INNOVATIVE RIGID CONCRETE FENDER SYSTEM REDUCES LIFE CYCLE COSTS

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In 2010 the Port of Rotterdam (PoR) tendered a new quay wall in a design and construct contract without maintenance. The contract is awarded to the contractor with the economically most favorable bid (and not necessarily the lowest price). The LCC (life cycle costs) value of the quay wall was the most important parameter.

Although the Port of Rotterdam imposed on the bidders rather strict technical terms of reference, bidders were challenged specifically on the optimization of the most expensive parts in terms of maintainability. This approach resulted in innovative designs for the rigid fender system. The most radical change was made by the winning contractor, Van Hattum en Blankevoort.

INTRODUCTION TO WIDENING AMAZONEHAVEN

The existing Maasvlakte in the Port of Rotterdam (figure 1) is the home base of one of Europe's largest container terminal, the ECT Delta Terminal. As can be seen in figure 2, the basin on the south side of the terminal is rather small (2700 x 255 m). This basin is called the Amazonehaven and is used by ECT on the north, Kramer in the far west and EMO, a dry bulk company, on the south over the first kilometer.

Figure 1 Location f Rotterdam and Maasvlakte 1 and 2

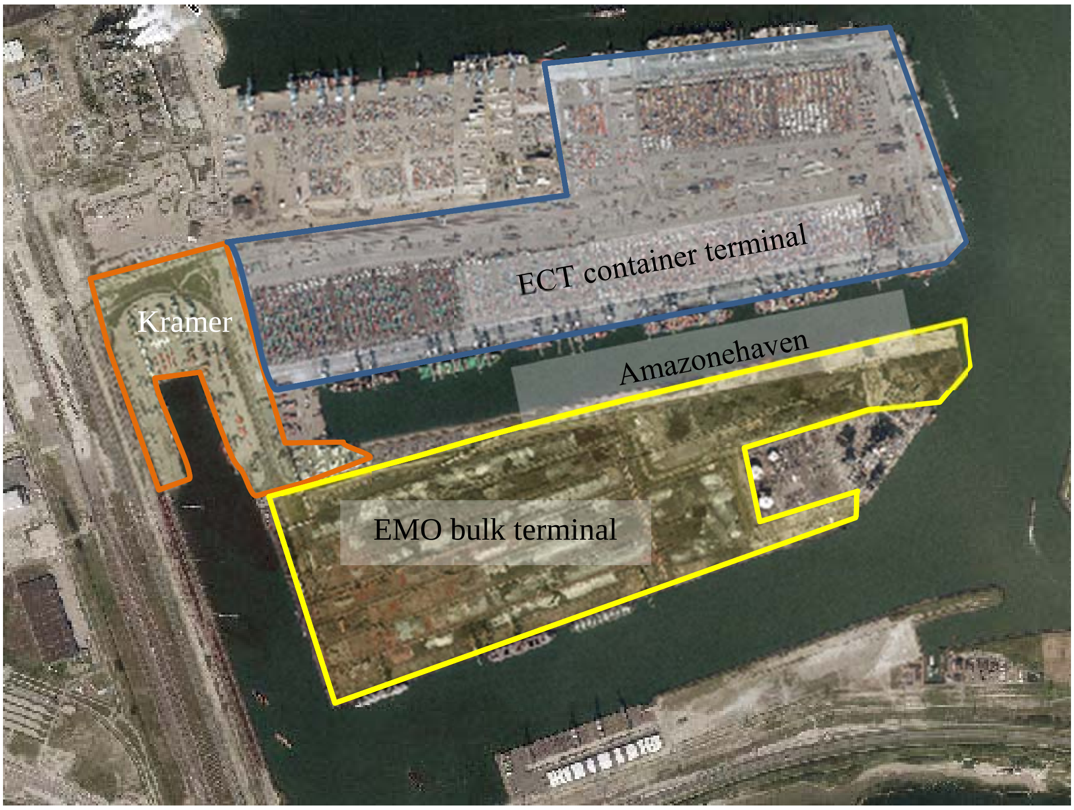

Figure 2 overview of customers Amazonehaven

Due to the fact that all large container shipping companies are replacing their vessels with Ultra Large Container Ships (ULCS) there is a need for more space. The design ULCS (382*57*15 m) can only sail into the basin under very severe restrictions like a maximum wind force of 3 Beaufort. Since wind conditions especially in the winter season very often exceed this level, it is almost impossible to operate a commercially relevant container loop on the basin with these ultra large container ships.

Because every single company has its own stacks on the terminal, where all ships are moored and handled, it is virtually impossible to operate the largest vessels only at the Europahaven on the northern side of the terminal. To prevent the loss of cargo to another port, the Port of Rotterdam, together with the ECT decided to widen the Amazonehaven.

To do so, two things will be done. The contract of EMO in the Amazonehaven will be terminated. This increases the 165 meters width of the nautical path by 50 meters to 215 meters because EMO is no longer allowed to moor vessels along this deep quay wall. The second measurement is the new building of a vertical quay wall on the south side of the entire basin and removal of the old deep quay wall and the existing slopes with an angle of 1 vertical 4 horizontal. This new quay wall increases the nautical path with another 55 m up to 270 m at the entrance. The entire basin width will become 310 m. ECT uses 40 m of mooring width at the basin entrance.

This project is currently under construction/ demolition and will be ready in early 2014. Before the contract of EMO could be terminated, a new quay wall with the same facilities as the old one had to be constructed. This quay wall is called Kade EMO M5/M6 and is the subject of this paper.

INTRODUCTION TO EMO AND THE NEW QUAY WALL

EMO is the largest dry bulk terminal in Europe and mainly handles iron ore and coal. They have a site of approximately 150 hectares on the first Maasvlakte. On the south side of the peninsula and terminal there are four berths in the basin called Mississippihaven. These berths (M1 to M4) have maximum nautical depths of 21 to 23 meters and can be used by the largest ships like the Chinamax class operated by Vale.

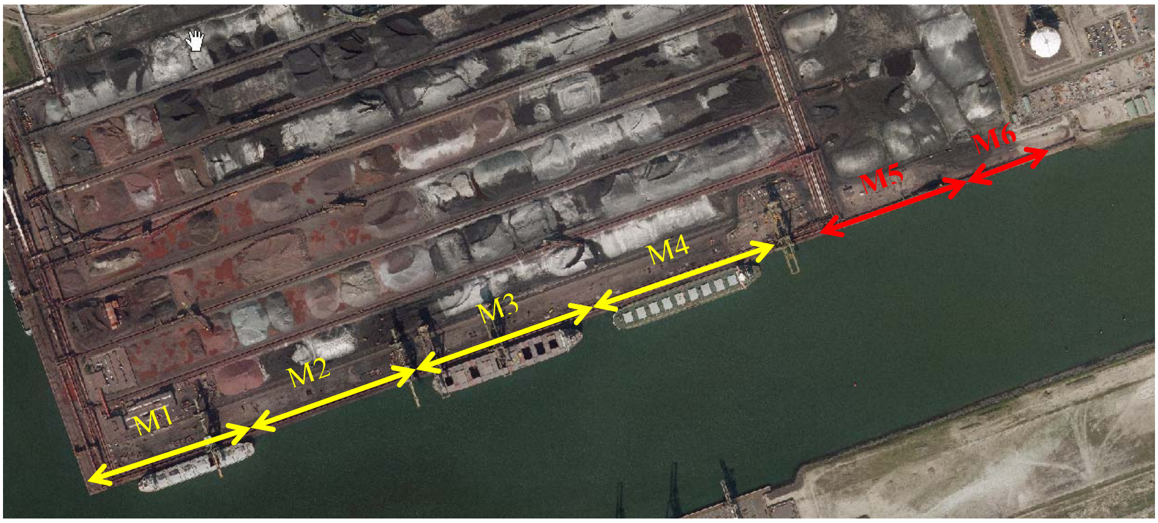

Figure 03 overview of EMO terminal with berths M1 to M6

Incoming dry bulk is unloaded at the quays M1 to M4 from large bulk carriers and mostly temporary stacked on site. Customers receive their bulk either by rail, barge or smaller sea going vessel. These smaller sea going vessels used to be handled at the quay wall in the Amazonehaven with a large ship loader. To be able to widen the Amazonehaven, EMO needed a new quay wall and new ship loader. This new quay wall is called Kade EMO M5/M6 (quay wall is kade or kademuur in Dutch) and is located on the southern part of the EMO peninsula in the same line as the existing berths.

THE SCOPE OF THE WORKS

The new quay wall should be able to accommodate two berths, one panamax berth (M5) with a design vessel of DWT 80,000 and one barge berth (M6), mainly for barge convoys up to class VI (4 barges together, 195*22,8*4,5 m). The total length of the quay wall is roughly 485 meters, the retaining height is 23.65 meters.

Main challenges in the design of the new quay wall are the connection with the existing quay wall M4 and the combined use of the quay by sea going vessels and barges. The quay wall M4 was built in the late eighties and consists of a relief construction with a height of 11,5 meters, founded on a combined wall system made of hexagonal composed tubes instead of circular tubes. See figure 04 for a cross section of the M4 quay wall.

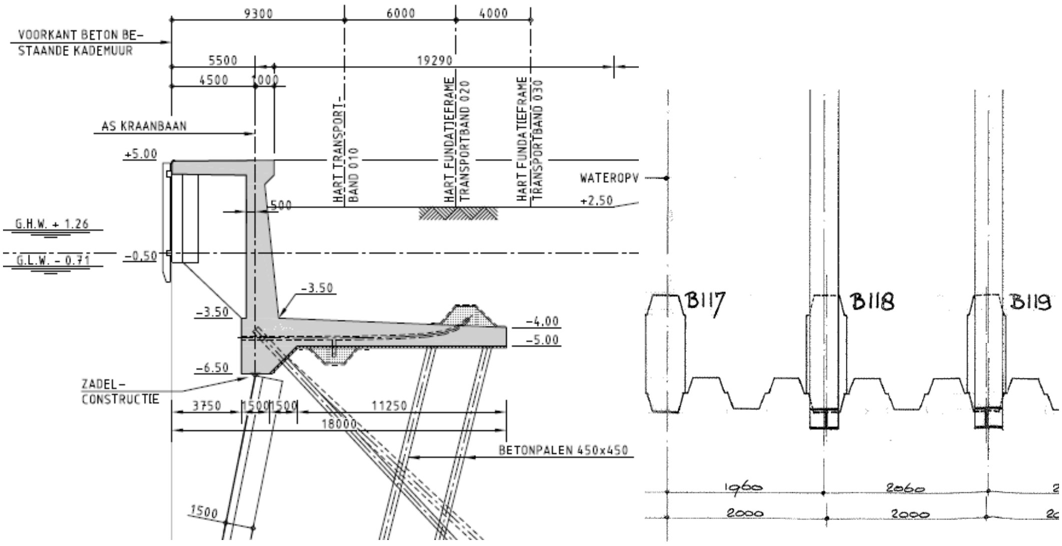

Figure 04 cross section quay wall M4 and combi wall foundation

Barges are famous for their destructive capacity and sea going vessels want to be moored as gently as possible. To be able to meet both specifications as much as possible Port of Rotterdam designed a traditional rigid fender system. Since Port of Rotterdam wants to minimize the use of tropical hard woods like Azobé (Lophira alata), it was designed in steel with the vertical beams covered with UHMW-PE. See figure 05. This design with five horizontal bars (purlins) makes it almost impossible for barges to hit and harm the concrete and the UHMW-PE covers will protect the coating of the moored vessels moving up and down due to tidal differences and loading operations. Although it was a good design, it was also a very expensive design, costing almost €4000 per m1, >10% of the initial investment.

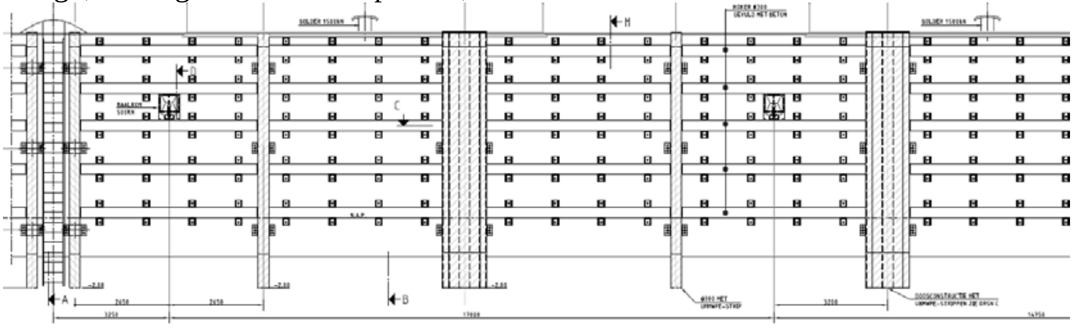

Figure 05 reference design of rigid fender system

THE CONTRACT USED

As the Port of Rotterdam identified real design challenges, it was decided that the best way to procure the quay wall was a design and construct contract with much design freedom to the contractor. There was no prescribed reference design, only some details like ladders, cathodic protection and bollards where prescribed. These details are optimized by the asset management department based on their maintenance experiences and are replaceable from the spare parts stock. The fender system in the specifications was a reference design that could be adapted and the contractors where explicitly challenged to redesign the fender system.

The contract document used by the Port of Rotterdam is a custom made D&C contract, but can be compared to the Dutch UAV GC, which again can be compared to the Fidic Yellow book. The main difference between Fidic and the Dutch contract is the Dutch law. The Dutch law is based on the principles of reasonableness and fairness. These two elements are not used in Anglo-Saxon style laws and therefore not in the Fidic contracts.

THE TENDER PROCEDURE

The Port of Rotterdam has used the European tender procedure by negotiation with prior notice. Five companies where selected out of seven interested parties to join the tender. These companies received all the relevant documents at the same time and had 4 months to prepare a design for the quay wall.

During the design period bilateral meetings between Port of Rotterdam and the individual contractors were held. After these four months the contractors presented their plans to the tender committee. The Port of Rotterdam used “economically most favorable bid” instead of the lowest price as award criterion. The bids where judged on the following parameters:

Table 1. award criteria.

Award Criterion	**Points**
LCC value	500
robustness of design (lessons learned from Handbook Quay wall design)	75
Quality of systems engineering	100
Sustainability	75
project management plan	75
Maintenance plan and maintainability	100
Planning	75
Total	1000

The LCC value is the most important parameter. It is the sum of the financial bid and the net present value of the maintenance over the coming 50 years. The Port of Rotterdam calculated the maintenance costs by itself although the contractors were asked as well. It happened that the differences between the contractors and Port of Rotterdam calculations were large, The main reason was the amount of maintenance experience that was calculated by the Port of Rotterdam, where contractors used a more theoretical approach. Maintenance costs for quay walls with a combi wall foundation (as designed by all companies) are mainly influenced by corrosion prevention, which has to be done by cathodic protection on the combi wall and by coating on the quay wall furniture like ladders and especially the fender system.

THE WINNING TECHNICAL SOLUTION

The economically most favorable bid was offered by the company Van Hattum en Blankevoort (VHB); see figure 06 for the cross section of the design. The key success factor in this bid was the alternative fender system. Instead of using the steel reference fender system mounted on the quay wall, Volker InfraDesign the design department of VHB designed an integrated concrete fender system, consisting of prefabricated steel fiber reinforced high performance concrete (SFRHPC) slabs. The slabs have a thickness of 8 cm. The used concrete mixture has a very high resistance against peak loads and is very hard to penetrate. It is often used at locations with high peak loads. Typically one should think of scrap yards, bunkers, bank vaults. But steel fibre reinforced high performance concrete is also not vulnerable to wear and tear and this combination makes it the ideal product to make a quay wall barge proof.

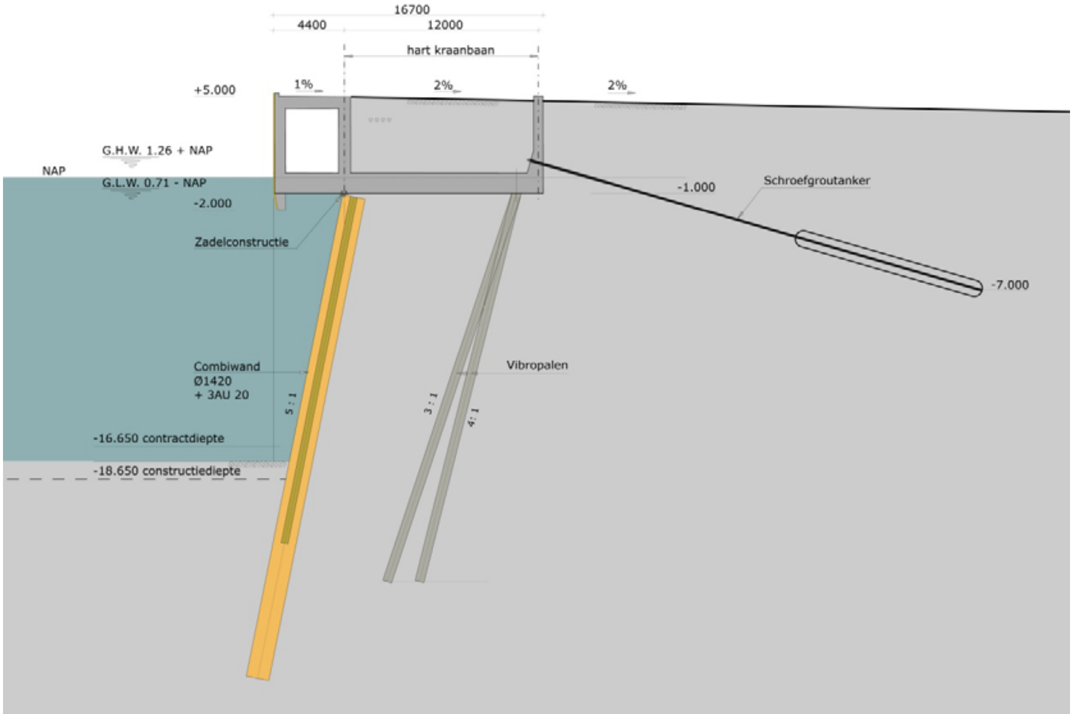

figure 06 cross section of quay wall EMO M5

Convincing the Port of Rotterdam, SFRHPC is a better rigid fender

Because it was an entirely new idea, much effort has been put into convincing the Port of Rotterdam that it is in fact a good solution for the port.

SFRHPC has been used in lock gates, so using it in marine engineering is not totally new, but the proposed fender system is a real innovation in port construction.

Research at Delft University shows that SFRHPC is indeed a very tough material. Figure 07 (Markovic, 2006) shows the behavior of normal concrete compared with high performance steel fiber reinforced concrete

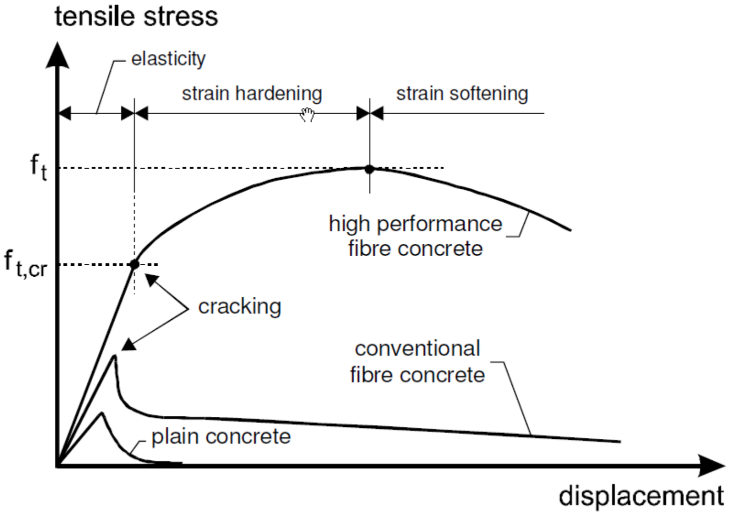

Figure 07 comparison of uniaxial tensile behavior obtained in testing of plain concrete, conventional fiber concrete and high performance fiber concrete

Research by the ministry of defense in the Netherlands also indicates that SFRHPC has a superior behavior under explosive loads. As can be seen in figure 08 a and b. Figure a shows a normal reinforced concrete slab (a so called 'stelcon slab'). Figure 08b shows a similar slab made of SFRHPC. Both slabs are exposed to the detonation of a contact explosive with a detonation gas pressure speed of over 4000 m/s. As can be seen, the normal reinforced concrete slab is heavily damaged, while the SFRHPC slab has only minor surface damage.

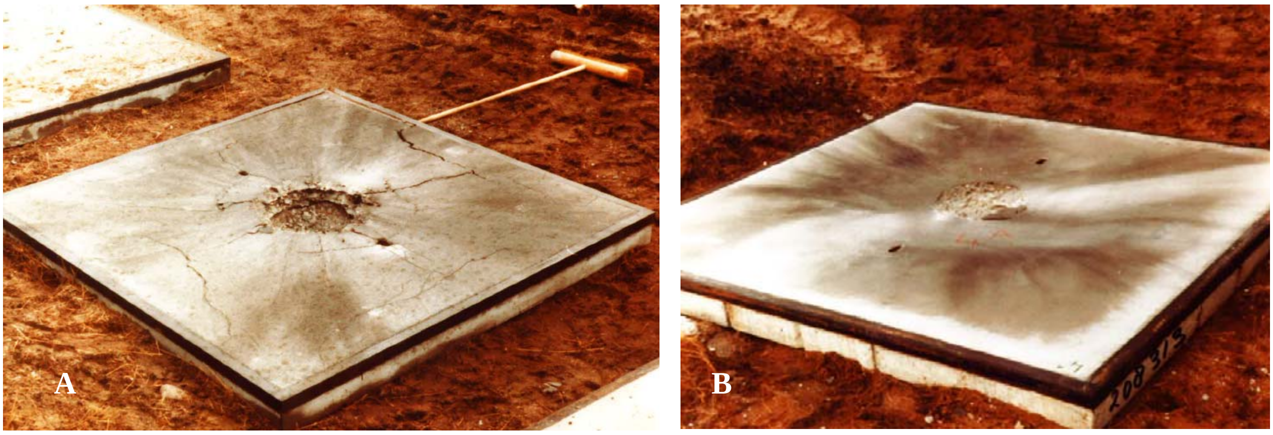

Figure 08: Impact tests Dutch Ministry of Defense. A is normal reinforced concrete, B is SFRHPC (Source: A.Verhagen - Breda).

The third test to convince the Port of Rotterdam was a range of rather simple but effective experiments to observe the wear and tear resistance of SFRHPC. At the yard of Dutch contractor Bruil-Infra in the city of Ede, a large slab was in place for over a few years. This slab could be compared in mixture and elastically behavior with the proposed fender system on the quay wall.

On this slab VHB arranged a demonstration with a heavy trackhoe. The trackhoe abused the slab in various ways in front of a Port of Rotterdam delegation. It intensely turned with its steel tracks, line and point loads where simulated with the cutting edge of the bucket and concrete masses of 950 kg were dropped on the plate. All these actions only generated some dust, but no harm to the SFRHPC plate.

Figure 09: left: testing with trackhoe, right: maximum wear and tear

Protection of sea going vessels

Obviously the SFRHPC plates would protect the quay wall against the impact of barges, but would also cause damage to moored sea going vessels as the hulls of these vessels would be scraped by the concrete while they move with the tide and loading activities. To prevent damage to moored vessels UHMW-PE strips where placed at a 10 m interval. These are the same strips as the Port of Rotterdam uses on the traditional steel fender system, but broader.

The strips have a thickness of 70 mm and protrude 40 mm from the concrete front. The strips have large bevels into the recesses that should make them less vulnerable against a scraping barge. If damage occurs or the wear on the strips is too heavy, they can be replaced. The strips are bolted to the concrete and divided in sections. On request of Port of Rotterdam the section below mean water level is a separate section. Divers are only required if a low section is damaged. Normal wear and tear is not expected that low on the quay, but a little higher with ships gunwale as the main damage factor.

The solution with the UHMW-PE plates makes the quay as safe as any other quay with rigid fender systems for sea going vessels to berth. Besides that, UHMW-PE provides better mooring conditions than Azobe fender systems due to the lower friction ratio between fender and hull coating.

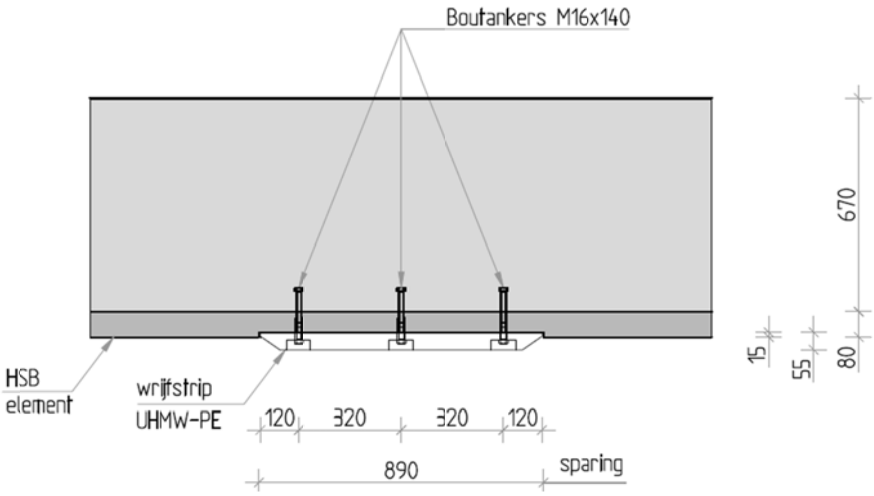

Figure 10: cross section of UHMW-PE fender plate ("wrijfstrip") in SFRHPC shell ("HSB element")

Environmental benefit

An additional advantage of this innovative fender system is that the gap between shore and ship is reduced from 400 mm to 40 mm. The smaller this gap is, the less chance for spill of product. Although all measures are taken by EMO, some coal or iron ore dust will fall in this gap and pollute the water bottom. Minimizing the gap minimizes the spill. Obviously EMO was very pleased with the solution as well.

Patent & Other possible use of the concept

Van Hattum en Blankevoort has obtained a patent on the innovation. The patent describes a wide range of applications. Beside as fender system, the SFRHPC can also be used on other locations with high chances of ship impact like bridge piers. Using an integrated SFRHPC cover makes the use of a separate fender system unnecessary. The patent has an open license, so any one can use the concept, but has to pay a small fee.

Experiences with the fender system

The Port of Rotterdam has used the quay wall and the fender system since summer 2012. Due to the economical crisis in Europe berth occupation is smaller than expected. The quay has been used by barges, inland vessels and some sea going vessels with the Weser Stahl (192x32m) being the biggest. Up to now no damage has been seen on the wall. The current observation is that captains are deterred by the concrete wall and moor their ships extra carefully.

The low LCC value of the SFRHPC fender system

Compared to the reference design of the Port of Rotterdam, the SFRHPC fender system has some advantages:

- Lower construction costs compared with the steel fender system.

- Expected lower maintenance cost due to absence of coating and horizontal beams.
- Fewer and faster visual inspections during entire lifetime
- No midlife replacement of the fender system. SFRHPC shell has same lifetime as main concrete structure.
- If damage occurs, it is easy to repair. Damage can be sawn out and the gap filled with steel fiber reinforced repair mortar.

Technical specifications of the SFRHPC fender plates

The technical specifications of the SFRHPC shell are determined by Volker Infra Design. The Strength class is C90/105 according to EN 206-1. The steel fibers are 12,5 mm long and 0,4 mm thick. Little over 75 kg fibers per m^3 is used.

The shell will be loaded by a mooring barge. This results in a 2500 kN force (by one corner of the rectangular bow) on a surface of 80 x 200 mm and thus a local pressure of 150 N/mm^2. The material is very capable in dealing with this. Cracking will be absorbed and divided over the surface by the steel fibers.

CONCLUSION

The combination of references to other (marine) use, the scientific research, the test results from the ministry of defense and the field tests with the trackhoe proved the suitability of SFRHPC as fender system to the Port of Rotterdam. As the fender system is cheaper in construction and will have almost no maintenance costs (no steel to be coated), it resulted in the lowest LCC value of all the bids. The Port of Rotterdam is convinced that the new fender system will behave better than traditional concepts and will adapt it in future developments where inland barges and sea going vessels have to be combined at one berth.

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