have been taken into account:

Production of materials, Transport, Construction, Use, Demolish, Process

Step 3: Impact Assessment

Since all processes have been defined, the quantities of materials, transport kilometres and use of equipment during the construction phase are calculated.

Subsequently the emissions per impact category have been determined.

National and international, a variety of databases are composed, of which some are public and some not. In this case it is best to make use of local databases, since they are based on local processes and material production. For determining the Carbon Footprint of the quay wall designs, two databases have been used. The first one is composed by IVAM (Department of environment, University of Amsterdam). They make use of the Ecoinvent 2.0 database and IVAM LCA Data 4. The last contains data concerning construction products and processes, gathered in projects executed by IVAM.

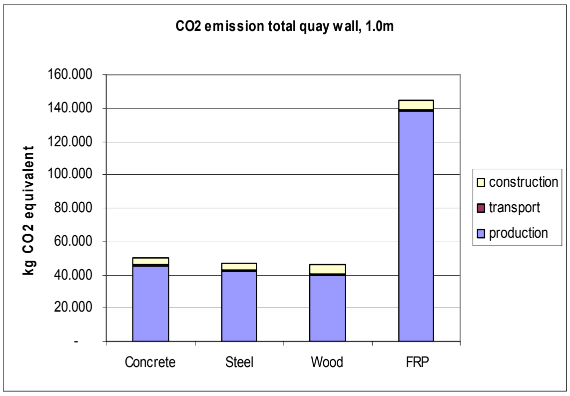

Figure 6. CO_2-emissions per 1.0 m quay wall

The results of the Carbon Footprints regarding the different materials are shown in Fig. 6.

Next, the emissions due to the 13 impact categories specified in step 1 are calculated. These emissions have been determined with help of a material database of NIBE (Dutch institute for building biology and ecology). NIBE makes environmental assessments for building products based on the LCA methodology. They represent the so called shadow costs, costs for the preventive measures which must be taken to reduce the emissions to a sustainable level. Monetization is a weighing factor, which makes it possible to add the emissions of each impact category, resulting in one final indicator for each design. In this way the designs can be compared. The shadow costs per design are shown in Fig. 7.

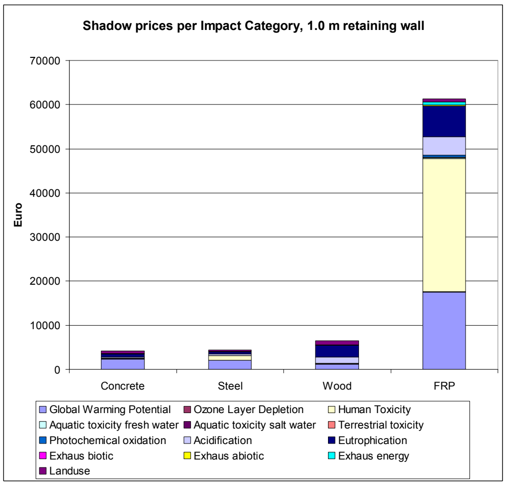

Figure 7. Shadow costs per 1.0 m retaining wall

8. CO_2-EMISSION AND LIFE CYCLE ANALYSIS BRIDGES

Like to the analyses for the quay walls, the analysis for the bridges was made for three small constructions, used for bicycles and pedestrians, all built in the city of Rotterdam (see table 2)

Table 1 dimensions and costs of bridges

	Length	Width	Price
Concrete	12,0	3,7	€ 1.100
Steel	11,0	3,0	€ 500
Wood	12,4	3,0	€ 500
Composite	12,1	2,0	€ 1.800

In figure 8 the CO_2 emission (Global warming potential) is presented for the concerned bridges. This figure shows that synthetic (VVK) has the highest CO_2 emission; while for wood it is the lowest for the considered materials.

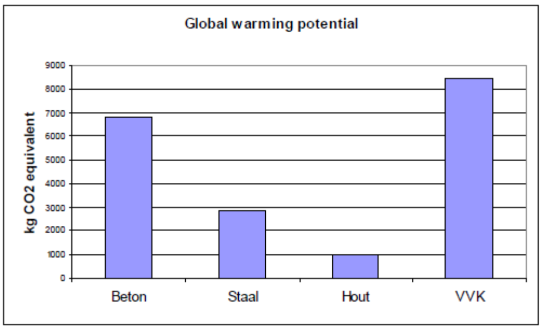

Figure 8. CO_2 emission (Global Warming Potential) per running meter bridge

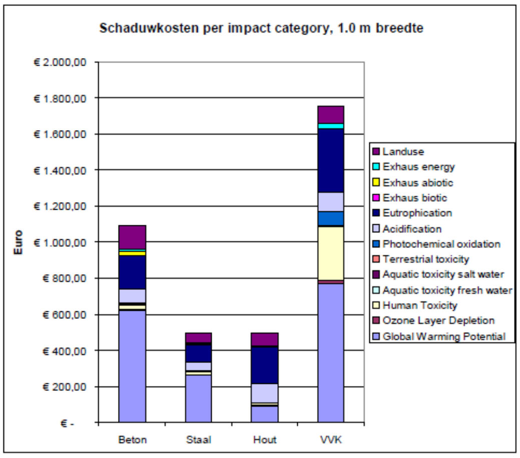

Figure 9. Shadow costs (Schaduwkosten) per running meter bridge

The data in figure 9 indicate that the shadow costs , costs needed to compensate for negative environmentally aspects, are a factor three higher for synthetic materials (VVK) than for wood. For steel the costs are about the same as for wood.

9. CONCLUSIONS

In general it can be concluded, that each material needs its own design method, depending on its specific material properties.

Due to the mechanical and chemical properties of hardwood and softwood, it can be concluded that with respect to durability, hardwood is the better choice for constructing a quay wall in a salty environment. Note that sustainable forestry is an important matter.

Production of the materials has the highest impact on the Carbon Footprint of a structure.

The wooden retaining wall results in the lowest Carbon Footprint. The Carbon Footprint of the FRP sandwich panel is much higher. A FRP structure needs to be 37 times lighter than a concrete structure to have the same impact on the environment. Due to the small allowable strains in the sandwich panels, this seems difficult to realize in hydraulic structures. Therefore it can be concluded that the “sustainability” of a material is not only depending on the emissions per kg material, but also on its application. When the specific properties of a material are used in their best way, this result in the use of less material, creating a lower Carbon Footprint. Relating to the bridges investigated it followed that synthetic materials are about three times more stressful than steel and wood in terms of environmental impact. This is considerably lower than for quay walls, where it was a factor of 37. From Fig. 7seven can be concluded, that the other impact categories, which are weighed with monetization, give a comparable output to the Carbon Footprint, although Azobé results in higher values than concrete and steel. Attention must be paid to the end of life scenarios. In this study variations in reuse, recycling, incineration or dump have not been taken into account. Note that these scenarios can have a high impact on the sustainability of a structure.

10. REFERENCES

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