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# Means of Reducing the Consequences of Ship Collisions with Bridges and Offshore Structures

Ouvrages de protection des ponts et des constructions maritimes contre des collisions de bateau

Beschränkung der Auswirkungen eines Schiffsanpralls gegen Brücken und Meeresbauten

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## SUMMARY
Possible structural measures to protect bridges and offshore structures against ship impact are described and their efficiencies are evaluated. Such measures are floating systems, systems using piles, fixed or sliding dolphins with or without fenders and protective islands. Finally conclusions are drawn for the planning of new bridges taking into account their protection against ship collision.

## RÉSUMÉ
Les ouvrages de protection des ponts et des constructions maritimes contre une collision de bateau sont décrites et examinées du point de vue de leur efficacité. On y traite des systèmes flottants, des systèmes sur pieux, des îlots artificiels. Des indications fondamentales sont données pour le projet de nouveaux ponts tenant compte de leur protection contre une collision de bateau.

## ZUSAMMENFASSUNG
Es werden konstruktive Möglichkeiten, um Brücken und Meeresbauten vor den Folgen eines Schiffsanpralls zu schützen, beschreiben und auf ihre Brauchbarkeit hin untersucht. Behandelt werden schwimmende Systeme, Systeme suf Pfählen, feste und bewegliche Kreiszellen mit oder ohne Fender und künstliche Aufschüttungen. Abschließend werden grundsätzliche Hinweise zum Entwurf neuer Brücken, unter Berücksichtigung des Schutzes gegen Schiffsanprall, gegeben.

## 1. INTRODUCTION

Over the recent years a constant increase of shipping accidents with bridges and offshore structures took place. The reasons for these are, on the one hand, attributed to the increase in shipping traffic and the size of the ships, Figure 1, on the other hand, to the fact that more bridges are being built in deep water and on poor ground. The protection of bridges is therefore becoming increasingly more important.

In the U.S.A. alone are about 100 major bridges across principal shipping lanes, 11 of which were involved in major ship collisions in recent years, which besides considerable material costs also exacted a toll of nearly 100 human lives. The damages stemming from ship collisions thereby exceed those connected with wind, waves, earthquakes or increased loads, [2].

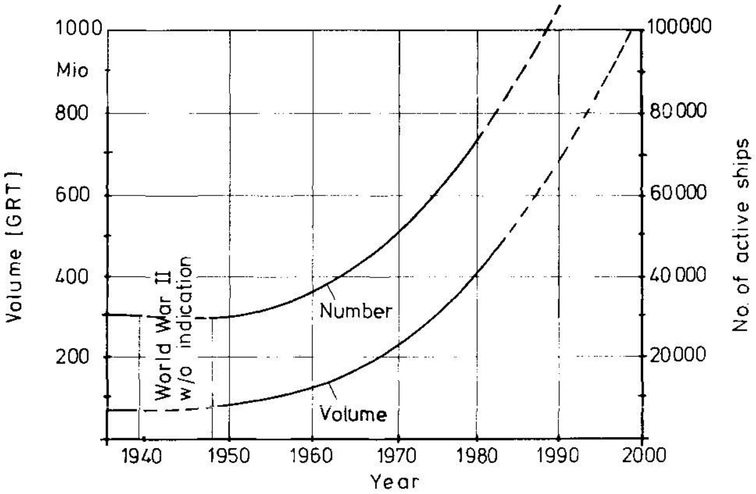



Fig.1 Development of merchant marine traffic. From [1]

Experience indicates that it will not be possible to avoid collisions completely, but it is possible to reduce their consequences: the damage to the struck structure must not lead to its collapse and to loss of human life and the ship must not sink or be damaged in such way that its cargo, e.g. oil, pollutes the environment.

Protective installations, therefore, should protect the structure as well as the ship. This paper deals only with protective installations for the structure.

## 2. COLLISION ENERGY AND IMPACT FORCES

The kinetic energy of a ship moving straight forward amounts to

$$E_K = \frac{1}{2} \cdot m_1 \cdot 1.05 \cdot v_0^2$$

with $m_1$ ship's mass
1.05 factor for additional hydrodynamic mass
$v_0$ ship's speed .

The collision energy $\Delta E$ to be transformed by the structure hit (in the following simplified called pier) and/or the ship into another energy form is hence

$$\Delta E = \eta \cdot E_K$$

as shown in [3], see Figure 2.

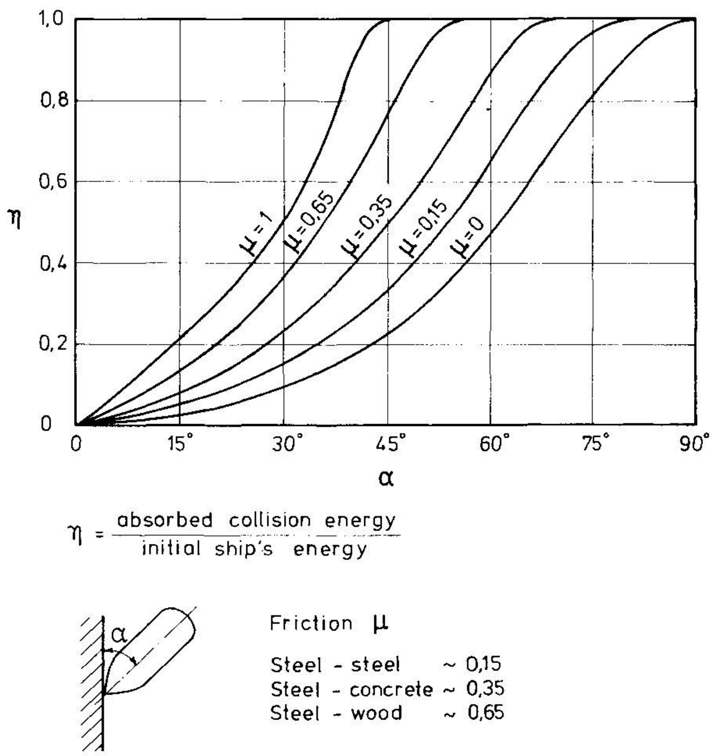



Fig.2 Part of collision energy $\eta$ to be absorbed by the ship and/or pier in relation to the collision angle $\alpha$ and the friction $\mu$

The impact force created by a right-angle collision of a ship against a stiff pier has been deduced by Woisin from measurements in collision tests.

From those tests it was concluded that the medium impact force

$$P_m = \frac{\Delta E}{a} \quad \text{(a: length of damage)}$$

is approximately constant during the collision. The maximum impact force $P_{max}$ increases at the beginning of the impact for approximately 0.1 - 0.2 seconds to double the amount of $P_m$, Figure 3.

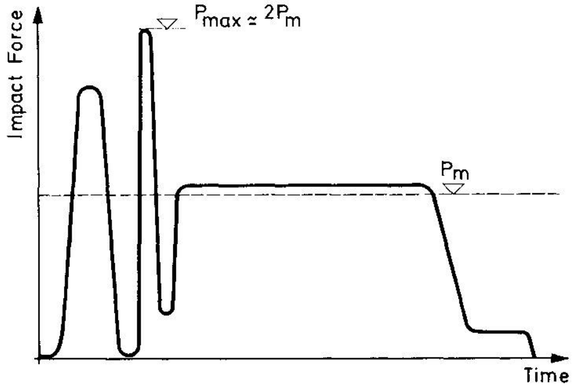



Fig.3 Impact forces from a collision test between the bow model of the passenger liner T/S Bremen against the side model of the N/S Otto Hahn, Test No.1 of the GKSS. From [4]

For bulk carriers it was concluded that the effective maximum impact force for an impact against a stiff pier follows in first approximation the formula

$$P_{max} \approx 0{,}88 \sqrt{dwt} \pm 50\% ,$$

[3], Figure 4, with ±50% = scatter in dependence of the structural type and shape of bow and of the degree the forepeak is filled with water.

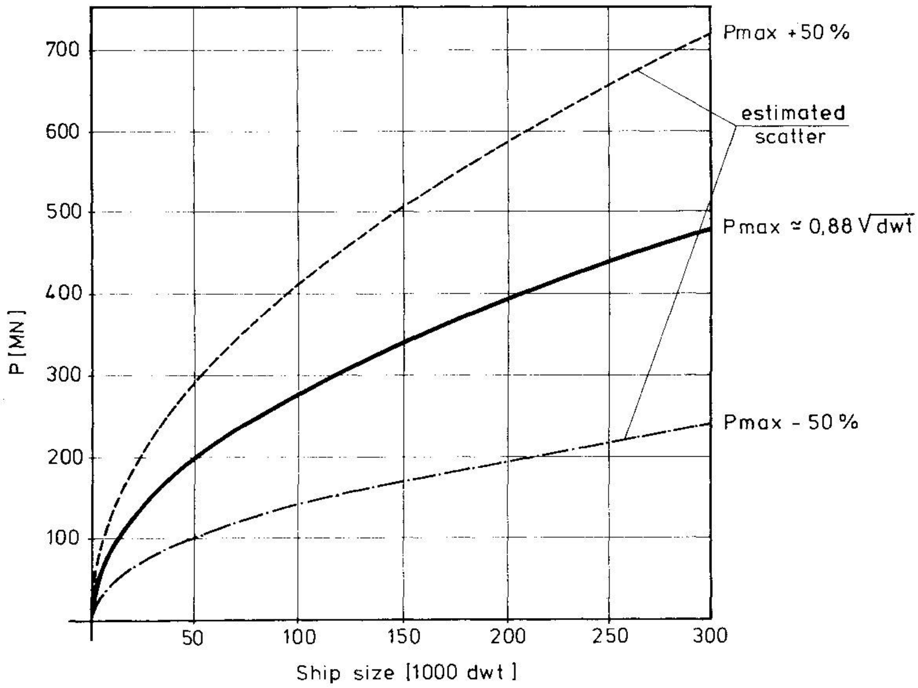



Fig.4 Woisin's approximation for the relation between the impact force $P_{max}$ and ship's size [dwt] for bulk carriers. From [5]

# 3. PROTECTIVE SYSTEMS

## 3.1 Possibilities of Energy Conversion

The kinetic collision energy must be converted into mechanical work:

$$\Delta E = A \qquad \Delta E\text{: Collision Energy}$$

$$A = \int K \cdot ds = f_i \cdot K \cdot s \qquad \text{A: mechanical work}$$

$$K = \frac{A}{f_i \cdot a} \qquad \text{K: reaction force}$$

The factor $f_i$ depends on the curve of the force deformation diagram and lies between 1 (ideal plastic, without stabilization), 1/2 (linear elastic), and 0 (powerless deformation), Figure 5.

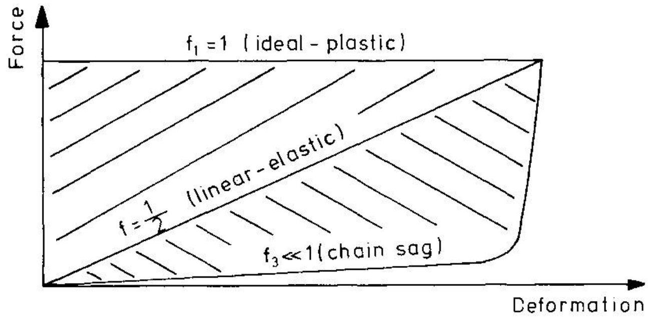



Fig.5 Possible work diagrams for converting collision energy

For the mooring of ships the elastic range comes into consideration for energy conversion, in which no exchange of protective devices becomes necessary. The more the probability of an impact decreases and the greater and more concentrated the forces to be absorbed become, the more important plastic deformations become which require repairs up to the point of complete replacement.

The energy to be converted in the impact may be absorbed by the protective device or an energy absorbing intermediate layer, a "fender", or by the ship itself. Generally all possibilities take place simultaneously. The reaction force thus generated has to be transmitted into the ground by the resisting structure. In order to permit an economical dimensioning of the pier and/or its protective structure, the reaction force must be limited by achieving large deformations and a factor $f_i$ approaching 1.

## 3.2 Floating Systems

The floating systems are based on the idea to absorb the ship's energy advantageously with small forces and large deformations and to overcome considerable water depths with high-strength tension members.

The floating systems differ with respect to their type of energy conversion, to their design against being overrun, as well as to the type of their tension members and their anchorages.

### 3.2.1 Elastic Energy Conversion

For the temporary protection of a drilling rig in the Akashi Channel, Japan, a floating protection device was developed in 1973, which was anchored in 50m deep water [6], [7], Figures 6, 7. The device was designed for ships up to about 2000 dwt with a speed of up to 5 m/sec and collision angles of up to 15°.

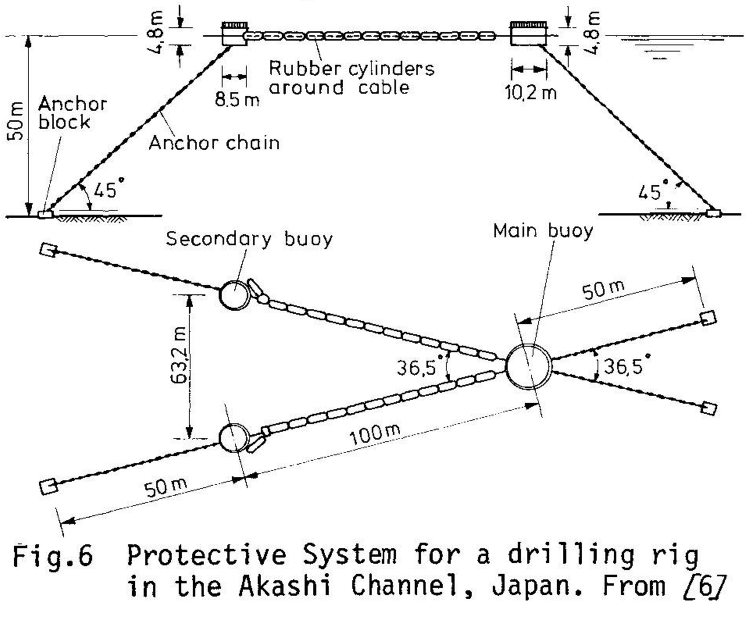



Fig.6 Protective System for a drilling rig in the Akashi Channel, Japan. From [6]

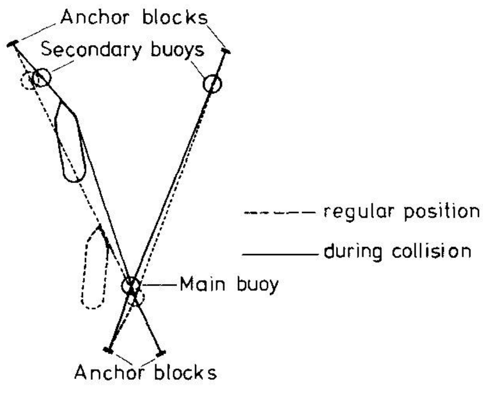



Fig.7 Operation of the protective system in the Akashi Channel. From [7]

After the severe collision of the S/S "Lake Illawara" with the Tasman Bridge on January 5, 1975, the future protection of the bridge was investigated [8].

One of the protective systems developed consists of the floating interceptor system shown on Figure 8.

The device is supposed to stop a ship of 35,000 t displacement at a speed of 4 m/sec. After a forceless deformation of about 30 m the anchor cables can be stretched by roughly 35 % and each thereby creates a force of 3.5 MN. The elastic potential work capacity of two nylon cables is

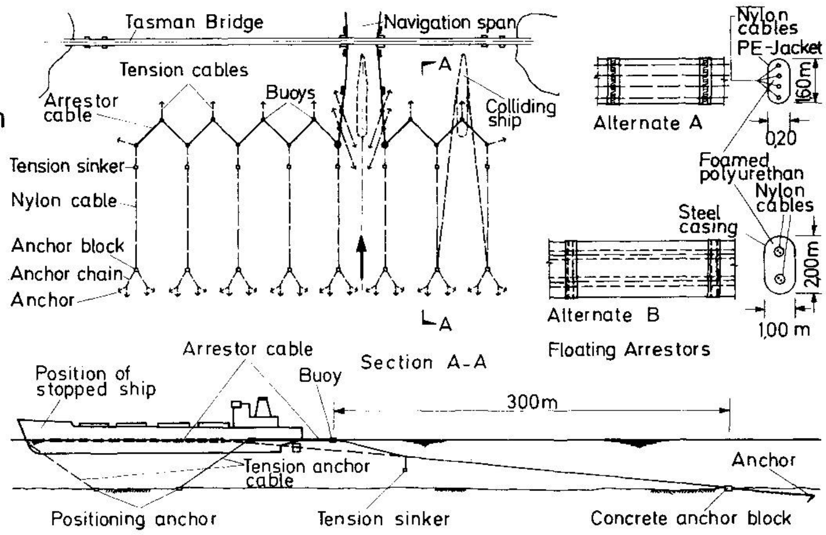



Fig.8 Protective system with elastic nylon ropes. From [8]

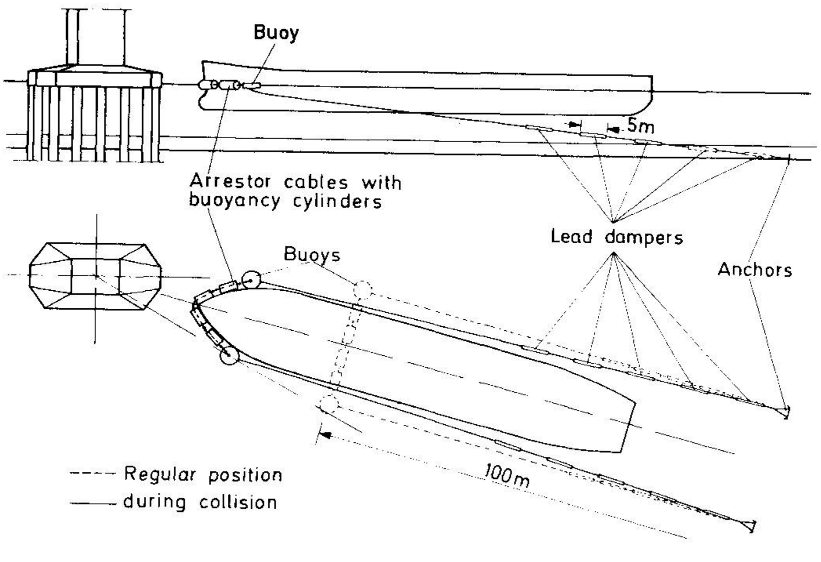
$$A = 1/2 \cdot 300 \cdot 0.35 \cdot 2 \cdot 3.5 = 368 \text{ MNm}$$

$$> E_K = 1/2 \cdot 35{,}000 \cdot 1.05 \cdot 4^2 = 294 \text{ MNm}$$

### 3.2.2 Non-elastic Energy Conversion

One of the few floating systems actually realized is the one for the bridge near Taranto across the Mare Piccolo in Italy [9]. The bridge has two main openings of 152 m and a total of six piers in 12 m deep water.

The system is designed for ships of up to 15,000 t displacement with a speed of 3.1 m/s. Such a ship should be decelerated at 0.2 m/sec² over a distance of 30 m through a retaining force of 3.2 MN. The arrestor on the surface consists of chains spanning between buoys anchored to concrete foundations with chains, Fig. 9.




The ship's energy is absorbed for each anchor chain by 5 dampers connected one behind the other, each 5m long. The dampers consist of a steel pipe, in which a drawbar absorbs energy through the deformation of a lead filling. The work lines of the dampers were determined by full-size model testing.

Fig. 9 Operation of the protective system for the Taranto Bridge

The braking process is characterized through (Figure 10)

$E_K = \Delta E = 76$ MNm

Deceleration $b = -0.2$ m/sec²

Braking distance

$s = 1/2 \cdot 3.1^2 \cdot \frac{1}{0.2} =$

$= 24.0$ m $< 5 \cdot 5 = 25$ m

Medium braking force per anchor cable

$P_A = \frac{76}{2 \cdot 24} = 1.6$ MN

Braking force on the ship

$P_S = 3.2$ MN

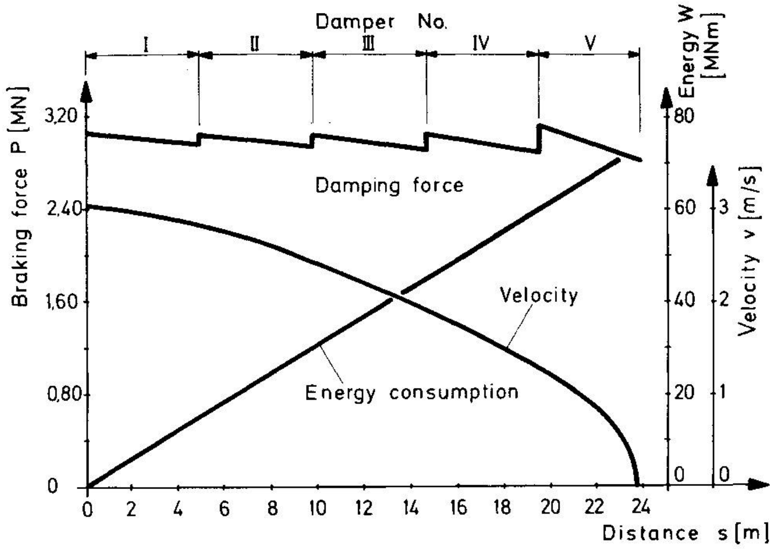



Fig.10 Force and speed diagram of the protective system for the Taranto Bridge. From [9]

As protection against larger ships the Honshu-Shikoku Bridge Authority (Japan) has developed a so-called indirect buffer system [10], Figure 11. The colliding ship is stopped or at least slowed down considerably depending on size and speed. The energy that may still remain is supposed to be absorbed through the direct buffer system, a framework collar affixed to the pier itself, see section 3.4.

The indirect system consists of the floating intercepting device and two holding buoys. The buoys are attached to anchor blocks with vertical chains.

In a collision the floating intercepting line and the anchor chain are tightened up and the buoys submerge. As soon as the static friction of the anchor blocks is overcome, the anchors start sliding.

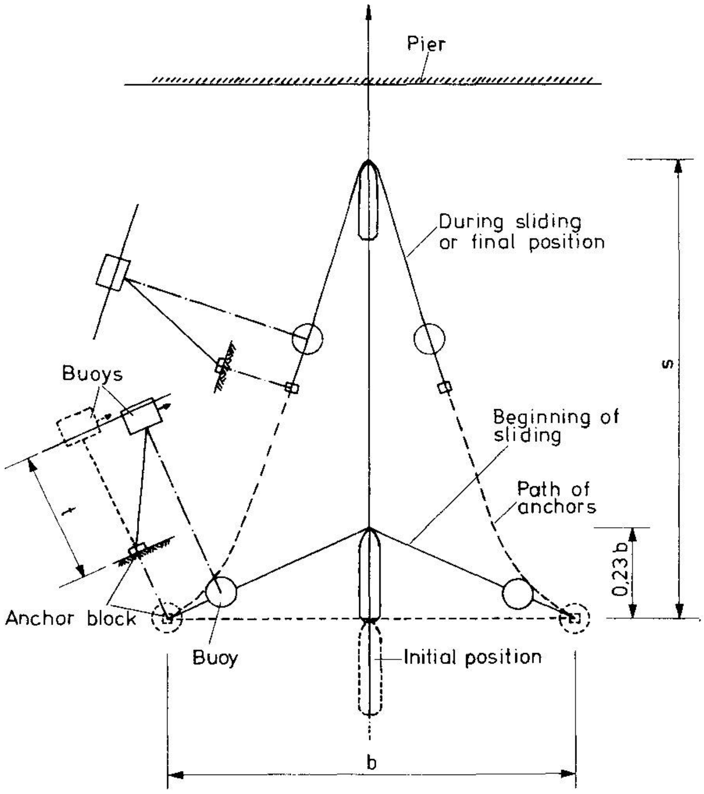



Fig.11 Operation of the system with sliding anchor blocks. From [10]

### 3.2.3 Protective Ships

In 1927, four ships were used as temporary collision protection of the main piers of the Carquinez Strait Bridge, U.S.A. [11].

It appears possible to anchor ships or pontoons of sufficient length transversely in the river in front of piers. The striking ship is completely stopped in the case of collision. The protective ship must not be severly torn up in that case, as it might otherwise sink. In order that merely the striking ship is flattened at its bow, side tanks would have to be subdivided in the protective ship and to be filled with concrete. The total kinetic energy of the striking ship has to be converted into another energy form or transferred into another energy carrier in the course of the impact.

According to Woisin, the following three energy constituents can be differentiated, Figure 12:

$$\Delta_1 E = \frac{m_2}{m_1 + m_2} \cdot E_K$$ energy absorbed practically immediately through plastic deformation

$$\Delta_2 E = \frac{m_1^2}{(m_1 + m_2)^2} \cdot E_K$$ kinetic energy at first remaining in the striking ship

$$\Delta_3 E = \frac{m_1 \cdot m_2}{(m_1 + m_2)^2} \cdot E_K$$ kinetic energy transferred onto the protective ship that is struck

with $m_1$ : striking mass including 5 % hydrodynamic additional mass

$m_2$ : struck mass including 50 % hydrodynamic additional mass

$E_K$ : kinetic energy of the striking ship.

From these the portions $\Delta_3 E$ must be converted completely and $\Delta_2 E$ partially into other energy forms through the effect of the anchorage, e.g., into deformation work of the anchor cables (nylon cables, lead dampers), in submergence work of the protective ship, into water resistance work or into friction work of the anchors on the river bed.

In order to keep the anchor forces small, an as large as possible mass of the protective ship is necessary, see Figure 12. However, economic limitations are thereby soon be faced.

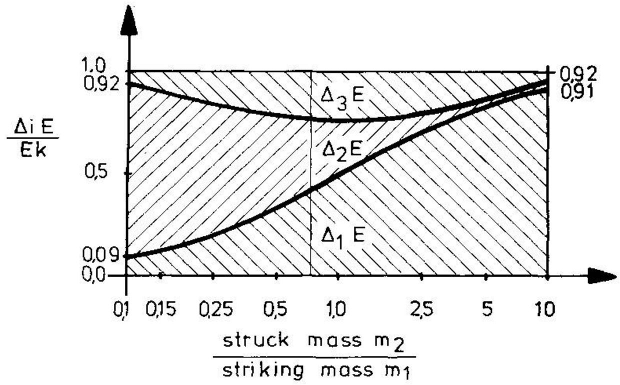



Fig.12 Distribution of the collision energy between anchored protective ship and colliding ship according to Woisin

The anchor forces reach considerable proportions; normal anchor equipment is out of question. The anchorages fore and aft have individually to be able to receive the full impact force in case of an eccentric impact.

3.2.4 Evaluation of Floating Systems

The greatest risk of the floating arrestor devices lies in the possibility that they can be submerged into the water by a ship's bow and thereby be passed over.

While the protection seems to function for the bulbous bow shapes a and b in Figure 13, this is an open question for bow shapes c and d, and depends on the buoyancy of the arrestor device, the friction between arrestor device and ship, the shape of the arrestor device – a round member will more likely roll under the bow than an oval one – and the inclination of the ship's bow. Furthermore, a ship's bow often consists of a cast iron part which may be relatively sharp-edged and can cut the anchor cables with its submerged portion.

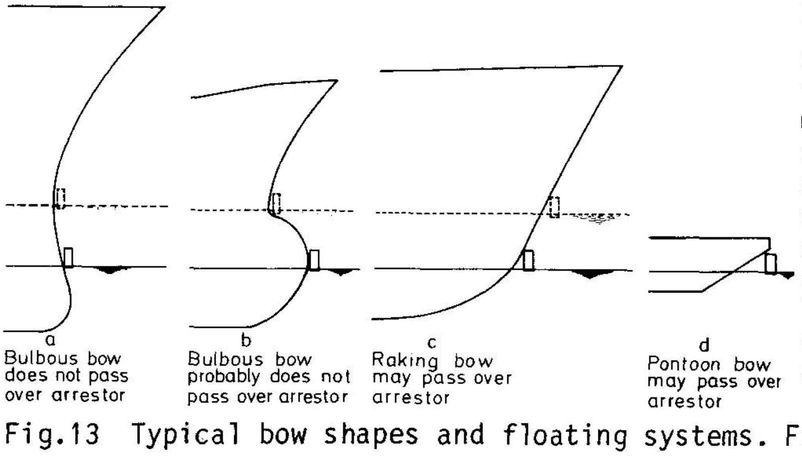



Fig.13 Typical bow shapes and floating systems. From [8]

Because of the possible erosion of the river, the lengths of the anchor cables of all floating protective devices may have to be adjusted frequently. Another essential disadvantage of all floating systems lies in the fact that the anchorage systems and their end linkages have to be checked continually as they are exposed to severe corrosion under water.

Chains, as was proven by Det Norske Veritas, are no reliable tension elements. On the whole, floating systems are subject to so many uncertainties that they are not considered a safe protection.

## 3.3 Pile Systems

Single-standing piles or pile groups of wood, steel or concrete have long been used for mooring.
In contrast to mooring operations, in which the small energy involved is received elastically by the piles, the far greater collision energy can be absorbed only through plastic deformation of the piles.

For protection of the Tasman Bridge, Australia, the two following protective systems were investigated [8].

The one system consists of vertical prestressed concrete piles, which are fixed below in rock and above in a strong fender beam, Figure 14. The ship's energy (assumed to be 300 MNm) is absorbed at both fixings through the rotation of plastic hinges. The energy reception of a pile measuring 3 m in diameter was calculated to be 18.3 MNm for a head deflection of 5 m, yielding $A_i = 2 \cdot 8 \cdot 18.3 = 293$ MNm. Because of this significant plastic deformation the entire protective device would have to be replaced after a collision.

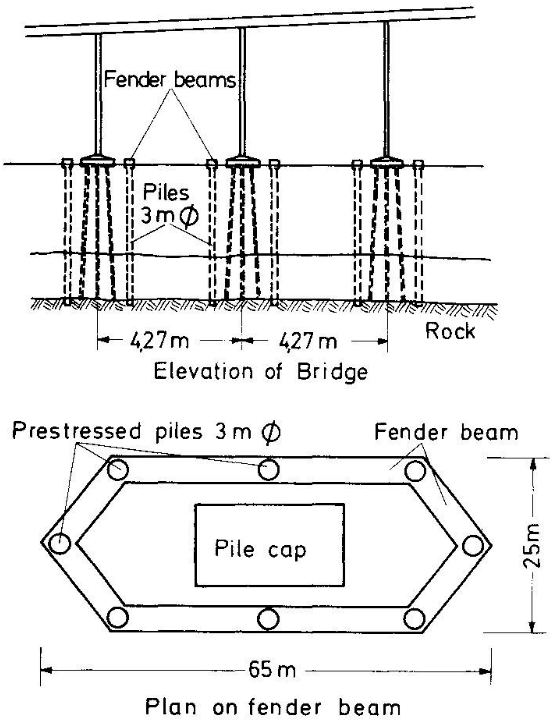



Fig.14 Protective system with vertical piles. From [8]

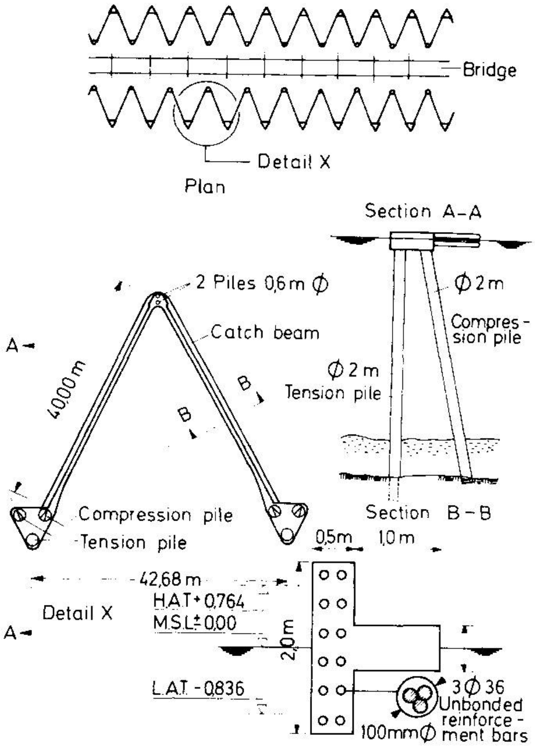



Fig.15 Protective system with tension piles. From [8]

The other system consists of V-shaped catch-beams on the surface of the water, which are anchored to tension and compression piles, Figure 15. Each of the catch-beams is reinforced with steel rods having a yield strength of 430 N/mm² and an elongation at failure of at least 22 %.

The energy of the design ship of 300 MNm is supposed to be received through plastic longitudinal deformation of the steel rods: maximum force per catch-beam

$$\max P = 36 \cdot 1018 \cdot 430 \cdot 10^{-6} = 15.8 \text{ MN}$$

maximum elongation $\max s = 0.22 \cdot 40 = 8.8$ m

internal work (practically completely plastic) for two catch-beams

$$A_i = 2 \cdot 15.8 \cdot 8.8 = 278 \text{ MNm} \approx 300 \text{ MNm} .$$

The tension force of 15.8 MN is conducted into the ground by the piles elastically. The struck catch-beams have to be replaced after a collision.

## 3.4 Fenders

Various fender types, mostly of rubber, wood or steel were developed for the protection of ships and offshore structures in mooring operations [12]. By distributing the ship's energy through fenders the bearing pressure on the ship's hull shall not exceed 0.2 MN/m². During mooring operations the fenders remain in the elastic area.

The traditional timber fenders from beam grids can be elastically compressed by about 5 % of their thickness. Recently elastic fenders of rubber have been developed which are working in compression, shear , bending or tension. The largest of the pneumatic fenders built so far - air-filled tubes of reinforced rubber, 4.5 m in diameter and 12 m in length - can absorb an impact energy of 5.3 MNm [13], which is considerably less than what is required in the collision of large ships.

Fenders effective in the plastic range, in which a corrugated steel pipe is compressed, achieve to date only an energy reception of 310 kNm [14]. It is practically impossible to distribute the concentrated impact forces over the necessary large number of fender units.

The framework collar for the Honshu-Shikoku Bridges, mentioned in section 3.2.2, is supposed to receive greater collision energies through successive plastic deformations of individual framework members. This development, however, appears to be in an early stage.

Great collision energies can be received in the plastic area by wood fenders; realized examples are given, e.g., in [11]. The plastic work reception capacity is indicated in [15] for various kinds of wood. In the entire range of plastic deformation the restoring pressure remains relatively constant, in other words, the increase in force at the beginning of the impact as shown in Fig.3 does not occur.

In order to protect the fenders in smaller collisions and to keep the friction values (and thereby the energy portion to be taken by the protective system, see Fig.2) low, an outer steel plate should be provided. In impact tests on timber fenders with this steel plate the volume of the wood activated for energy consumption increased up to the double [16], and the steel that is plastically deformed in the impact receives additional energy.

Wood fenders are relatively inexpensive and generally easily obtainable. Hardwood with appropriate pretreatment has a high longevity and is practically maintenance-free [12].

## 3.5 Dolphins

### 3.5.1 Sliding Caissons

As the expected impact forces could not be received by the piers next to the main opening of the planned Bahrain Causeway Bridge, concrete caissons filled with sand and placed on a layer of rocks, were originally proposed for its protection [17], Figure 16. The energy conversion is supposed to take place through the deformation of the ship's bow and by sliding of the caissons on the rock layer.

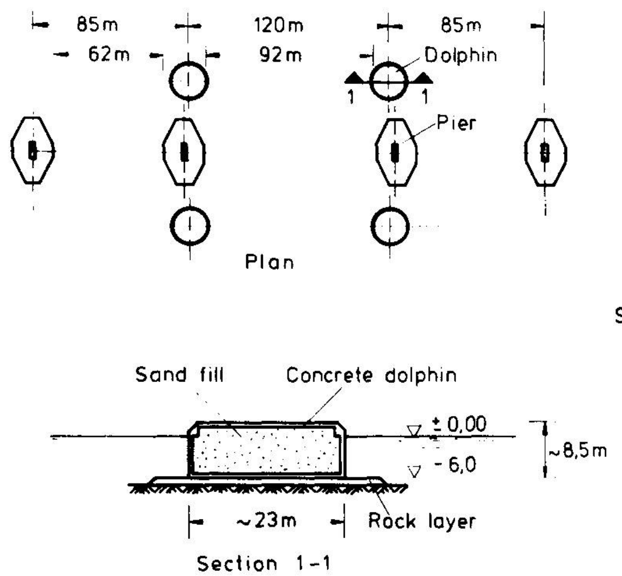



Fig. 16 Sliding caissons. From [17]

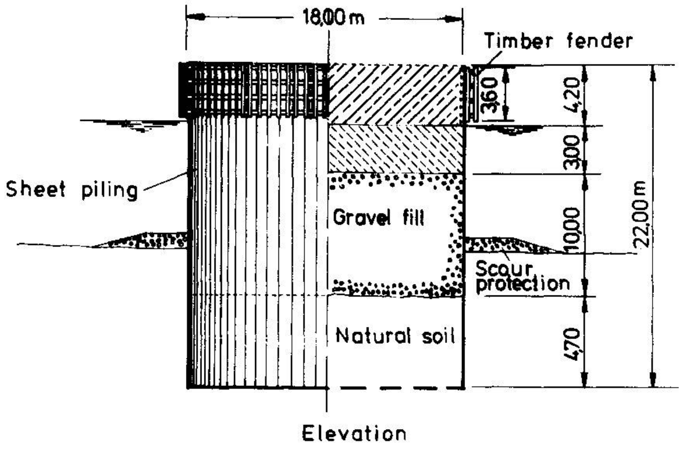



Fig.17 Circular cell

### 3.5.2 Fixed Dolphins

Circular cells from sheet piling, Figure 17, have already often been used as protection of bridge piers, e.g., for the Goethals Bridge and the Outerbridge Crossing, U.S.A. [18], the Rio Niteroi Bridge, Brazil [19] and the Betsy Ross Bridge, U.S.A. [20].
These cells generally consist of sheet piling filled with gravel or sand and a concrete slab on top. The fender system is mostly laid out for smaller ships. Such cells stopped a 35,000 dwt freighter with a speed of 4 m/s in the Port of Philadelphia, U.S.A. [11] and a 45,000 t tanker in front of the Outerbridge Crossing [18].

### 3.5.3 Caissons proposed for the Zárate-Brazo Largo Bridges

The protection proposed by the authors for the deep water piers of the two Zárate-Brazo Largo (ZBL) Bridges in Argentina, [2] and [21], consists of concrete caissons on piles with projecting, fender-protected concrete platforms, Figure 18.

The fenders of hardwood beams are 2m thick on the sides and 4m thick at the tip. They are armored on the outside with a 20 mm thick steel plating and extend 0.5 m below the low-water mark in order to prevent the penetration of driftwood and small boats. The fenders are installed on a subsidiary construction that is designed for the bearing pressure. In order to reduce maintenance the fenders are placed above water-level. In order to be effective for ships with bulbous bows, they are anchored to a platform protruding at least 3m over the foundation. If a ship with raking bow and with greater collision energy than envisioned collides, the ship is deformed in its relatively weak upper part, and smaller impact forces are generated than in the deformation of the stronger underwater part.

The platforms sits at the same height as the pile caps of the bridge piers, i.e., their lower edge is located about 2.5 m above the mid-water mark. In order to protect the piers also against flat barges at low tide, which otherwise could break off the downward projecting timber fenders and run underneath the platform onto a bridge pier, the platform edges in the end areas are extended down to the low-water mark. Due to the required width of the platform, a ship's impact may occur centrically as well as eccentrically. For the same force, the eccentric impact is the more dangerous because of the additional moment. In order to reduce the eccentric impact force, the collision angle and thereby the collision energy to be received by the protection is reduced by shaping the platform as an equal-

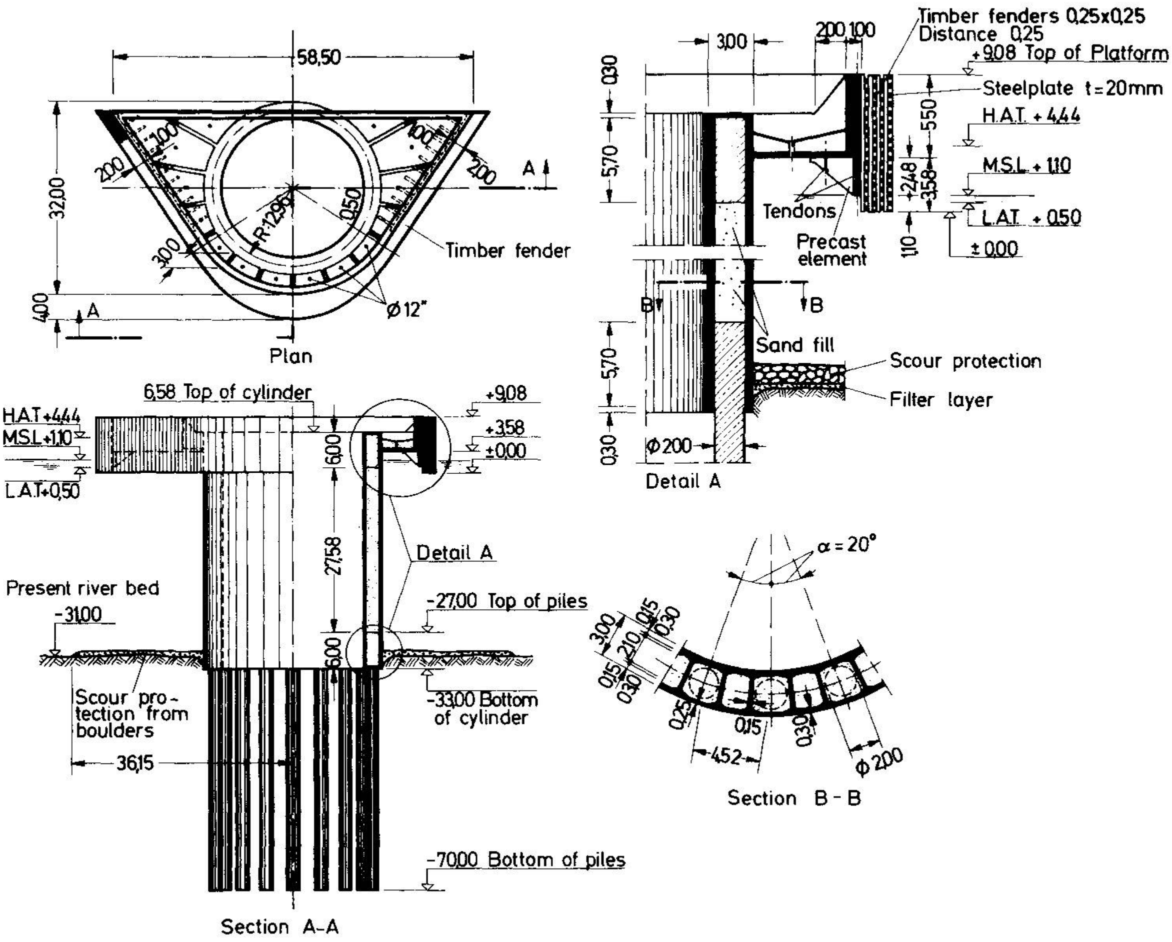



Fig.18 Dolphins proposed for the Zârate-Brazo Largo Bridges

sided triangle so that the collision energy of an eccentric impact for the given collision angles of the ZBL Bridges amounts to only about 1/3 of the ship's energy. The deformation of the fenders on the sides should not amount to more than about 1m in order to prevent that the colliding ship gets stuck in the fender and then gives more energy to the protection.

A frontal impact against the tip of the platform cannot be disregarded. The striking ship is so sluggish that during the brief impact duration of about 1-3 seconds no significant diversion from the tip of the platform takes place. The platforms are connected with caissons through their bottom slabs and radial walls which distribute the impact force over the caisson area and stiffen its upper edge.

The caissons themselves have the shape of hollow cylinders with 3m thick walls and rest on drill piles of 2m ∅ that extend all the way to the foundation elevation of the bridge piers. The circular arrangement of the piles is best suited to withstand the moments created by an eccentric impact.

The entire protective device is practically maintenance-free and is hardly subject to corrosion that would limit its efficiency.

## 3.5 Protective Islands

These "islands" consist of sand, gravel or boulders with a top layer of heavy stones. On soft ground it is also necessary to have a filter bed of graded gravel. The collision energy is converted through the deformation of the protective material as well as through the position shift of the ship and the surrounding water.

The efficiency of such islands has already been investigated in the U.S.A., in England and in France. In connection with the bridge across the Great Belt further comprehensive hydraulic model tests were conducted, the results of which were developed into a computer program [22]. The behavior of a 250,000 dwt tanker is shown in Figure 19.

The tests showed that container ships with sharp bows at collision angle $\alpha < 26°$ and tankers with cylinder bows at $\alpha < 45°$ slide off the island. The depth of penetration at greater collision angles depends, among other things, upon the ship's energy, its construction type and the island's layout.

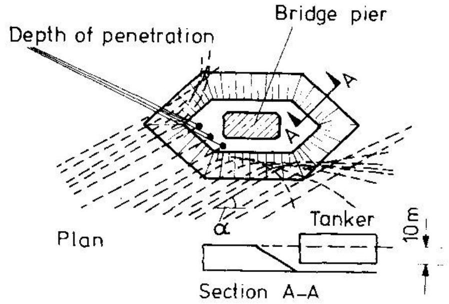
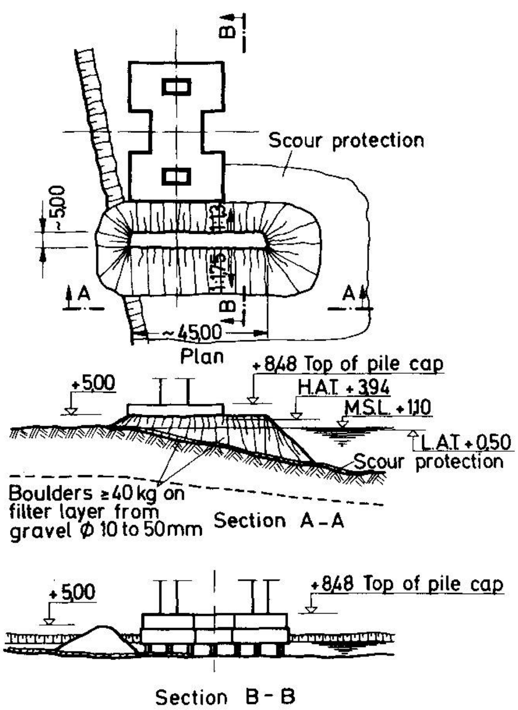



Fig.19 Operation of protective islands from model tests. From [22]

The advantages of such islands are that they combine a high degree of safety, confirmed through model tests, with economical factors in shallow water (the fill quantity enters in the third power of the water depth). They stop a ship slowly and prevent major damages of the hull. Furthermore, they have a high longevity, are maintenance-free, and require only minor repairs through additional filling after a collision.

Their potential may be limited by the fact that the flow cross section must not be reduced so much that the water-flow speed and hence the erosion of the bed are increased excessively. That would also result in an increased danger of collision. Fillings in the form of artificial islands around the foundation of bridge piers have already frequently been used, e.g., for a pier of the Westgate Bridge, Australia, for some side piers of the abovementioned Taranto Bridge in Italy, for the Verrazano Narrows Bridge, N.Y. [5], and for the Loire bridge near St. Nazaire, France [23].
A protective island has been proposed by the authors for one pier of the Zárate-Brazo Largo Bridges which was located in shallow water, Figure 20.




The width of its crown was determined on the basis of the model tests for the Great Belt Bridge.
In order to avoid a transfer of the impact force via the filling against the pile foundation of the bridge and to prevent additional loads on these piers through the weight of the filling and negative skin friction, the downstream slope ends in front of the piers.

Fig.20 Protective Island proposed for the Zárate-Brazo Largo Bridges

## 4. SUMMARY AND CONCLUSION FOR THE PLANNING OF NEW BRIDGES

Because of the high costs of afterwards installed protective systems, consideration of ship collision should be included in the concept of a bridge or offshore structure from the very beginning.

The safest would be to found the piers on land or in very shallow water to place them beyond reach for ships. An interesting case, although because of the great water depth and poor bottom conditions an extreme example, are the Zárate-Brazo Largo Bridges: the total costs of the approximately 11 km long bridge crossing amounted to about 600 million Deutschmark, of which roughly 175 million were for the main spans. The authors' proposed safe protection system would have cost about 65 million Deutschmark, that is, 11 % of the total cost and 37 % of the cost of the main spans. For this money the main spans of both cable-stayed bridges could have been increased from 330 m to about 410 m, and thus three of the four main piers could have been placed on dry land. A suitable scour protection would, of course, have to be provided against possible future erosion of the riverbed.

If the water is too wide to be bridged by one span, the main span length should at least be twice the length of the largest ship using the waterway, for navigational traffic in both directions [10]. The following possibilities are then recommended for the protection of the piers, the evaluation of which would depend on the local conditions:

- the piers and their foundations are designed in such way that the impact force resulting from the deformation of the ship alone can be withstood;
- the piers and their foundations are protected by fenders which reduce the impact force;
- the piers are placed out of reach for ships by means of protective islands;
- the piers are protected by dolphins founded independently.

It must not be overlooked that not only the piers adjacent to the navigational channel are endangered but also those away from the channel. The evaluation of collisions according to the position of the hit piers in Table 1 shows that out of 19 investigated accidents only 6 concerned the main spans, whereas 13 involved the approach spans.

| Bridge | Country | Year | Main pier | Side pier |
|---|---|---|---|---|
| Severn Railway | England | 1960 | | X |
| Richmond-SanRafael | USA | 1961 | X | |
| Outerbridge | USA | 1963 | X | |
| Sorsund | Norway | 1963 | | X |
| Maracaibo | Venezuela | 1964 | | X |
| Chesapeake Bay | USA | 1970 | | X |
| Chesapeake Bay | USA | 1972 | | X |
| Sidney Lanier | USA | 1972 | | X* |
| Mount Hope | USA | 1975 | X | |
| Tasman | Australia | 1975 | | X |
| Fraser River | Canada | 1975 | | X |
| Grand Narrows, CNR | Canada | 1975 | X | |
| Chesapeake Bay | USA | 1976 | | X |
| Pass Manchac | USA | 1976 | | X |
| Benj.Harrison Memor. | USA | 1977 | | X |
| Union Avenue | USA | 1977 | X | |
| Burrard Inlet, CNR | Canada | 1979 | | X* |
| Sunshine Skyway | USA | 1980 | | X |
| Newport Bridge | USA | 1981 | X | |
| | | 19 | 6 | 13 |

* superstructure of side span hit

Table 1: Ship - bridge collision listed after their location to the main span

Following the serious accident with the Tasman Bridge an investigation was undertaken to consider the feasibility of providing protection of all twenty piers in jeopardy [8]. However, the fixed protection systems that were considered safe proved to be so expensive that it was decided to build the Second Hobart Bridge close by and to leave the Tasman Bridge without protection. The volume of traffic alone would not have justified building a second bridge; however, it is to serve as a standby if the Tasman Bridge would be hit again [24]. Massive concrete caissons up to 45 m high and 25 m in diameter were selected for the foundations of the Second Hobart Bridge to enable it to withstand impacts of 10,000 t ships.

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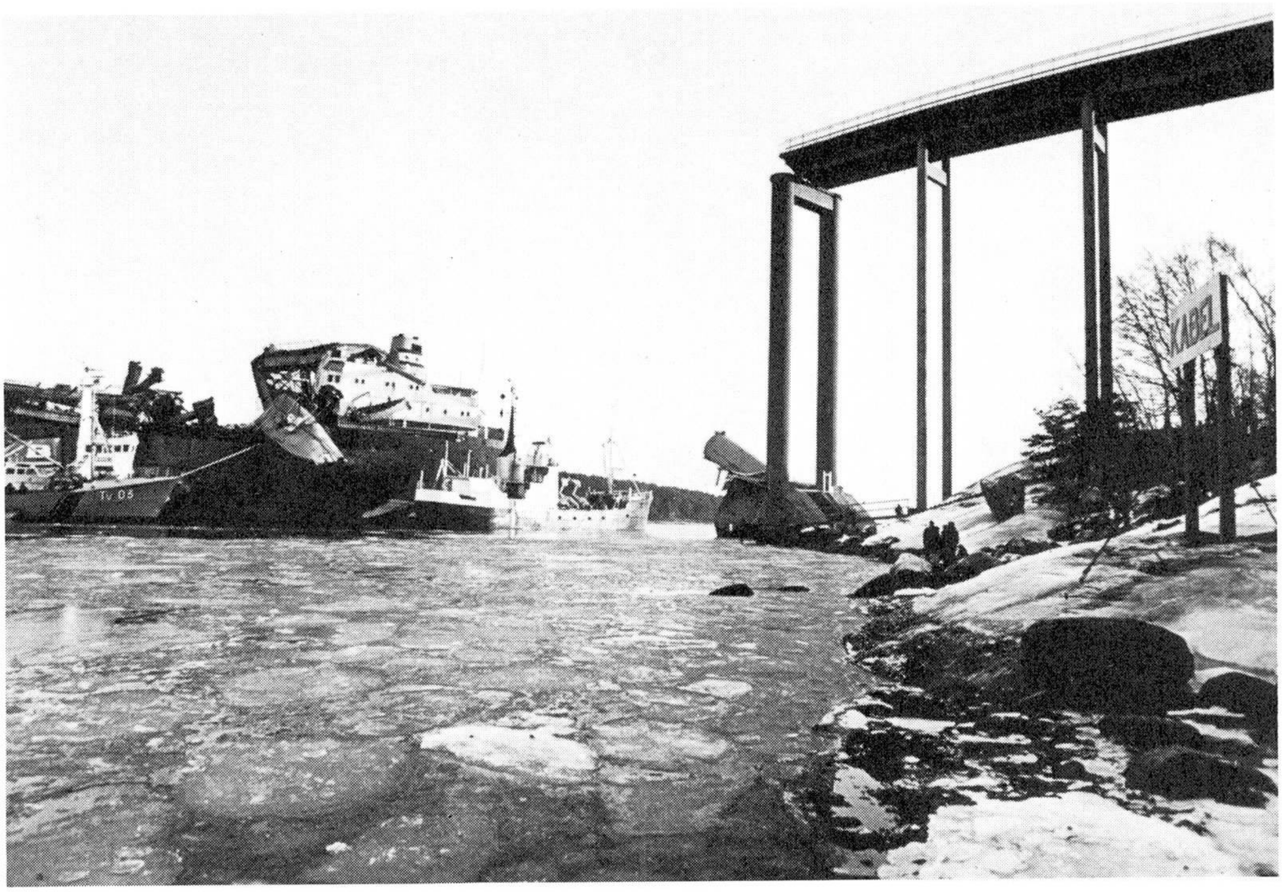


Almö-Bridge over the Askeröfjord, Sweden
Hit on January 18, 1980, by a 15.000 t - freighter. 8 persons killed.
Photo: Courtesy of Construction News, London, England

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