The safe use of cylindrical fenders on LNG, Oil and Container Terminals

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ABSTRACT

The PIANC 'Guidelines for the design of fender systems' MarCom report of WG 33 – 2002 specifies allowable maximum hull pressures for various vessels. Fender manufactures provide maximum hull pressures resulting from their fenders. The stated maximum hull pressures of cylindrical fenders exceed the recommended values by PIANC 2002 for gas carriers, oil tankers and container vessels. However, cylindrical fenders are in use for over 25 years in North West Europe on major container terminals without any complaints by masters, ship owners, pilots or any other stake holder.

In the Hamburg – Le Havre range only the Port of Rotterdam Authority had, mid eighties, these fenders (Delta Terminal) checked against the old fender guidelines. After PIANC 2002 release all new projects are equipped with panels with cone fenders or similar.

The maintenance department of the Port of Rotterdam has fairly bad experience with panel fenders as recently applied at the new container terminals and has quite positive experience with the 'old' cylindrical fenders.

The positive user experience with cylinders and the negative maintenance experience with panels lead to plans with cylindrical fenders on an LNG berth and on six oil berths. The actual ship-fender interaction was investigated by FEM calculations as these cylindrical fenders do not match PIANC 2002 recommendations. The outcome of these FEM calculations is that cylindrical fenders can safely be used for both LNG carriers and oil tankers.

This paper explains theseFEM calculations and the old calculations for the Delta Terminal and shows that cylindrical fenders can be used safely on liquid bulk terminals and gives a perspective for container terminals. The authors recommend that table 4.4.1 in PIANC 2002 will be updated.

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1. DESIGN AND USE OF FENDER TYPES ON QUAY WALLS IN ROTTERDAM

In the far past vessels were moored against wooden beams. Small rubber rolls were installed between the masonry and the wooden beam when some energy absorption was desired. Up to today dry bulk and break bulk vessels in Rotterdam are moored on either a wooden fender system, or a HDPE system, both fully rigid without energy absorption. These vessels don't need an energy absorbing fender system (Broos, 2013).

In the mid 80's Rotterdam started the development of Europe's largest container terminal, the ECT Delta Terminal. This modern container terminal then was fitted out with cylindrical fenders. The usability of these fenders was proven by intensive calculations by Lloyds in 1989.

In 2005 Rotterdam started with the construction of the Euromax container terminal, which was outfitted with cone fenders with large panels. Quay walls of the same design with similar fenders were built at Maasvlakte 2 for the container terminals RWG and APM. See figure 1.

Figure 1: Overview Maasvlakte 1 and 2 with container terminals (photo PoR GIS database)

1.1 Use of cylindrical fenders in North West Europe.

Cylindrical fenders are also widely used in the surrounding ports in North West Europe. Sometimes combined with floating foam fenders (the German Swim Fenders), often just with cylinders. Today these fenders are still in use to the satisfaction of the Port Authorities, the pilots, the ship owners and the Terminals. New projects however are often equipped with panel fenders.

Figure 2: Cylindrical fenders at Delta Terminal Rotterdam (photo PoR)

1.2 New container terminals and cone fenders with panel

The massive step in cone fender systems with large panels in Rotterdam comes from Euromax container terminal. For which a 1900 m deep sea quay wall was constructed between 2005 and 2007 on the most northern part of Maasvlakte 1. The choice for using fender panels was clearly derived from the hull pressure criterion stated in PIANC 2002. During the construction of Maasvlakte 2, 2.2 km of the same cross section, with the same fender system has been built for both RWG and APM container Terminals.

Although these quay walls are primarily designed for deep sea, there is a clear mixed use of the facilities by barges, short sea and deep sea vessels. As a result of the use by barges, 30% of the fender panels are equipped with ladders in or on the panel.

Figure 3: Damaged fender panels at Euromax Container Terminal Rotterdam (Photos PoR)

1.3 Maintenance of fenders

The asset management department of port of Rotterdam experiences differences between the fender systems. At the Delta terminal there is hardly any damage to the cylindrical fenders. Once in a while a fender is heavenly hit, the chain breaks and the rubber cylinder sinks directly in front of the quay wall. A diver is send down, the cylinder is hoisted to the surface and with a new shackle the fender is reinstalled. The cost of the entire operation is below 5,000 Euro without downtime at the terminal. Recently, after 25 years of operation, at the end of their technical life time, the chains and bars of the cylinders are replaced; the rubber cylinders are still in good condition and were completely maintained.

At the panel fenders a few damages occur very often:

- Damage to the PE sheets covering the panel. The sheets on the sides of the panel are so often damaged that these sheets are not be replaced any more. Figure 3;
- Damage to the steel of the fender panel, mainly due to bow contact by barges or feeders;
- Corrosion of the panel, leading to leakage;
- Damage to the platform that connects the in panel ladders with the quay front, mainly caused by mooring lines;
- Damage to the ladders on the side of the panel;
- Rupture of rubber cylinder by shear force, average 2 per year in Rotterdam;
- Breaking chains, mainly by ropes or by ship contact;
- Loss of tension in the chains, reason unknown but a lack of action will damage primarily the rubber and the walk platform towards the shore.

For most of the repairs, it is necessary to remove the panel from the quay wall, bring in a spare panel. There is downtime at the terminal and the costs of a repair action are on average between 50,000 and 70,000 Euro.

The amount of damages to cylinders is significantly lower than damage to fender panels. Over the last ten years less than 5% of the cylinders were teared off and are brought back. Only at Euromax 70% of the panels has been removed, repaired and installed back to the quay.

1.4 Experience of Pilots with the different fender systems

The pilots don’t experience real differences during berthing operations. The only aspect mentioned by pilots is, when mooring tankers, with the steel lines connected but slack so the lines are under water, the spring lines can get stuck under the cylinders when heaved. If such happens, the line has to be released; that requires quick release hooks for steel spring lines.

1.5 Experience on container terminals with the two fender systems

When a vessel is moored alongside a quay wall there is a different behavior between rubber cylinders and HDPE panels. Between the rubber cylinders and the concrete quay wall, as well as between the ship hull and the fender, there is friction. When properly moored this friction dampens the surge motions of a vessel. The HDPE sheets on the panels with cone fenders generate hardly any friction. Especially with passing vessels it is easier to reduce ship movements with cylindrical fenders (statement Rotterdam Boatmen - KRVE). Less surge motion at container terminals means a more efficient loading or unloading operation.

In Rotterdam often ShoreTension® is used to improve the mooring of Ultra Large Container Ships. At terminals with cylindrical fenders the pair of ShoreTensions is applied to the breasting lines, pulling the vessel a little into the rubber, reducing both surge and sway (figure 4). At terminals with fender panels, a pair of ShoreTensions is applied on the spring lines to reduce surge motion. Sway motions are not dampened in this way, but hinder by sway for operations is only limited.

Figure 4: Shore tension applied at Delta Terminal (Photo PoR-Erik Broos)

Most terminal operators only work with one fender system, so up to now this difference has never been an issue in project development. But from an operational point of view cylinders are recommended.

2. THE DEVELOPMENT OF THE SMALL SCALE LNG TERMINAL IN ROTTERDAM

As LNG is demanded in smaller volumes, both for small ports, power plants and especially for bunkering sea going vessels, the Port of Rotterdam developed a small scale facility together with Gate Terminal. This was a quay wall in a separate basin, the Yukonhaven (Broos, 2016). Oil bunkering in Rotterdam is always executed with barges and such is also foreseen for LNG in the future. So this Small scale facility will receive a mixture of barges and small sea going vessels (LOA up to 160 m in phase 1 and 210 in phase 2). Design according to SIGTTO standards will result in the need for energy absorbing fenders. Being the home base for bunker barges, there will be a lot of inland vessels to the quay as well. This, in combination with the experiences on the container terminals lead to a design with cylindrical fenders.

2.1 The issue: cylinders do not match PIANC recommend hull pressures

When designing cylindrical fenders one specific aspect arose. The cylinders will result in a hull pressure more than twice as high as the PIANC Guidelines for the design of fender systems 2002 (PIANC 2002) recommends in table 4.4.1

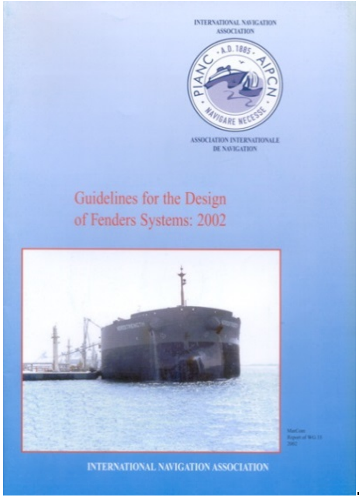


Table 4.4.1. Hull Pressure Guide

Type of vessel	Hull Pressure kN/m²
Container vessels 1st and 2nd generation	<400
3rd generation (Panamax)	<300
4th generation	<250
5th and 6th generation (Superpost Panamax)	<200
General cargo vessels	
=/< 20.000 DWT	400-700
> 20.000 DWT 40	<400
Oil tankers	
=/< 60.000 DWT	<300
> 60.000 DWT	<350
VLCC	150-200
Gas carriers (LNG /LPG)	<200
Bulk carriers	<200
SWATH	}
RO-RO vessels	} these vessels are usually belted
Passenger Vessels	}

Figure 5: PIANC 2002 table 4.4.1 Hull Pressure Guide

Hull pressure resulting from cylindrical fenders will be around 400 to 500 kN/m^2. However, looking to the table only 200 kN/m^2 is allowed for gas carriers. So there is a mismatch, looking further into the table, there is also a mismatch between large container vessels and cylindrical fenders. However no ship owner or terminal ever complained about the cylindrical fenders damaging the vessel in the last 25 years in Rotterdam, nor in the surrounding large ports. This increased confidence about the use of cylindrical fenders, but also started a tough discussion with the launching customer of the Gate Small Scale Terminal about the fender design, stating that it is not an industry standard and therefor unacceptable. At this point TNO was contracted to examine the real impact of cylindrical fenders on LNG carriers.

The PIANC 2002 table 4.4.1 is also present in the British Standard (BS 6349-4:2014, paragraph 4.6.2 table 3). Where PIANC is still a recommendation, the British Standard is a design code.

2.2 The FEM analyses executed for Small Scale LNG

The analyses done by TNO started with a desk design of the weakest ship web frame section of the weakest possible vessel that could come into contact with the fenders (see figure 6). The ship side plating is modelled using Mild Steel properties for the upper strake (yield stress 235 MPa, tensile strength 400 MPa and 'minimum fracture strain 22%) and AH 32 for the remainder (yield stress 315 MPa, tensile strength 440 MPa and 'minimum fracture strain 22%), as per Lloyd's Register material specification. This is therefore a conservative design.

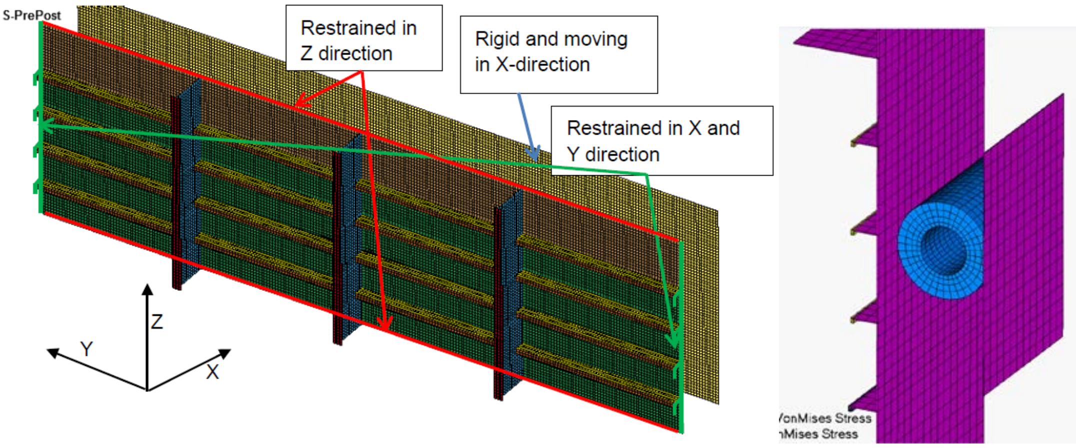


Figure 6: design hull section FE model, original case: no constraints in x-direction on web frames

The design of the fenders was determined by the engineering consultant from the Port of Rotterdam Authority. The physical behavior of the cylindrical fenders was modelled according to lower bound data provided by supplier ,Shibata (2017), see figure 7.

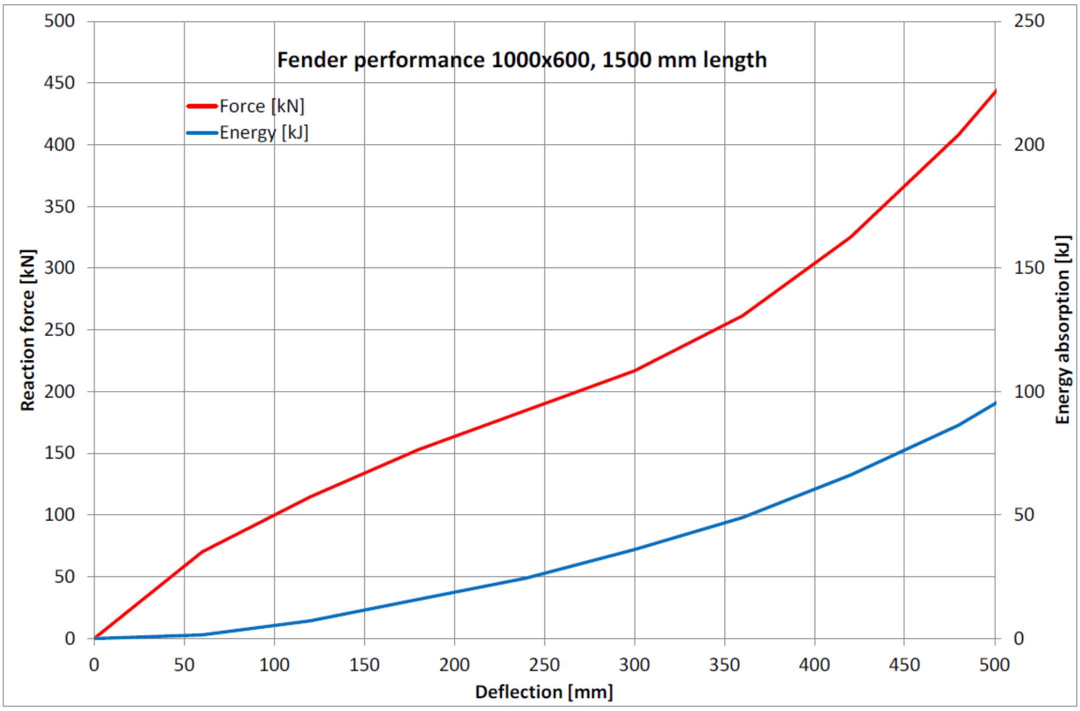
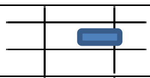
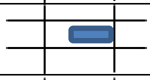
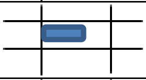
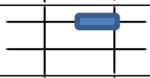
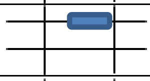
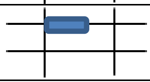


Figure 7: Energy-Displacement diagram 1000 x 600 fender, 1500 mm length, according to supplier catalogue

Then the ship hull section was impacted at all possible positions by the cylindrical fender with various cylinders. The criteria for stating the limit deformation on the fenders is based on the allowable stress level in the side structure. This is chosen such that the Von Mises stress shall not exceed 90% of yield stress. The operations for which the analyses are performed are normal operating conditions, hence plasticity shall not be accepted. From the deformation of the fender, the absorbed energy can be retrieved. This shall be compared with the energy absorption requirement from the berthing analysis.

Table 1: Overview of results of series without constraint of web frame in x-direction. Results shown where ship side structure reaches 90% yield stress criterion

Case	Impact location	Compression [m]	Energy [kJ]	Reaction Force [kN]	Local Y stress [MPa]*
I		0.41	47	250	272
II		0.44	55	265	281
III		0.44	55	270	282 (near web frame)
IV		0.34	32	185	283
V		0.35	34	200	282 (@ 1/3 of long'l)
VI		0.33	30	180	282 (near web frame)

A secondary outcome was that the stiff cylinders, with a resulting hull pressure of 700 kN/m^2 will give damage to the ship hull. The stiffness of a cylindrical fender is determined by the ratio between inner and outer diameter. It was concluded that only the 'soft' cylinders can be used safely. For Gate terminal that means 1000-600 mm cylinders are good but 1000-500 mm cylinders are not good under all conditions.

The outcome of the study was to the full satisfaction of Gate Terminal, Shell the client behind Gate and PoR. The cylindrical fenders are installed and the terminal is in operation since September 2016. See figure 8.

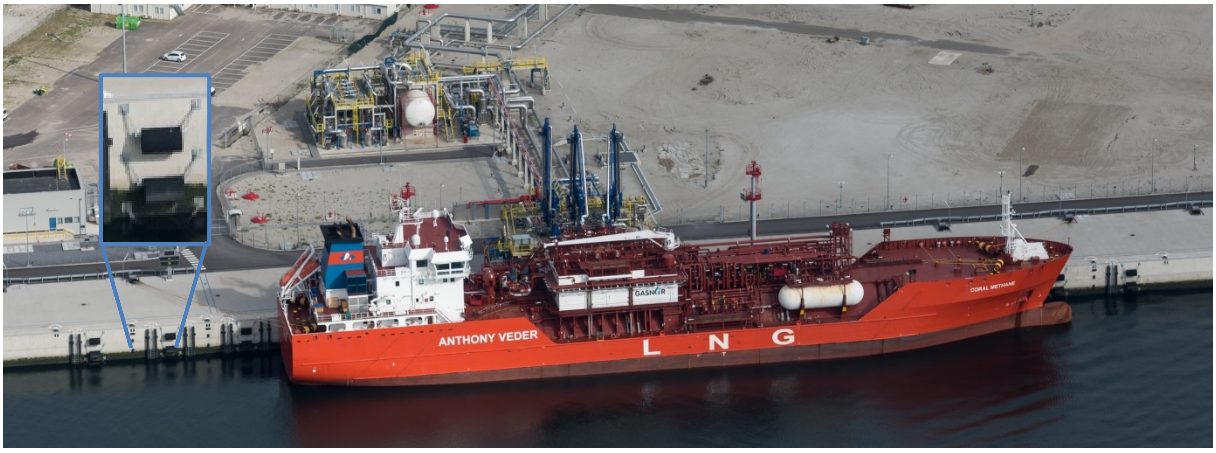


Figure 8: Gate Jetty 3, the Small Scale facility (Photo Paul Martens).

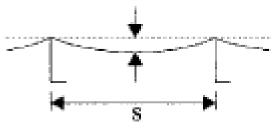
3. THE OIL TERMINAL (HES HARTEL TANK TERMINAL)

Knowing the outcome of the LNG Study for Gate Terminal, PoR decided to design the new HES Hartel Tank Terminal also with cylindrical fenders at the quay wall. This terminal will give berth to the entire vessel range from VLCC down to 70m 'long' coasters. Again TNO was asked to calculate if cylindrical fenders could be used safely.

Again FEM models were made, in this case for VLCC, Aframax and Handymax type of vessels. The other vessels in between are judged on basis of expert judgement, as there is not a large difference in the construction of the various class tankers.

This time the vessels were judged against the clear damage criterion. Guidelines for a damage criterion can be found in IACS (2013), the Recommendation No. 47 Shipbuilding and Repair Quality Standard - Rev.7 June 2013 of the International Association of Classification Societies. Chapter 6 in this document addresses fabrication and fairness of plating between frames (Table 6.10). The table shows that 5 mm permanent deformation of the shell plate is allowable for fore and aft parts of the structure (see Table 2 below). This criterion is used as damage limit.

Table 2: Damage criterion for fairness of plating between frames (from Table 6.10 [X]).

Item		Standard	Limit	Remarks
Shell plate	Fore and Aft part	5 mm	8 mm	

This study determined the fender impact on the vessel following the PoR design berthing velocities derived from Roubos 2017 & 2018. After that, the berthing velocity was determined at which the IACS damage criterion was reached. The outcome of this study is summarized in table 3, the used fenders are D= 1400 mm, d = 800 mm and L= 2200 mm.

Table 3: Standard sea going tanker berthing dynamic results.

Ship type	Normal berthing Impact speed PoR [m/s]	Maximum fender deformation [mm]	Maximum fender force [kN]	IACS 5 mm damage impact speed [m/s]	Maximum fender deformation [mm]	Maximum fender force [kN]
Coaster	0.15	90	254	0.27	180	346
Handysize	0.15	173	340	0.27	366	529
Handymax	0.12	188	354	0.18	316	468
Panamax	0.12	214	376	0.18	359	520
Aframax	0.10	256	414	0.15	426	608
Suezmax	0.10	341	498	0.13	469	669
VLCC	0.08	388	556	0.10	504	724

This study again proved that cylindrical fenders can be beneficially used at oil terminals for the entire range of vessels under “Port of Rotterdam conditions”, which means sheltered conditions, deployment of sufficient tugs and experienced pilots. Secondly one has to consider the fact that the berthing velocities are determined on jetty and dolphin structures. At a quay wall there is also a water cushion that reduces the berthing velocity. Thirdly at a quay wall multiple fenders absorb the berthing energy and there is a low angle at the moment of impact (Roubos 2017 & 2018).

Hull pressures on oil tankers

The maximum occurring hull pressures can easily be calculated. The compression of the fenders is know, the contact surface with quay wall and vessel is known. This results with the data from table 3 in table 4. Again for the HHTT fenders (D= 1400 mm, d = 800 mm and L= 2200 mm).

Table 4: hull pressures by cylindrical fender during berthing

Ship type	Design Impact speed PoR [m/s]	Maximum fender deformation [mm]	Contact height [mm]	Pressure [kPa]	IACS 5mm damage impact speed [m/s]	Maximum fender deformation [mm]	Contact height [mm]	Pressure [kPa]
Coaster	0,15	90	141	817	0,27	180	283	556
Handysize	0,15	173	272	569	0,27	366	575	418
Handymax	0,12	188	295	545	0,18	316	496	429
Panamax	0,12	214	336	508	0,18	359	564	419
Aframax	0,10	256	402	468	0,15	426	669	413
Suezmax	0,10	341	536	423	0,13	469	737	413
VLCC	0,08	388	609	415	0,10	504	792	416

As clearly can be seen from table 4 that berthing velocities that result in no damage to the vessel, actually result in higher pressure on the ship hull than the critical berthing velocities. The lighter the ship, the larger this difference is. This is because the cylindrical fender reacts more stiff when hardly compressed. This clearly indicates that using hull pressure as a design criterion for cylindrical fenders is not the right approach. The Port of Rotterdam impact speeds result in a safe berthing with hull pressures way above the recommended values in PIANC 2002 table 4.4.1. and with no damage to the ships. There is however at this moment not a simple replacement available for this table.

The majority of the load on the hull is taken by the web frames and stiffeners, only a small percentage (roughly 5%) is taken by the hull membrane. The worst case is a cilindrical fender directly on one stiffener, not as might be expected in the middle of the frame on only the hull plate.

Therefore we can conclude also that if a panel fender is properly designed, and significant larger than the spacing between the stiffeners, the load will be entirely taken by the stiffeners (and the web frames). This makes hull pressure an irrelevant criterion for panel fenders as well.

4. PERSPECTIVE FOR CONTAINER VESSELS

The last standing question is obviously what to do with the container vessels. In the 80’s Lloyds proved the safe use of cylindrical fenders on the large ships at that time. Lloyds actually checked a 280 m long 4000 TEU vessel for use on super cone panel fenders and the use with cylindrical fenders. This study concluded that cylinders could perfectly well be used without harming the vessels. As an outcome the Delta Terminal was equipped with cylindrical fenders 1400-800 mm. As stated, these fenders are in use to the satisfaction of almost all stakeholders. Only barge shippers don’t like the cylinders because they can’t reach the quay top easily. Therefor PoR designed a special ladder on small buckling fenders, see figure 9. In this way also the stepping criterion stated by the ADN (2008) can be met.

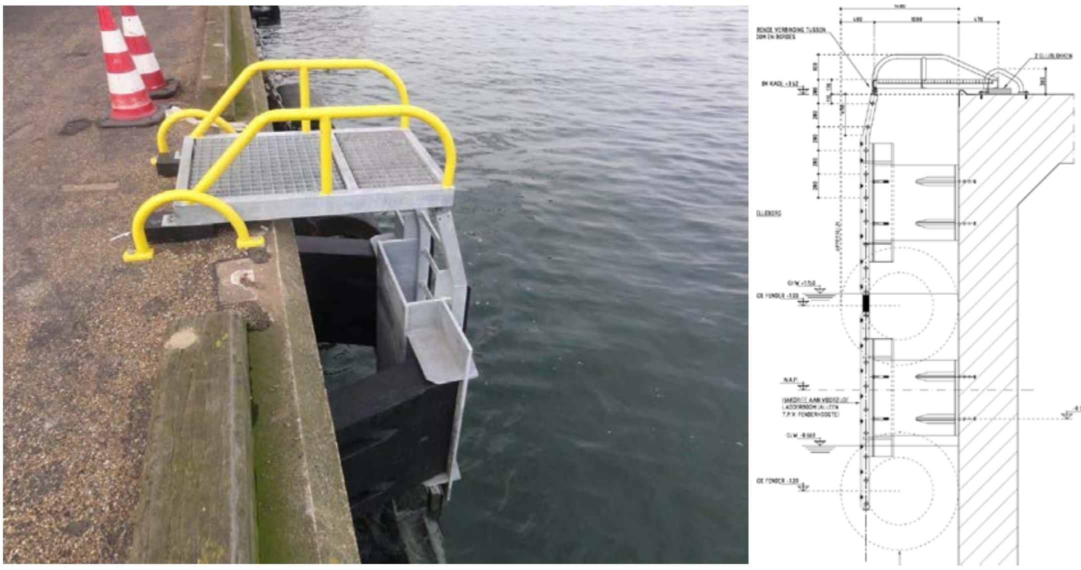


Figure 9: barge ladder between cylindrical fenders to provide barge access (photo PoR)

To verify that cylindrical fenders indeed can be safely used for the entire range of container vessels (as experienced in Rotterdam) further FEM calculations are currently being executed. The preliminary findings will be published separately as they are expected April 2018. On the conference there will be a preview on the outcome.

5. CONCLUSIONS & RECOMMENDATIONS

Cylindrical fenders can be used to berth and moor liquid bulk tankers ranging from small oil tanker towards large LNG carriers or VLCC.

It is expected that in the near future additional FEM calculations will confirm daily practice that all container vessels can berth safely on cylindrical fenders. For smaller vessels it has been proven in the 80’s

As dry bulk and break bulk vessels can moor safely on rigid wooden fenders, they can also moor on cylindrical fenders.

The occurring hull pressures when using cylindrical fenders, are much higher than recommended by PIANC 2002 and the BS-6349-4. This study indicates that these hull pressures are however of no risk to the vessels. Therefor it is recommended to replace these tables into a more suitable criterion. The best way to replace these tables should be subject to further study in which the Port of Rotterdam Authority wants to participate.

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