Ship collisions with bridges in Sweden

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Ship Collisions with Bridges in Sweden

Collisions de bateaux avec des ponts, en Suède

Schiffskollisionen mit Brücken in Schweden

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SUMMARY
The article gives some facts about five ship collisions with bridges, which have happened in Sweden since 1965. The road administration has developed design rules, which have been applied for new bridges since 1967. After the Tjörn bridge disaster in 1980 a complete survey was made of the collision risk at all Swedish bridges.

RÉSUMÉ
L'article décrit cinq collisions de navires avec des ponts, qui se sont passées en Suède depuis 1965. La Direction Nationale des Routes de Suède a établi des règles de calcul concernant le risque de collision, et ces règles ont été utilisées pour la construction de nouveaux ponts depuis 1967. Après le désastre du pont de Tjörn en 1980, une étude complète à l'égard du risque de collision a été réalisée pour tous les ponts suédois.

ZUSAMMENFASSUNG
Der Artikel gibt einige Daten über fünf Schiffskollisionen mit Brücken, die seit 1965 in Schweden eingetreten sind. Die Verwaltung verwendet seit 1967 für neue Brücken Dimensionierungsregeln, die Schiffsstöße berücksichtigen. Nach dem Tjörnbrückenunglück 1980 wurde eine Untersuchung des Risikos für Schiffskollisionen an allen schwedischen Brücken ausgeführt.

1. SHIP COLLISIONS WITH BRIDGES IN SWEDEN

1.1 Short reports on five collisions

1.11 The Tjörnbridge (Almö-bridge) near Gothenburg

The former Tjörnbridge was a 278 m steel-arch bridge, built about 1960, fig 1. The arch consisted of two 3,8 m circular tubes with 14-22 mm platethickness ("tube-tandem"). The navigation channel under the arch had a height of 41 m on 50 m width.- On the 18th of Januari 1980 at 1.30 a.m. in bad weather the arch was struck by a 27.000 dwt ship and collapsed totally. 8 people lost their lives, driving in their motorcars into the water over the edges of the remaining viaducts, before the road traffic could be stopped. The arch fell partly upon the ship without causing any injuries , fig 2. For further details, see /1/.

The collaps of the bridge interrupted a very important communication for the people on the islands of Orust and Tjörn, prolonging the roadway distance to Gothenburg by about 80 km. A provisional ferry-lane was therefore established immediately after the disaster, giving a capacity of about 2000 vehicles/day. At the same time a new bridge was planned and - after an international competition - the order for its construction was given in medio July 1980 to a Swedish-German consortium. The new bridge was built on the same place,but as a cable-stayed steel boxbeam of 366 m theoretical span. The about 100 m high pylons and the approaches were made in reinforced concrete. In order to make sure that the new bridge not could be hit by a ship, the pylons were placed on the rocks about 25 m on land. The free height was chosen to 45,3 m on 110 m width.-

About 16 month after the order - certainly a remarkable record in construction time - two lanes of the new bridge could be taken into use on Nov. 9th 1981, fig 3. The total cost for the new bridge and the temporary ferries was about 210 M SEK.

1.12 Tingstad Bridge, Gothenburgs harbour

The Tingstad railwaybridge is a steel truss-bridge with a 56,7 m swingspan, giving 2 navigation openings of 15,7 m width. There are two fixed approach spans of 31 m length.- On the 10th of September 1977 a 1600 dwt tankship hit a side span of the bridge, causing serious damage on the superstructure and the abutment. - The bridge was repaired for a cost of about 2 M SEK. For further details,see the introductory report, page 22.

1.13 Bridge over lake Mälaren at Hjulsta

The Hjulsta roadbridge is a two lane steel truss-swingbridge of 87,6 m length, giving 2 navigation channels of about 35 m width. On each side of the swing-span there are approaching bridges of 152 m resp. 266 m total length, consisting of 3 plategirders with concrete slabs of about 38 m spans, arranged continuously over two or three spans.- On the 12th Dec 1965 a 1.500 dwt ship hit the approaching bridge about 50 m south of the navigationchannel. Two spans of the superstructure were destroyed and fell into the water.

A provisional military-bridge was erected immediately on the undamaged piers. The superstructure was then rebuilt beside the military-bridge. Repairing cost about 2,5 M SEK.

1.14 Bridge over Göta river near Kungälv (Jordfallet)

The bridge over Göta-river near Kungälv is a double bascule bridge of about 44 m free width, giving a navigation channel of 42 m between guard-railings.

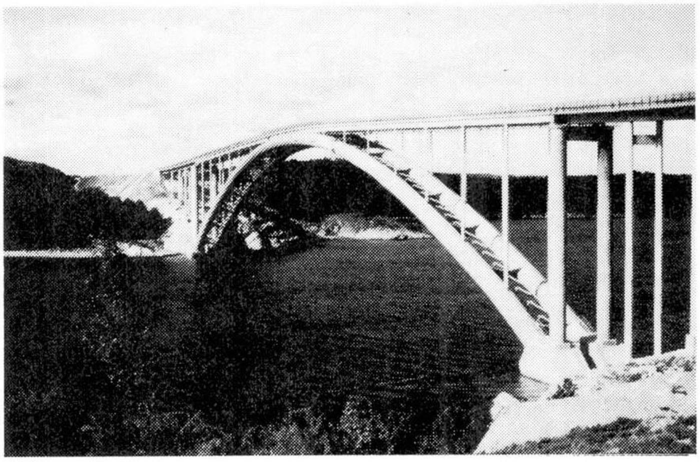

Fig 1. The former Tjörnbridge

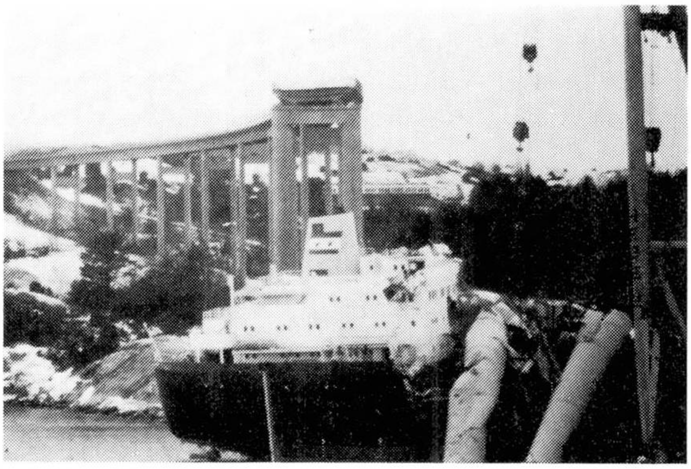

Fig 2. The collapsed Tjörnbridge

Fig 3. The new Tjörnbridge

There are about 20 m long bascule-piers of reinforced concrete on each side and then approaching bridges of about 240 respectively 362 m length. - On 30th April 1979 a 3.000 dwt ship hit the superstructure of one bascule, which could not be opened because of an electrical failure on the bridge. The ship,which had a breadth of only 12 m,could have passed in the remaining channel of 21,0 m, but she touched the bascule with her deckshouse. - A triangular bit of the bascules´ortotropic deck,with the bending points about 9 resp. 9 m from the corner,was bent downward at an angle of about 70°, fig 4. In spite of the very strong impact,the machinery and the counter-weight-arm of the bascule were undamaged. - The repair consisted of replacing of the damaged parts of the bridge deck and the maingirder. Repair-cost about 1,5 M SEK.

The same bridge was hit again on 28th Okt 1981 by a 480 dwt ship, which missed the channel and struck into the bascule-piers concrete wall about 8 m behind the guard-railing. The vessel went at about 3 knt speed uppstream. The shipsbow passed through the 0,45 m thick wall, reinforced by ø 12 c 300 on both sides, leaving a triangular hole of about 3 x 3,5 m just above the water level, fig 5.A concrete stiffener with 0,3 x 1,00 m cross-section was also destroyed. The bow never reached the backarm of the bascule. - The repair consisted of rebuilding of the concrete wall. Cost about 0,2 M SEK.

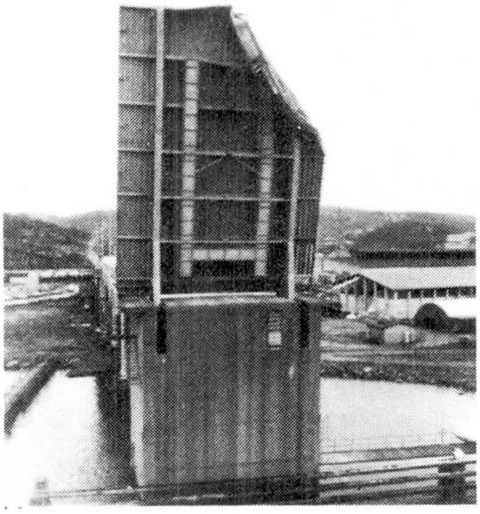

Fig 4. Damage on the Jordfallet bascule-bridge

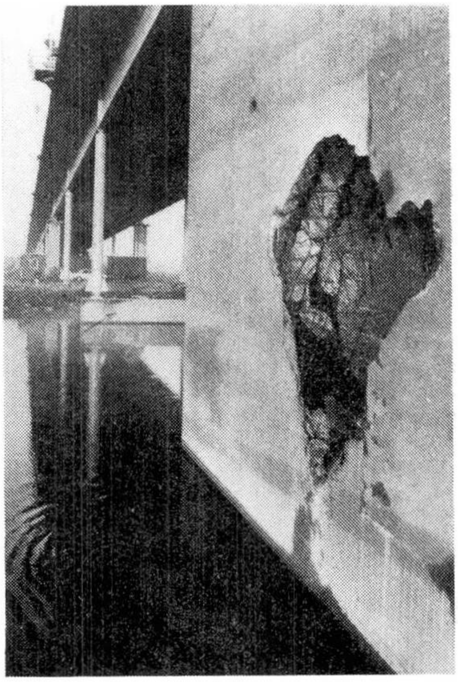

Fig 5. Damage on a bascule-pier at the Jordfallet-bridge

1.2 Some lessons from the Swedish accidents

The Swedish accidents are not very special, compared with others, which have happened all over the world. Nevertheless,they elucidate some elementary facts:

a. The threat of ship collisions with bridges is a real risk, which has to be regarded in the design concept. If possible, all piers and the superstructure should be placed out of the navigation area.

b. The superstructure of a bridge can not withstand any important ship collision. Normal steelplate structures are extremely sensitive for impact. The energy absorption of the bridge structure is very small.

c. Concrete structures must be made very thick and heavy reinforced if they shall withstand the collision impact from ships.

d. Guard-railings and other common navigation-aids are not enough effective, to prevent a collision. A colliding ship often hits the bridge besides of the navigationchannel. All piers in deep water must be regarded as threatened.

The Swedish design rules for ship collisions try to observe the above mentioned facts. It is supposed that the piers, if placed in deep water, are totally rigid and that all the collision energy must be absorbed by movements or deformations (damage) of the ship.

2. SWEDISH DESIGN REGULATIONS REGARDING SHIP COLLISIONS WITH BRIDGE PIERS

2.1 General remarks

In connection with the discussions about a planned new 18 km long bridge over the Öresund between Sweden and Denmark 1964-65 a study of measures against the risk of ship collisions with bridge piers was made in the Swedish Road Administration /2/. The need of regarding such risks was pointed out by the above mentioned accident at the Hjulsta bridge and became strongly stressed by the Maracaibo disaster, which had happened in May 1964.

The study, which was based on the Minorsky-analysis of energy absorption at collisions between two ships, resulted in the statement, that it is possible to design the piers of large bridges against the forces, which can arise by collisions with small ships (5000 dwt) and with mediumsized (40.000 dwt) ships. A series of some basic design rules were made up for the Öresund bridge, which then have been modified and applied to about a dozen of new Swedish bridges since 1965. Later on, these rules have been developed to the unified Nordic Recommendations, given in /3/.

2.2 Design rules for the Öresundbridge project

The proposed design forces for the piers of the Öresundbridge are given in fig 6. They have a maximum of 150 MN and are based on the assumption of a full speed collision (16 knt) of an ordinary 40.000 dwt tanker. It was even stated, that a 100.000 dwt tanker gives forces of about 240 MN (dotted extrapolition of the main line to a draught of about 16 m).

The design rules prescribed furthermore:

that piling foundations - if possible - should be avoided,

that the pier shafts should be made of reinforced concrete with at least 2 m walls, surface reinforcement ø 25 ≠ c 200,

that the cross section of the pier should be given a form which would be capable to break through the shipshull,

that the pier shafts should be made in one piece, if minor than 10 m wide,

that the bearings should be properly fixed on the top of the pier,

that the collision forces may be regarded as ultimate loads, safety factor 1,0.

The above mentioned regulations have been made especially for the Öresunds-bridge. They had to be modified for other bridges with regard to ship size, speed and other conditions.

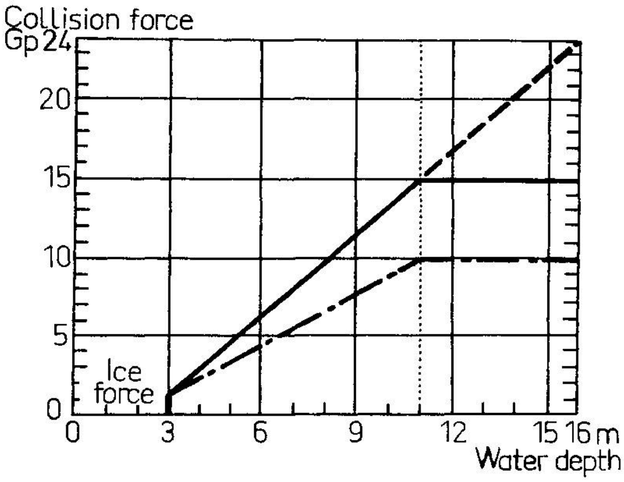

Fig 6. Design-forces due to ship-collisions for planned Öresundsbridge

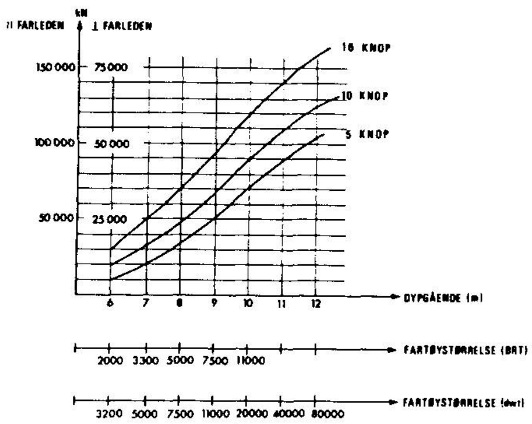

Fig 7. Shipcollision forces according to Nordic Recommendations

2.3 Nordic Recommendations of 1975

The Nordic Recommendations /3/ have been developed from the Swedish rules. The proposed collision forces are based on the same study /2/, using Minorskys energy-formula. But there are made some justifications in order to take account of the risk that big ships can sail in shallow water when unloaded. Moreover the risk of side-way collisions at low speed has been observed. Last not least some extrapolation has been made into the low energy area, which not can be handled according Minorskys formula, but which is of great importance for small bridges passed by minor ships.

The recommended design forces are shown in fig 7. They are applied as statical loads in the water level on the piers on each side of the navigation channel, perpendicular to the bridge´s axis (parallell to the channel). In the direction of the bridge´s axis and on other piers,far away from the channel, minor forces (e.g. 50 %) can be chosen as design loads. The characteristic ship size, when using the diagram fig 7, is that size of ships, which can be expected to pass the channel a certain number of passages a year, depending on the nautical difficulties in the channel, e.g. 100 passages/year in a easy navigated channel.

The general detailing rules, as mentioned in 2.2 above are valid also according to the Nordic Recommendations. The pier-dimensions may be changed in relation to the various impact forces. The large forces might be handled as surface loadings of about 2000 kN/m^2, which corresponds to the strength of the hull of large ships. For minor impact about 500 kN/m^2 is adequate.

2.4 Decisions of the administration

The Swedish design rules as well as the Nordic Recommendations lead normally to severe economical consequenses. They are therefore reconsidered by the administration in every special case in order to get both an acceptable cost and risk-level. It seems not yet possible to give correct figurs of the probability of ships collisions and of the consecuting risk- and safety levels. If figures are available they are valid only for very special circumstances, or they are the result of very grove assumptions. In normal cases is it neccessary to specify the collision design forces by a deterministic process after discussion of the costs and benefits of various possible measurements intended to increase the collision safety and the total safety.

The first question in this process is: Is it possible to avoid all collision problems, e.g. by altering the position of the bridge or of the piers?

If not, the next question is: What is the largest shipsize, which will pass the bridgesite and with what speed and frequency? Can piers of normal design withstand the possible impact forces?

If not, the next question might be: Is it reasonable to take a higher risk and to design the piers for a smaller ship size, which is more frequent? In Sweden we accept a number of between 20 and 100 passages/year, depending on the navigational difficulties of the channel.

The next question is usually: What is the cost of strengthening the piers for the actual design forces? Or what is the cost of alternative guard measures as protective piers, fenders or guard railings? In Sweden we have accepted a cost increase of between 5 to 20 % of the whole bridgecost, depending on the importance of the roadway.

The next question might be: What can be done by navigational means for improving of safety? Possible means in this field are: Speed limit, pilot-duty, direction-division, limit of ship-size, limit of admitted time, sight or weather-conditions, prescription of tug-aid, bridge-to bridge-contact and others.

A very important question is also: What can be done for safety by installing navigational aids? Here might be mentioned: Racon for marking of the channel, the superstructure or the piers. Lighthouses, beacons and buoys as manoeuvre-aids. Signals, lights, colour-marks for improving of visibility.

These questions are regularly discussed between the road administration and the navigational administration, which nearly always can come to an agreement. If there is a conflict of various interests, it is possible to get a special courts judgement. In that case often the nautical interests will win, as they can rely on "the elder legal right". The case may then go to the government, which can judge with regard to the total national-economical background of the project.

When all the premises have been clarified, the road administration, which normally is responsible for the planning, the construction and the maintenance of the roadway and the bridge, has to make the final decision regarding spans, piers, design-assumptions and protective measures of the bridge. In that way a certain risk-level is determined, but it is not very well-defined.

The risk-level, without taking special regard to the collision-risks in design, may be estimated from the Swedish experiences to a collision-probability of $\frac{5}{200 \times 20} = 1{,}25 \cdot 10^{-3}$, based on 5 collisions at 200 bridges during 20 years. (All movable bridges are included here). This ratio is higher than what can be obtained from the fact that about 1,5 collisions occur each year on about 10.000 risky bridges all over the world. The Swedish ratio might be reduced to the order of 10^{-4} to 10^{-5} p.a. by adopting all the above mentioned risk reducing measures. The international ratio may increase, if <u>all</u> accidents should be reported.

3. REVIEW OF EXISTING BRIDGES

3.1 Guidelines

After the Tjörn-accident the Swedish Road Administration made a survey of all Swedish bridges across shipping channels in order to detect especially exposed bridges. In the study the following presumptions were made:

- all bridges designed for ships-collision-forces (as above) are regarded as safe
- all bridges with a navigation-channel used by ships of 500 dwt or less are regarded as safe
- all movable bridges are regarded as safe, as they are under permanent observation by the operator, they are always equipped with special guard-railings and they are passed by the vessels with outmost caution.

3.2 Results

The Swedish Road Administration is responsible for totally about 11.300 road-bridges, about 140 of these are movable. The first round of the study brought about 60 bridges to discussion, beside of the movable bridges. The above mentioned presumptions left in the last round only six bridges for special considerations of measures.

At two bridges the thin-walled box-piers have been filled with reinforced concrete. At one bridge artificial islands were established around two of the piers. At one bridge a by-pass channel was closed for all navigation. At four bridges the navigational channel and the visibility of the bridge piers were improved and on three bridges radar-echo equipment of the most effective modern type was installed.

There are remaining risks on two big bridges, where the collision-force capacity could be improved to about 10 MN, but it seems for technical and economical reasons impossible to improve it more. Because of large depth of water over large areas, protective piers become very expensive and uneffective. Floating protective equipment seems not adequate as it must be removed during winter, when there is heavy ice on the sea and no navigation. Everything is done to improve navigational safety. As the frequency of big ships is low, we are going to accept the remaining risks for the moment. In future the complete closure of the navigation channel for ships over 2000 dwt is discussed for one bridge. At the other bridge the need of navigation with big ships is decreasing because of changes in the industrial structure of the area.

On the actual bridges also permanent warning systems have been discussed, which can stop the road circulation if something happens to the bridges.

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