PORT AND OCEAN ENGINEERING UNDER ARCTIC CONDITIONS
TECHNICAL UNIVERSITY OF NORWAY

MAINTAINING STABILITY OF A SLENDER ORE-LOADING PIER FOR SHIPS OF THREE TIMES DESIGN TONNAGE. ANALYSIS AND FENDERING

Anton Brandtzæg
Dr.techn. professor, retired

Technical University of Norway

Trondheim
Norway

INTRODUCTION

The greater part of the iron ore from the well known Swedish mines at Kiiruna is being shipped through the Norwegian port of Narvik. Here a new ore-loading pier was built shortly after World War 2, intended to load ships of up to 27 000 dwt, somewhat bigger than actually used at the time. However, by 1965 - 66 ships of 70 000 to 80 000 tons were berthing at the pier, and the owners were concerned about its stability.

Fig. 1 shows the pier as it was in 1965 in full drawn lines in plan and elevation. Fig. 2 shows the cross-section of the pier, with ships of 1951 and 1965 alongside. The pier structure is high and narrow. The steel piles carrying most of the concrete pillars supporting the pier are standing in very soft and partly quick clay and silt and resting on the rock surface some 30 to 35 metres below the quay deck, on top of which the superstructure, carrying the conveyor belts for the ore, rises another 15 metres. The transverse spread of the piles on the rock base is only about 20 metres. The mass of the biggest ship is about 4 times the mass of the entire pier structure from top of pile to top of superstructure, and 6 times the mass from the top of the concrete foundations up. One might well have misgivings about the ability of the pier to withstand even a mild jolt from such a ship. Moreover, the bigger ship required the reach of the cross-conveyors to be increased from 11 to 18 metres, while the weight of ore per hour was increased to 2,5 times the basis of design.

Since any damage to the pier putting it out of service for some length of time would imperil the jobs of many thousands of workers and cause very great losses to the owners and to the community of Narvik, plans

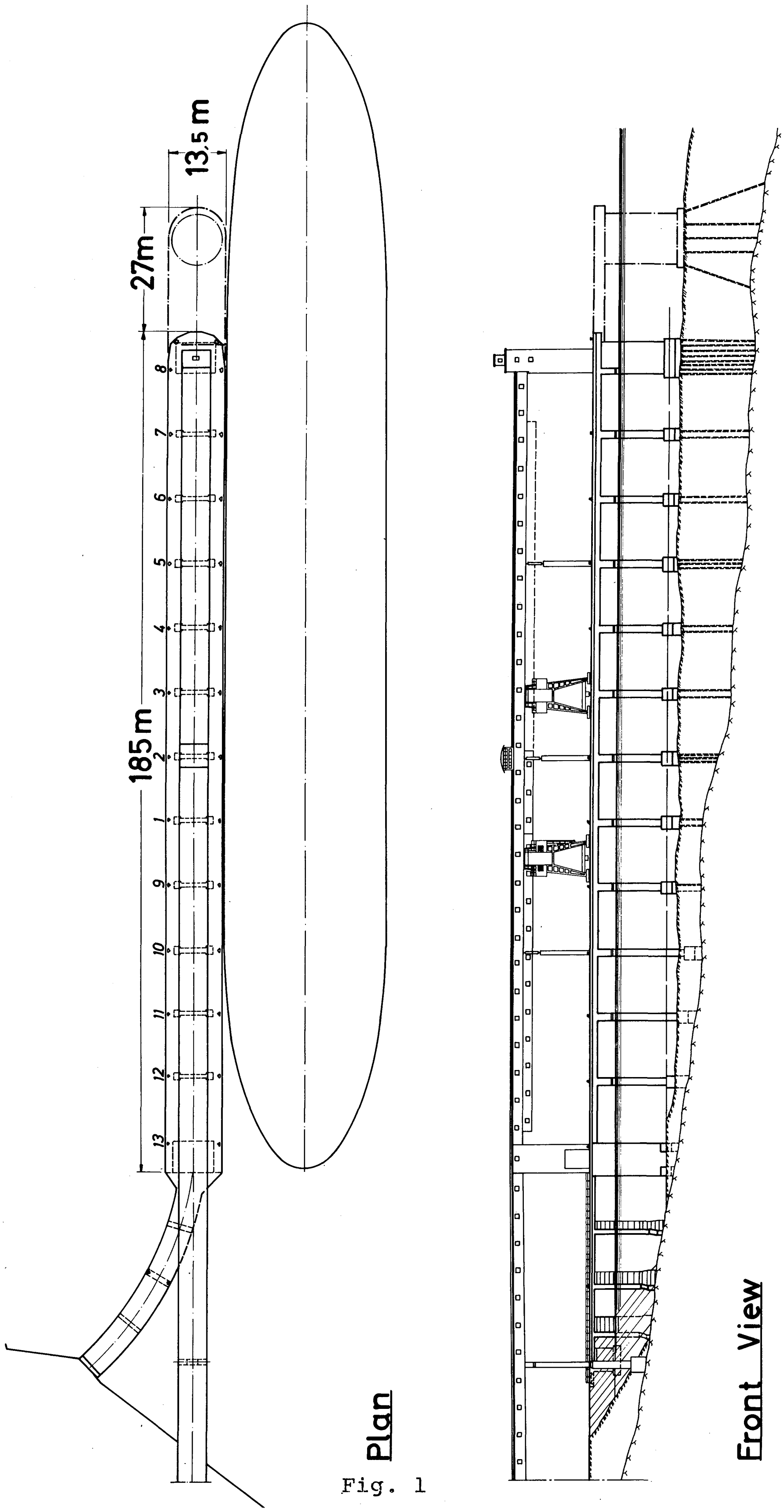

Fig. 1

for increasing the stability of the pier were called for. Such increase may be achieved either by providing new lateral support or by reducing possible impact forces by means of energy-absorbing fendering, or by a combination of these measures.

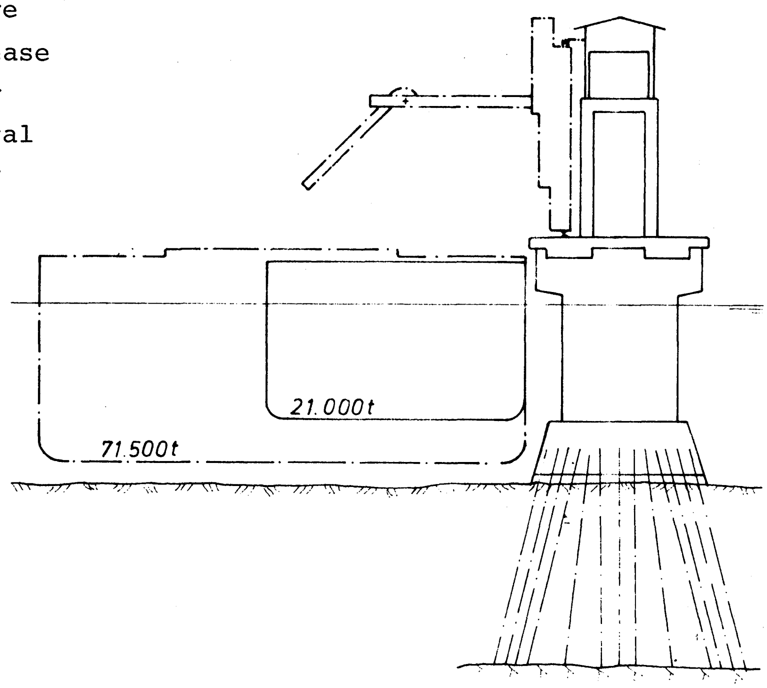

Fig. 2

PRELIMINARY ANALYSIS

A. Impact Energy and Force

The basic problem is what amount of impact energy should be assumed for the design. The problem has no exact solution. It might be logically solved by statistics, if sufficient data were available, which they are not. Attempts at deriving a solution from an analysis of the many possible causes of impact seem futile, since obviously human shortcomings make up a very important part of such causes. Nevertheless, a basis of design must be arrived at, even if it has to be by assumptions, not too adequately supported by such facts as can be established.

In the present case two facts were considered:

a) Currents and waves in the harbour are insignificant. But wind velocity of 25 m/sec (about 50 knots) against the west side of the pier may occur. Arriving ships are taken to and from the pier by tugs. A ship of some 70 000 dwt drifting freely sideways before the wind over some 30 m distance, might hit the pier with a total energy of about 500 metre-tons if the point of impact were close to the center of gravity of the ship (Case A), and about half of that amount if the point of impact were about half way between the center of the ship and its bow or stern (Case B). However, even in an emergency the tugs should be able to reduce the energy considerably. It does not seem unreasonable to expect a reduction by up to 50 %. By such reasoning the minimum figures in Table I were arrived at.

Table I

Impact energy and force adopted for the analysis

	Case A: Impact close to middle of ship's length		Case B: Impact close to 1/4-point of ship's length	
	Energy mtons	Force tons	Energy mtons	Force tons
Minimum	250	1160	125	580
Maximum	370	1720	185	860

b) Heavy impact has been known to occur elsewhere with very little wind or current. An example is the well known case at the Finnart Ocean Terminal back in 1960, where a ship with displacement 52 000 tons hit the pier with an impact energy of about 160 metre-tons. The velocity of current was about 1/4 knot along the pier, the wind force was about 1 beaufort, and the impact was well towards the stern of the ship. While this case may belong to the "accident class", it did happen, and if it should happen in Narvik, this classification would not much alleviate the consequences of a failure of the pier. By adjusting the figure from Finnart to the greater displacement of the ships considered here, the impact energies listed as "maximum" in Table I were arrived at.

The figures in Table I were used as an indication of what was desirable to achieve in the way of stability of the pier, if it could be done with reasonable expence. The impact forces stated in the table were calculated from the energy figures on the basis of a preliminary assumption as to the energy absorbing capacity of the fendering.

B. Stability of the pier

Only the pier head is exposed to a Case A impact, since along the pier only the curved part of the ship's side can deal a concentrated blow (Case B). In both cases the force will be distributed to the various pillars by the quay deck. A rough preliminary calculation based on Table I showed the minimum and maximum impact forces on the pier head pillar (Case A), to be 990 tons and 1460 tons respectively. The greatest force transmitted to any one of the other pillars by a Case B impact was estimated to be minimum 180 tons and maximum 270 tons.

On the basis of some simple pullout tests made on a few foundation piles during construction, a pullout impact force of 10 tons was allowed on any pile, corresponding to an allowable horizontal force at deck level on the pier head pillar of 790 tons and on the others 280 tons, with very slight margin of safety.

C. Conclusions from the Preliminary Analysis

a) To withstand impact forces of the order og magnitude stated above, the pier head needed additional lateral support as well as efficient fendering. A supporting dolphin as indicated in dotted lines in Fig. 1 was decided on. It will eliminate the danger of a Case A impact on the pier head besides giving it direct support.

b) For the rest of the pier,fenders with energy absorbing capacity about as assumed in the analysis should be sufficient.

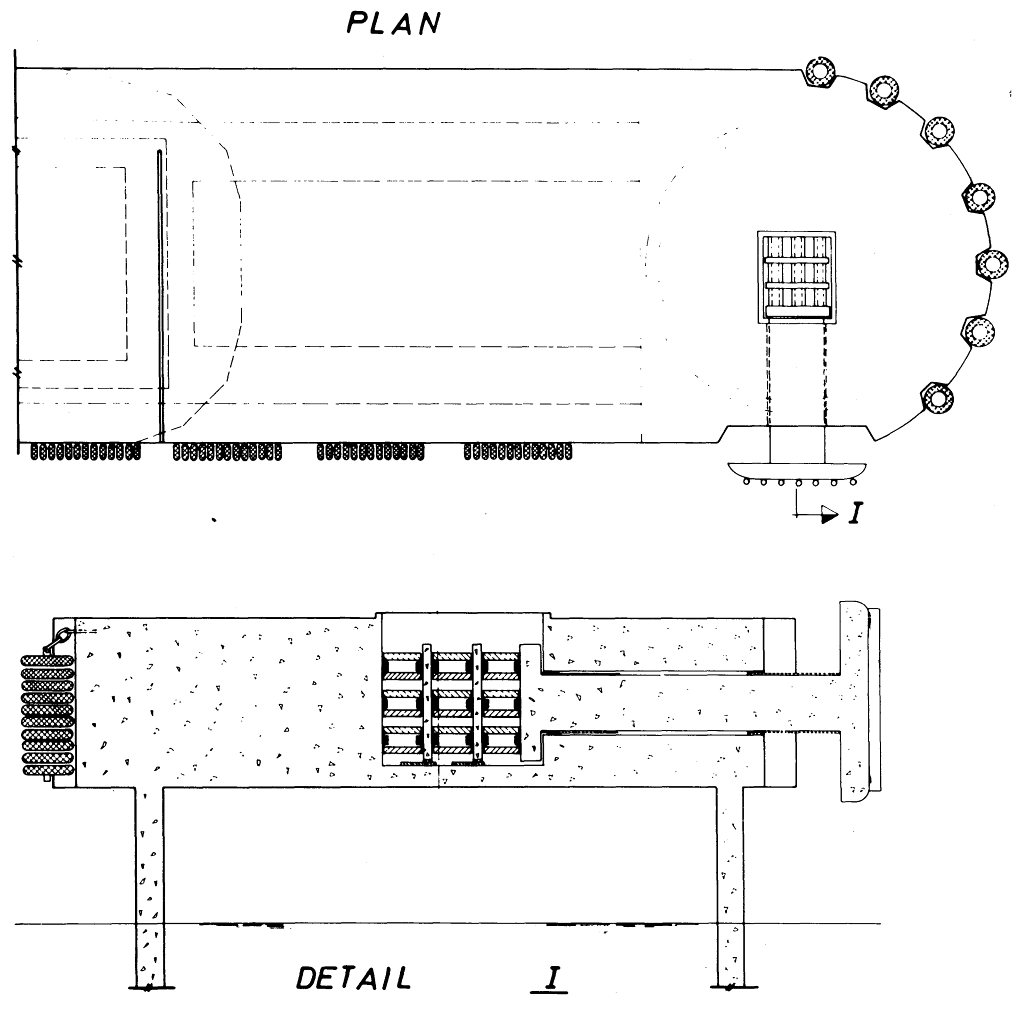

Fig. 3

FENDERING

a) Fendering in or on the dolphin

The dolphin was designed to have double safety against overturning under an impact force of 400 tons. This should be made to correspond to the minimum impact, Table I, Case A, while at the maximum, the force must still be well below 800 tons. This required a very efficient fendering.

At first it was intended to construct in the dolphin itself (Fig. 3) a fender consisting of a large concrete piston, butting against a battery of 24 axially loaded hollow rubber cylinders, 18" and 9" diameter and length 27". This would satisfy the above requirements. The scheme had, however, to be abandoned, because a test of one cylinder showed very serious buckling at less than half the design load (Fig. 4).

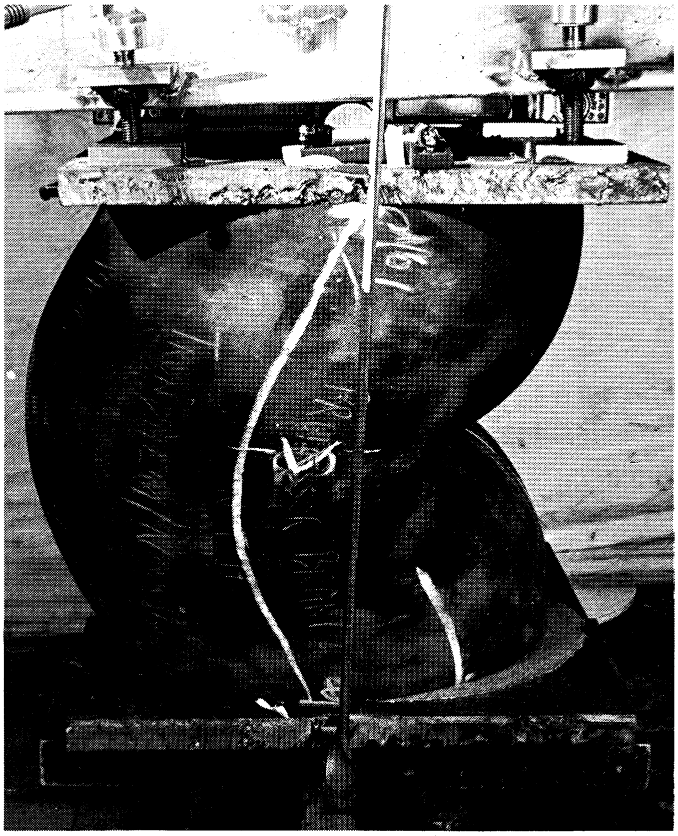

Fig. 4

The problem of fendering on the dolphin finally was solved by means of the Japanese made Seibu rubber fender, with four units combined as shown in Fig. 5 and Fig. 6. These large hollow rubber units have exceptionally high energy-absorbing capacity compared to the impact forces involved.

b) Fendering along the pier itself

Some very special requirements limited the choice of fendering system. First, nothing must protrude more than 60 cm beyond the edge of the concrete quay slab, so as to not reduce the reach of the loaders. Secondly, continuity of loading operation limited access to the quay front to the brief intervals between departure of one ship and berthing of the next. Thus, for instance, fenders supported by piles were excluded.

Many terminals for big ships are provided with elaborate fendering only at corners and other points where impact from ships seems most likely to hit. In the present case it was felt that sufficient fendering should be provided wherever a ship might touch.

As stated, only the curved parts of the ships hull towards stern or bow can deal a concentrated blow to points along the side of the pier. Therefore the minimum efficiency of any fendering will depend also on the curvature of the hull at the level of the fenders, as may be seen from Fig. 7. After some hulls had been studied, an average radius of curvature of 58 metres was assumed for the design.

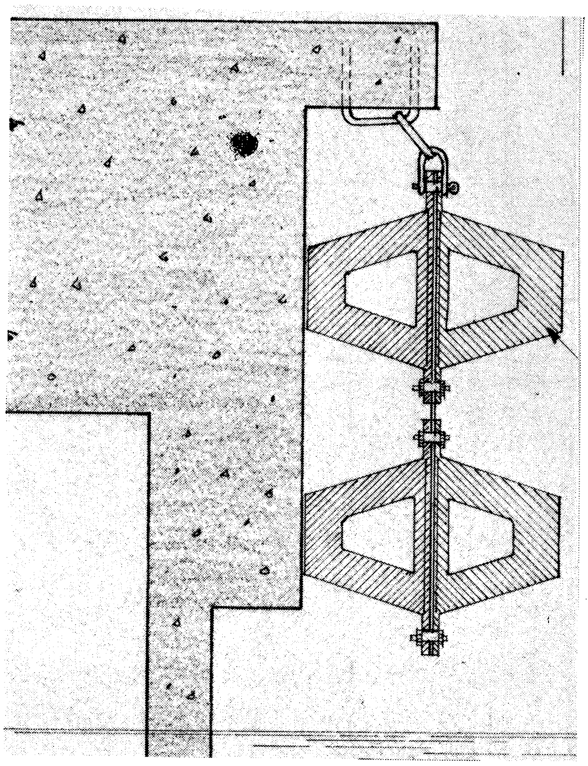

Fig. 5

In total six different fender types were investigated. Here only two of them will be discussed, the Seibu fender and the Cordkapp fender. The latter is seen in Fig. 6 as secondary fendering on the dolphin. It is less sophisticated but also less costly than the former. Each of these Cordkapp units consists of a number of heavy truck tires, filled with pieces of cut cord, strung on a steel center rod and compressed axially to about 70 % of the original length. Under pressure normal to the axis

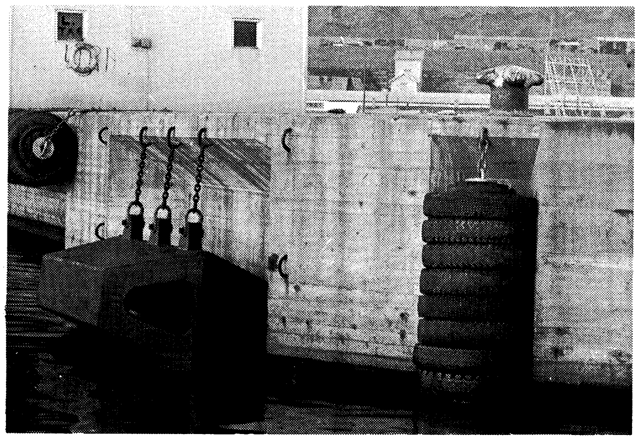

Fig. 6

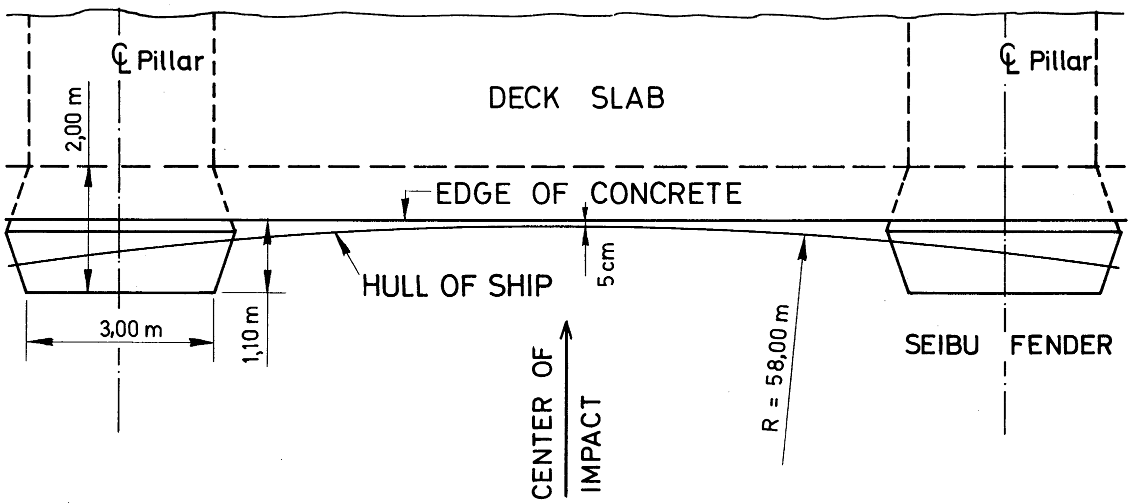

Fig. 7

they can absorb some 7 or 8 metre-tons of energy per metre of length of the unit. The corresponding force may be some 70 or 80 tons with a deflection of the points of contact of some 45 cm. With further compression the force rises rapidly, and soon reaches the point where no reversible energy-absorbing capacity is left. Any impact energy in excess of this capacity can only be taken up by damage to fender, ship and/or pier. Both types of fender reach this limit when the maximum deflection of the points of contact reaches some 50 to 55 cm.

Three fender arrangements were considered:

1) A combination of Seibu and Cordkapp fenders, as shown in Fig. 8, with two Seibu units side by side at each pillar, and with Cordkapp units placed horizontally in between. By this arrangement, called Alternative VII, a fair amount of fender capacity could be attained without violating the 60 cm rule.

2) By removing the outer 50 cm of the quay slab, it was possible to place two Seibu units in series, one behind the other, at each pillar, as shown in Fig. 9 (Alternative VIII). A total compression of the two units of 100 cm could be allowed. Thereby a greater energy absorbtion could be attained with much less impact force than possible with Alternative VII, as shown in Table II.

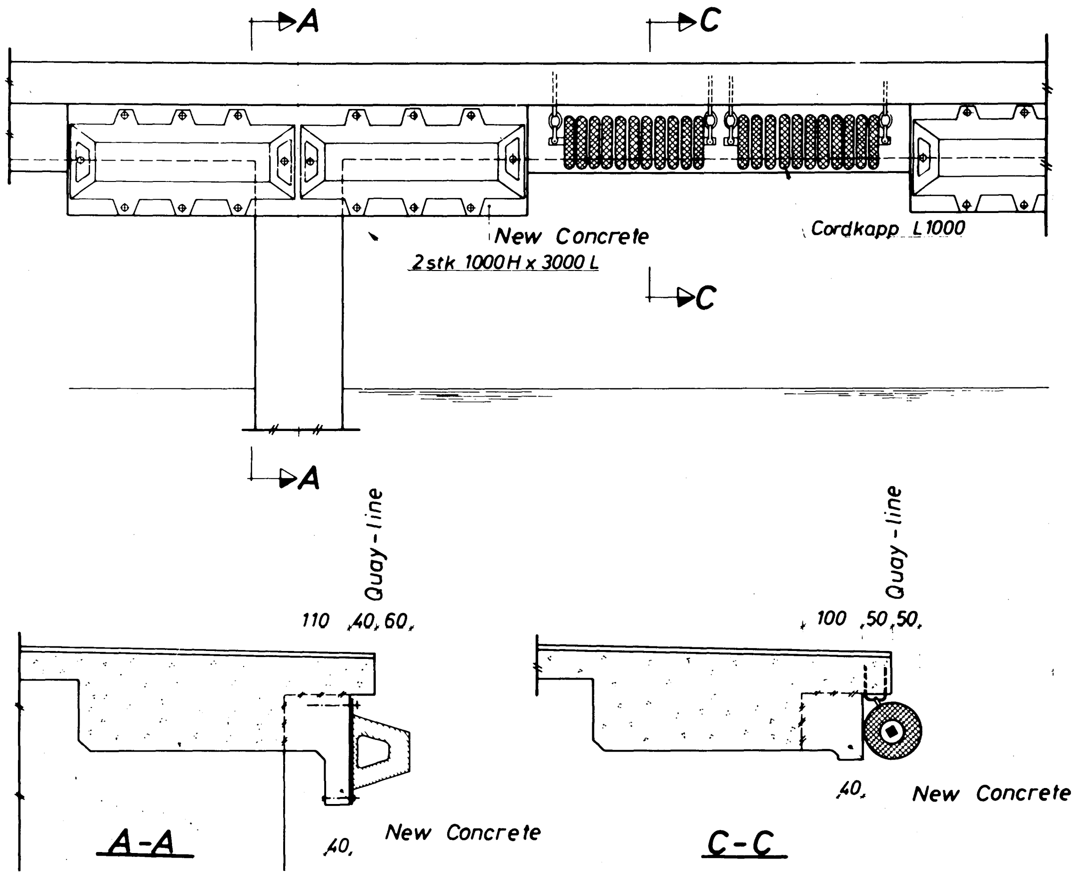

Fig. 8

Table II

Energy Absorbtion and Impact Force with Seibu
V-1000 H x 3000 Fender

System	Center of Impact	Maximum Displacement f max cm	Emax m tons	Pmax tons	Pmax on 3,0 m Seibu Fender tons	Pmax per l.m. tons/m
Alternative VII	At. Pillar	50	165	525	263	88
	Half-way between Pillars	52	120	775	213	71
Alternative VIII	At Pillar	100	175	305	305	100
	Half-way between Pillars	100	155	440	220	74

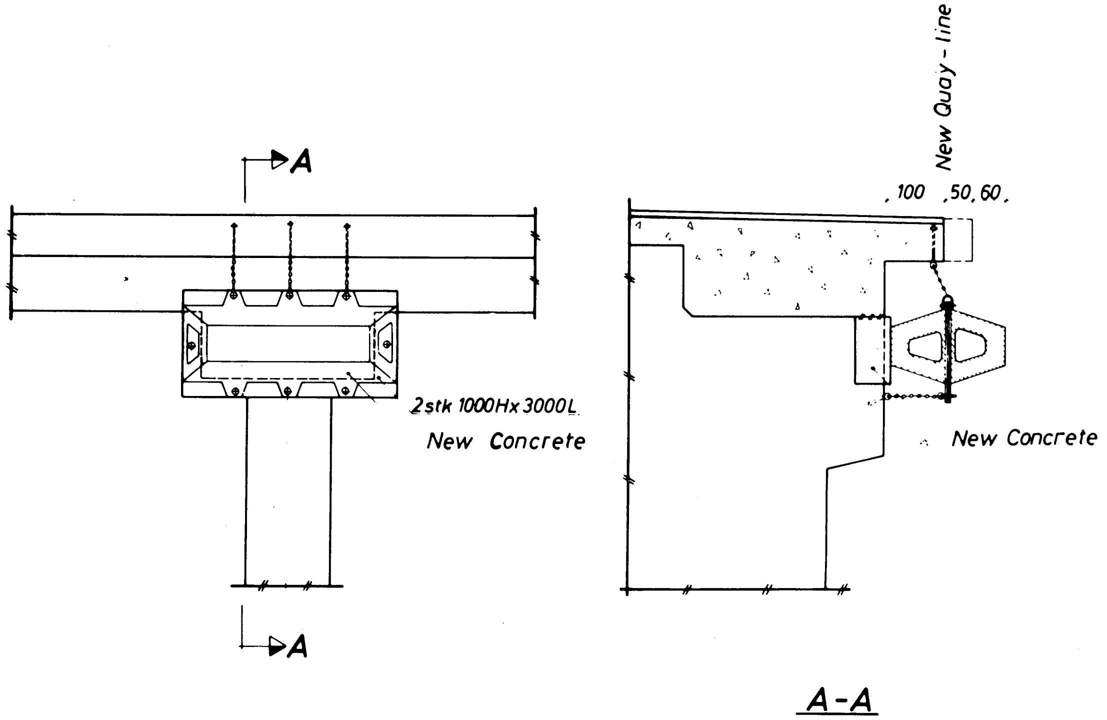

Fig. 9

Table III

Energy Absorbtion and Impact Force with Cordkapp Fender L 1000 continuous along the Quay Front

Maximum Displace-ment f max cm	Energy absorbed m tons	Maximum Force Total tons	Maximum Force Per 1m at Center of Impact tons/m	Total Length of Contact between Ship and Fender m
49	55 +10% -6,5%	490 +15% -15%	86	15
51,5	68 +11,2% -7,8%	590 +7,9% -6,6%	113	15,5
55	86 +10% -6,5%	855 +17% -10%	144	16

3) The third system considered was a continuous line of horizontal Cordkapp units all along the west side of the pier. The energy and forces were estimated on the basis of four tests performed at the Technical University of Norway. The results are shown in Table III, where also the range of variation in the test results is indicated. This system is much cheaper than the two others, but is seen to yield much less energy absorbtion with much greater forces.

Table IV Impact Energy and Force at Capacity Limit of Fenders.

(Compare Table V)

Fendering	Max. Energy m tons	Max. Force tons
Cordkapp f max = 55,0	86	855
" " = 51,5	68	590
Seibu Syst. VII	120	775
" " VIII	155	440

FINAL EVALUATION OF STABILITY

It remained to be seen how the impact forces listed in Tables II and III for the three different fender systems at their capacity limits would affect the pier structure. It would hardly be expedient to invest in fender systems whose capacity could not be fully utilized due to weakness of the pier. The energy capacities limits and the corresponding forces are summarized in Table IV.

In Table V the resulting forces at the top of each pillar and the corresponding stresses in the deck reinforcement due to horizontal bending moments, are compared with the maximum allowable horizontal force at each pillar top and with the yield point stress of the steel. Forces and stresses in excess of these limits are underlined.

It is seen that the figures for Seibu system Alternative VIII are well within the limits by a wide margin, except for impact at pillar 1, where the force just barely passes the requirement. This is due to the existence of a so called expansion joint at this pillar, whereby the pier is tied together lengthwise with no bending moment being taken. This is one of the not infrequent cases where, in the opinion of the writer, expansion joints are not only superfluous but harmful.

Table V

Pillar Stability and Deck Strength at Capacity Limit of Fenders

(see Fig. 1 for designation of Pillars)

Yield point stress in reinforcing steel σ_F = 3100 kp/cm^2

Pillar No.	Stability limit of horizontal force H_{max} tons	Max. horizontal force (H) at pillar top and stress (σ_a) in deck steel at capacity limits of fender as stated in Table IV x)							
		Seibu System VII f_{max} = 52 cm		Seibu System VIII f_{max} = 100 cm		Cordkapp' L1000 continuous f_{max} = 55 cm		Cordkapp' L1000 continuous f_{max} = 51,5 cm	
		H(tons)	σ_a (kp/cm^2)	H(tons)	σ_a (kp/cm^2)	H(tons)	σ_a (kp/cm^2)	H(tons)	σ_a (kp/cm^2)
12	300	195	2206	110	1250	214	2430	148	1680
11	280	254	2170	144	1230	280	2390	194	1650
10	300	285	2430	177	1510	312	2650	228	1920
9	220	195	2860	111	1630	215	3160	148	2180
1	220	378	xx)	216	xx)	419	xx)	288	xx)
2	280	273	2330	169	1440	298	2600	215	1880
3	220	157	2860	89	1620	173	3150	119	2180
4	220	180	2880	103	1640	200	3170	138	2200
5	280	260	3190	161	1980	284	3480	206	2520
6	220	146	3100	83	1760	161	3420	111	2360
7	220	117	2590	67	1470	129	1850	89	1980
Pier Head 8	790	730		445		797		591	

x) Including horizontal forces from superstructure

xx) Expansion joint at pillar 1

The Cordkapp alternative with 55 cm deflection would give excessive figures at nearly all points, if such a deflection should be possible. With a deflection of 51,5 cm the force at pillar 1 still considerably exceeds the limit.

It is seen that the energy capacity of Cordkapp fenders with deflection 51,5 cm is only 44 % of that of Seibu VIII, while the corresponding impact force is 34 % greater, and does not stay within the limits given.

The cost of the Cordkapp fendering was only 41 % of that of Seibu VIII. Nevertheless the owners felt the much greater safety of the pier to be worth the greater cost.

It will be noted that no account has been taken of the ability of the ship to withstand the forces mentioned. This is intensional. In this special case the consequences of a collapse of the pier are much more serious than those of even great damage to the ship. In fact, if a very serious impact should occur, the probability that some energy would be consumed in damaging the ship, represents added safety to the pier.

Fig. 10 shows the fendering in place along the pier.

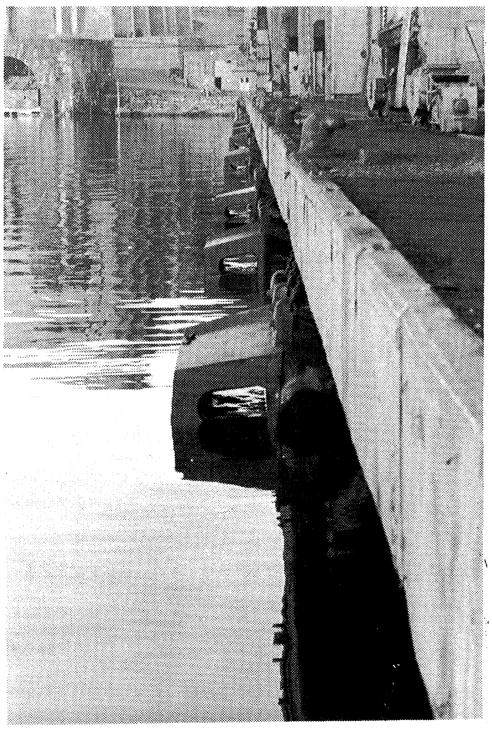

Fig. 14