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Autor: Tambs-Lyche, Per

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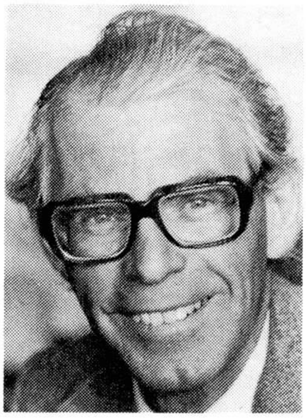
Vulnerability of Norwegian Bridges across Channels

Vulnérabilité des ponts enjambant des canaux de navigation, en Norvège

Verwundbarkeit von Wasserstraßen überquerender Brücken in Norwegen

Per TAMBS-LYCHE
Director Bridge Division
Public Roads Administration
Oslo, Norway



Per Tambs-Lyche, born in 1920, got his M. Sc. in civil engineering at the Technical University of Norway 1946. He has worked in the Public Roads Administration since 1946, as director of the Bridge Division from 1973.

SUMMARY
The paper describes the procedures for protective actions taken for securing bridge foundations against ship collisions. Relevant loads used in the design are given. No major catastrophe has occured. Some minor collisions causing relatively serious damage are described. A survey undertaken in 1982 to spot and evaluate the bridges that could be in danger of ship collision are presented.

RÉSUMÉ
L'article décrit les procédés de mise en place de systèmes de sécurité pour la circulation maritime et la manière de construire les fondations de ponts pour prévenir d'éventuelles collisions. L'article donne également les forces d'impact retenues pour le calcul. Aucun accident grave n'est survenu. Quelques collisions causant d'assez graves dégâts sont mentionnées. Une étude des ponts les plus exposés à des collisions a été réalisée en 1982.

ZUSAMMENFASSUNG
Das Vorgehen beim Festlegen von Sicherheitsvorkehrungen für den Schiffsverkehr und für den Brükkenbau in bezug auf Zusammenstöße wird beschrieben. Die Aufprallasten für die Bemessung werden angegeben. Von größeren Katastrophen ist man verschont geblieben, es wird jedoch von einigen Auffahrunfällen mit erheblichem Sachschaden berichtet. Das Ergebnis einer im Jahr 1982 durchgeführten Überprüfung der am meisten gefährdeten Brücken wird vorgelegt.

1. INTRODUCTION

The Norwegian topography, with the narrow and deep fjords and numerous islands has resulted in a considerable amount of bridges crossing ship channels. The survey has detected 102 bridges of the kind. In each single case the criteria are worked out together with the Coast Directorate, which is the main authority for marine traffic. Requirements for sailing height, channel width and necessary actions for directions of ship traffic and bridge protections are worked out.

It is a difficult task to determine the load acting on a bridge during a ship collision. The actual force is depending upon the size of the vessel, its construction that determines the deformation length, velocity, deformation of the bridge foundation, the angle of collision etc.

In Norway it has, for practical and economical reasons been the rule to protect only the main foundations adjoining the ship channel, and only to a lesser degree protect the other foundations. However, by proper design these are given the best possible protection.

In the Norwegian ship navigation instructions, spesifications of the permissible size of the ship and width and height of the sailing channel are given.

Even with the rules described above, it is possible that larger ships accidentally may hit a bridge foundation. This might be due to navigation errors, bad weather, engine troubles etc.

The possibility of a ship collision is therefore always present. The degree of protection must be a compromise between the acceptable risk and the cost of establishing protection.

As part of the work done by the association of nordic road administrations, spesifications for the static forces to be used in the design has been worked out. These are related to the size of the ship, the ship depth and velocity. See fig. 1. (1).

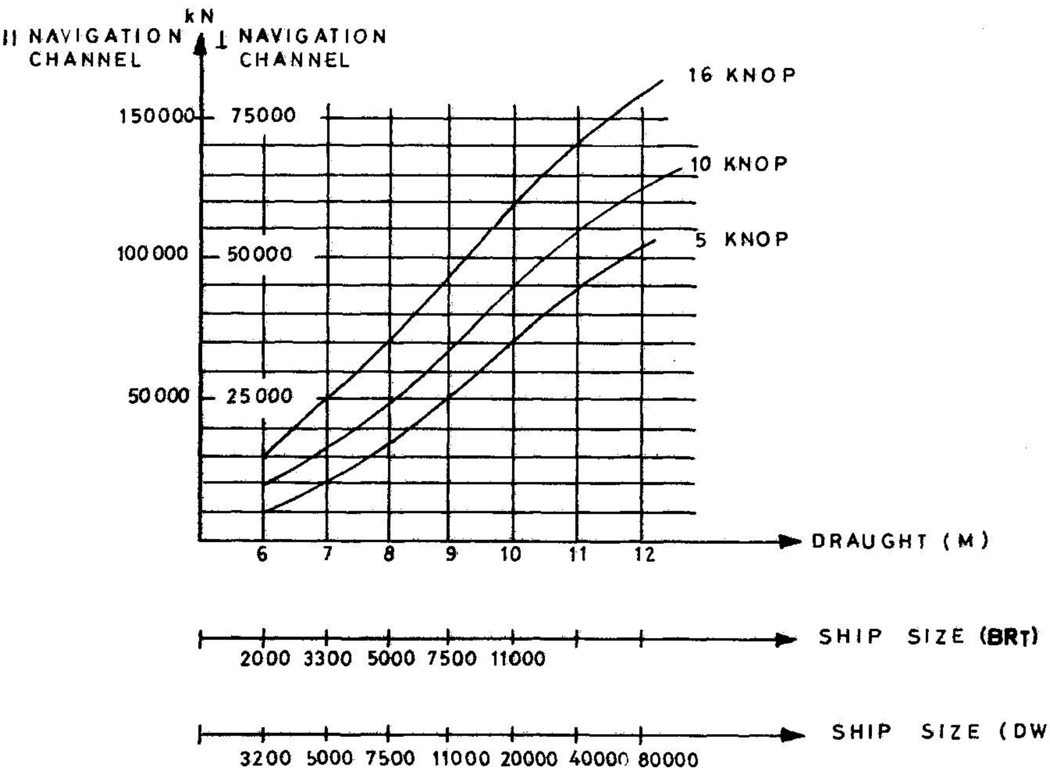


Fig. 1 Magnitude of ship collision force as a function of ship size and speed

It is for this matter refered to the article by Werner von Olnhausen, head of the bridge section, Sweden Road Administration.

Norwegian bridge foundations adjoining a ship channel are as a rule designed for a static force of 3000 MP perpendicular to the bridge's axis (parallel to the channel) and 1500 MP parallel to the bridge. The foundations are usually supposed to be rigid. The size of this force is approxemately supposed to represent a ship of 8000 dwt at a speed of 5 knot.

2. SHIP COLLISION ACCIDENTS IN NORWAY

Fortunately, there has been no disasters caused by ship collision involving Norwegian bridges. However, some major accidents, requireing large repairs have occured, as will be described briefly as follows:

2.1 Tromsø Bridge

This bridge, which was opened to traffic in 1960, was one of the most remarkable concrete bridges in Norway at that time.

With its 1016 metres long superstructure resting on slender columns above Tromsø Sound, it is, together with the near situated "Artic Cathedral", perhaps the most well-known landmark in Northern Norway. Fig. 2.

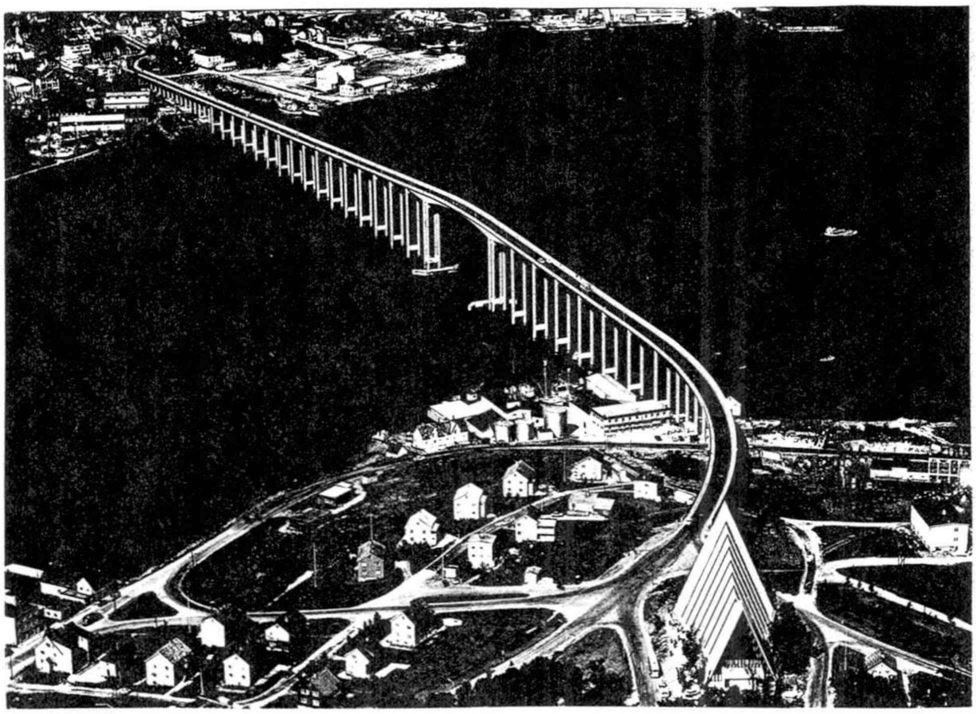


Fig. 2 Tromsø Bridge

To day, having learned by experience from several serious accidents around the world, and also a great number of smaller accidents in Tromsø Sound, we must state that the risk of collision between passing ships and the columns of Tromsø Bridge, was not satisfactorily judged when the bridge was planned.

The center to center distance between the two pairs of columns on each side of the main span is only 80 metres, and between fenders protecting these columns, the channel is only 60 metres wide. Between the main span and the abutments on the Tromsø side and the Tromsdal side respectively, the distance between the pairs of columns varies from 24 to 10 metres.

Especially against the Tromsø side, i.e. about 600 metres of the bridge length, the depthof water varies from about 12 to 7 metres. In July 1977, M/S May Veronica, a large fishing vessel, ran into a column 134 metres from the channel. Fortunately the damage was limited and not serious.

The tidal stream can reach a speed of 4-5 knots in the channel, and ships passing should then keep 8-10 knots to have steering control. Each of the original fenders were designed for a static force of only 100 tons acting parallel to the channel, and for 5 tons pr. meter of length of the fender structure acting parallel to the axis of the bridge. (The fender was about 20 metres long, i.e., the force used in the calculations was approximately 100 tons.)

In a letter from July 1957 one can read that concrete piles were considered as more longlasting than steel piles and therefore chosen in the first fender structures.

Danger of cracks in these stiff piles would occur if, during a collision, the fender slab was given a horizontal deformation of 30 centimetres only.

On the 21 November 1961, the 10 000 dwt. S/S "Gloria" ran into the eastern fender. The fender slab above the water as well as most of the concrete piles carrying the slab were completely destroyed and ended on the bottom of the sea. Fig. 3 shows the dimensions of the ship, the channel and the fenders.

On the 21 May 1963 the western fender suffered the same fate as its easterly twin. M/S "Rotesand", a 1560 dwt ore-ship, then ran foul of the fender which collapsed and had to be removed. Fig. 4 shows the fender structure after the breakdown.

When the two fenders were rebuilt in 1962-63, hollow steel piles KP 35, filled with concrete, were used. The clearance between the fender slab and the nearest columns was 5 metres. Fracture of the piles were expected at a horizontal deformation of the fender of 4.3 metres. This would, approximately, be sufficient to stop a 10 000 dwt ship drifting into the fender at a speed of 0.5 m/sec.

In its first years of service, the Tromsø Bridge was a toll bridge under local administration. When the Public Road Administration (PRA) later was asked to take over the responsibility for the bridge, the Administration made demands for stronger fender structures.

The port authorities informed that the yearly traffic in Tromsø Sound included about 100 ships in the class 8-10 000 grt and 25 ships in the class 10-15 000 grt.

The PRA therefore worked out tender spesifications for new fender structures, each designed to give satisfactory protection of the main columns of the bridge even if a ship representing a weight of 12 000 tons (calculated as the sum of displacement and hydraulic mass) ran into the fender at a speed of 4 m/sec (8 knots). Such fenders would be 10 times as strong as the existing ones.

The tenders' offers were so expensive that the Administration reviewed the whole project, taking into consideration that a neighbouring channel, the Sandnes Sound, in the future could serve as fairway for larger ships and thereby relieve the Tromsø Sound.

The existing fender structure which were built in 1974-75, were therefore designed to withstand the impact of a 7000 tons body (ship plus hydraulic mass) with a speed of 4 m/sec. The design was based on assumptions so chosen that the resulting forces should be on the safe side as far as the bridge structure is considered. (2), (3).

Ring-shaped reinforced concrete structures resting on steel piles, now encircles the groups of four columns on each side of the main span. The clearance between concrete ring and the nearest pair of columns, is 5.25 metres measured at right angle to the channel, and 7.05 metres measured parallel to the channel. Fig. 5.

The ability of the fenders to protect the bridge was demonstrated in av very re-

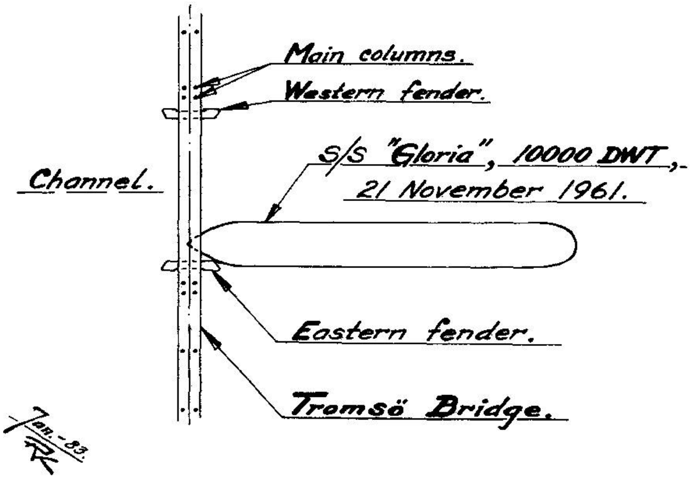


Fig. 3 TromsØ Bridge:
Collision, November 1961.
Dimensions of ship,
channel and fenders.

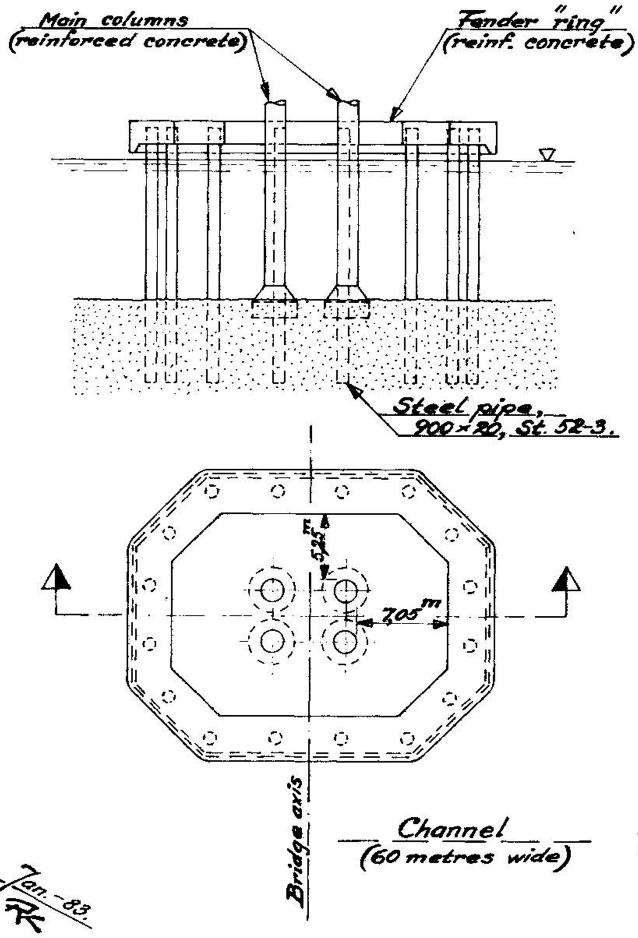


Fig. 4 TromsØ Bridge:
Western fender before and after having been destroyed. (The destroyed fender was partly resting on heaps of broken piles, which are not shown on the figure).

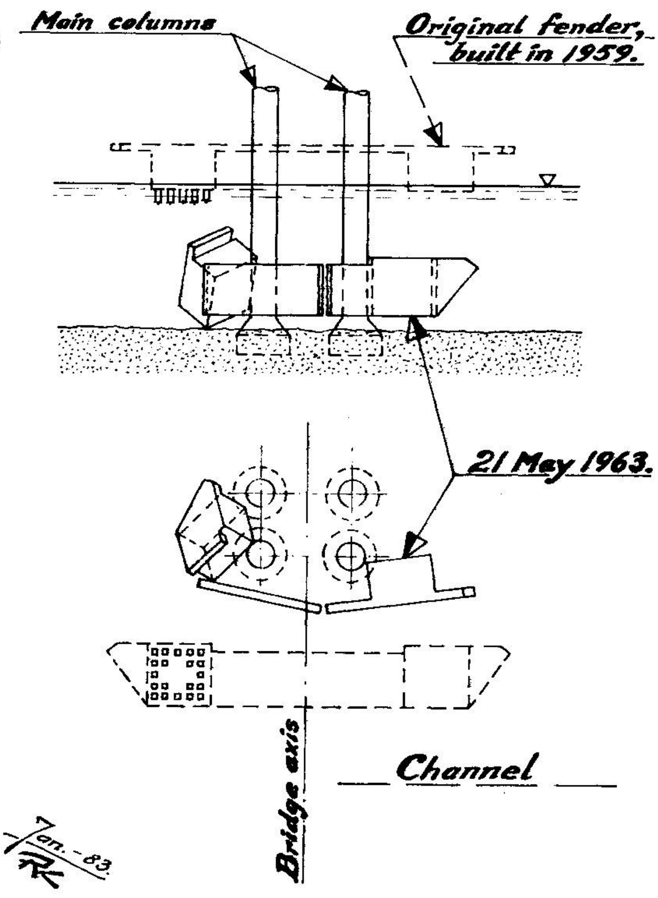


Fig. 5 TromsØ Bridge:
New fender.
Ring-shaped reinforced concrete structure resting on steel piles.

alistic manner on the 5 July 1975. Then the passenger ship "Ragnvald Jarl" ran into one of the fenders resulting in a big crack in the side of the ship and four damaged cabins.

The wooden planks along the concrete fender were more or less crushed and torn off, but the concrete and the steel parts of the structure were not damaged.

If the new fenders had not been built, the whole mid-section of the bridge would probably have fallen down.

A better protection of most of the columns carrying the smaller spans of the bridge could have been desirable, but very expensive. Obviously, a new bridge might be a better solution.

With the limited resources at our's disposal, the following precautions are recommended in the report on vulnerable Norwegian bridges across channels. (4):

I Installation of radar echo equipment along the main channel (on buoys of skerries).

II Installation of navigation lamps and/or improving existing lighting systems on the bridge.

III Installation of special warning devices to stop all the traffic across the bridge in case of serious damage to the structure.

2.2 Brevik Bridge

The Brevik bridge is situated on the main route E18, approximately a hundred miles southwest of Oslo.

The 677m long structure consists of suspended main- and sidespans of 272m and 85m respectiveliy in addition to 16 viaducts. Fig. 6.

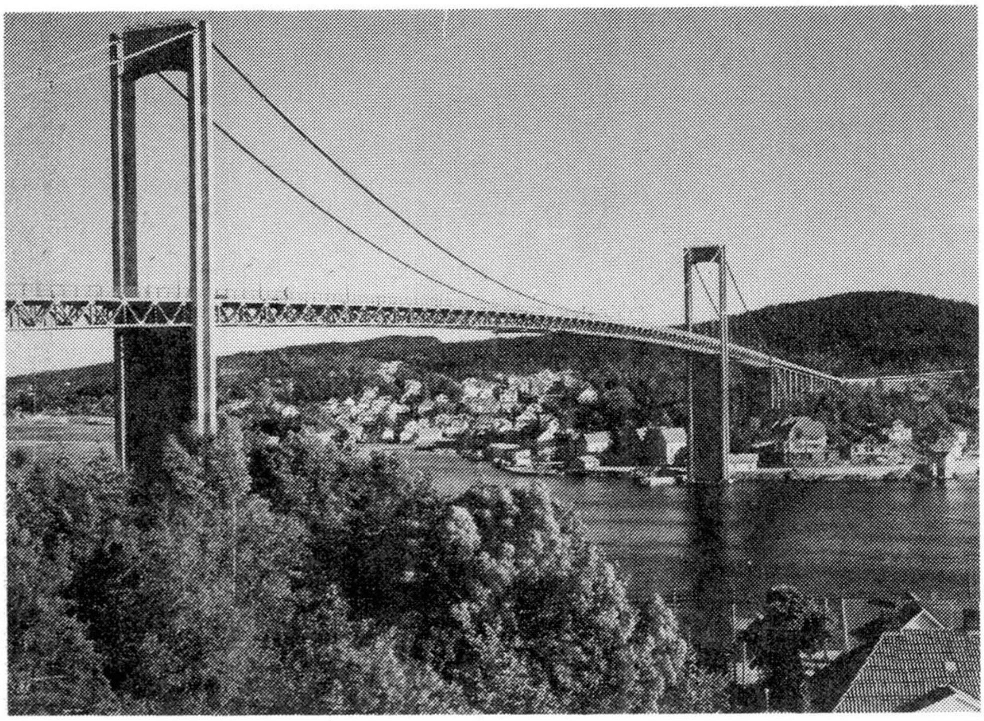


Fig. 6 Brevik Bridge

It was opened to traffic in 1962 and spans the inlet to the Frierfjord where the harbour of Porsgrunn and the largest chemical industrial centre of the country are situated.

The southern tower of the main span has been regarded as vulnerable to the ship-traffic taking place through the channel. The navigational conditions are not the best ones through the shallow, narrow and tidal waters of the inlet, though certain equipment with regard to surveillance of the ships concerned has been in operation for some time.

Even though, incidents are now and then taking place in the channel including two cases of running aground close by the tower. One of the towerpiers was left with spalled concrete after one of these episodes. In addition three other close by incidents (agrounds within 20m from the tower) have been registered. All the run-agrounds in the bridge area have taken place while ships were leaving the harbour. According to attached figure 7 the tower is obviously most exposed to collision from ships moving in that direction. It should be emphasized that part of the tonnage passing the sound carries dangerous cargo, e.g. gastankers.

Some years ago the stiffening truss system of the suspended mainspan was hit by a floating crane. The cantilevered cranearm struck the bridge about midspan 48m above sea level.

The bottom girder of the stiffening truss was locally bent without causing serious damage to the structure. Hence the bridge was open to one lane traffic througout the replacement operation of the girder and bracings.

The largerst ship having passed the bridge is said to be about 35 000 dwt. Permissible speed is set to 5 knots but might be slightly higher due to heavy tidal streams.

In order to protect the bridge and increase the safety generally, the following precautions are recommended in the report on vulnerable Norwegian bridges across channels. (4):

I A proposed filling up zone as indicated in figure 7, will reduce sailing depths at the southern tower and will also provide an energy absorbing cushion for ships running aground.

II Installation of warning devices to stop road traffic in case of serious damage to the structure.

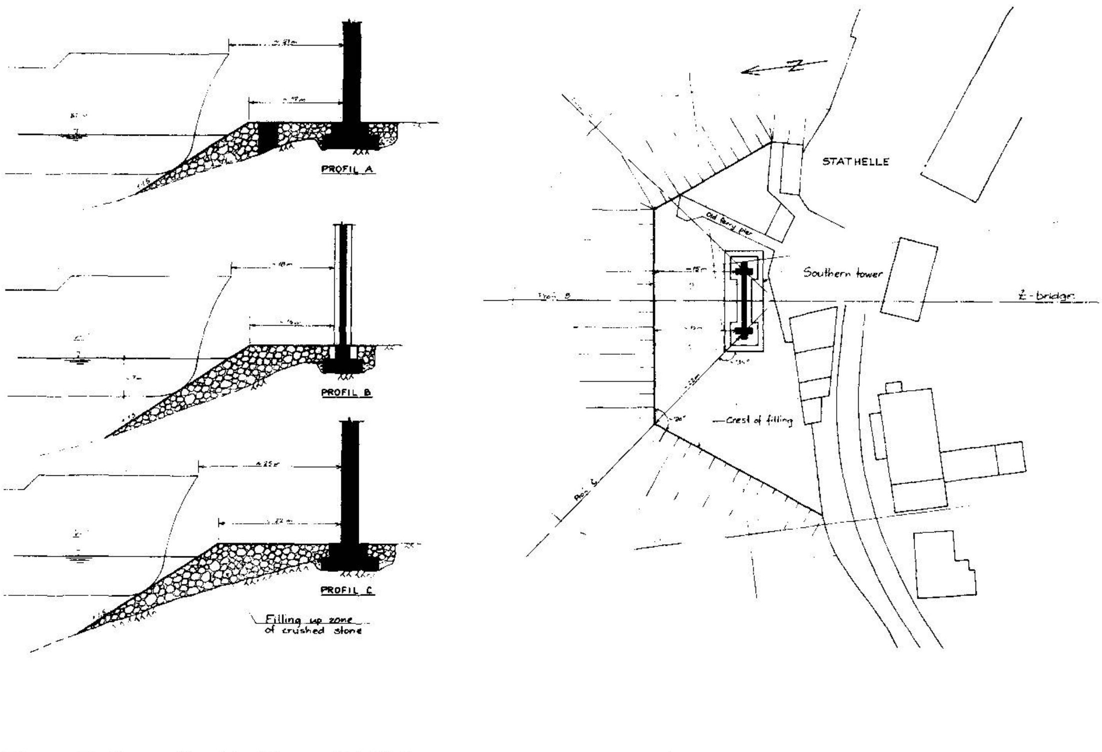


Fig. 7 Brevik Bridge; Filling up zone, southern tower

2.3 Sørsund Bridge, Kristiansund harbour

The bridge was opened in 1963. This is a free cantilever construction with a prestressed 100m main span, and 2 adjoining span of 50m. The 16 sidespans with span width of 13m are reinforced concrete, supported by a pair of circular columns with a diameter of 140cm. Sailing height is 35m over a width of 50m.

The regular ship traffic is directed through the main span. However, in 1963 a Russian ship lost control and hit the innermost of the sidespan columns. The depth of water was only 2.5m, and thus the ship was slowed down by hitting the bottom. The velocity at the moment of collision is estimated to have been 0.5 knot.

The column, having a height of approx. 38m from bottom, was hit directly by the ship and failed both at the bottom and at the point of collision. The deformation of the column was approximately 65cm. The expansion joint at the bridge deck was deformed by 3cm at one side and 8cm at the other.

The bridge was repaired by construction of two supports on the rock giving a triangle for jacking directly opposite of the point of collision. The repair was successful. The ship received a 35cm dent in the front.

2.4 Kjøkøysund Bridge, Hvaler

This bridge was opened in 1971. It represents a different type of ship collision. The bridge is a free cantilever prestressed construction. The main span is 100m. The sailing height is 25m over a width of 80m. In 1976 it was hit in the middle of the main span by the crane of a boat in regular traffic under the bridge.

The lower part of the box section in an area of 2m width, and 3.6m length at right angles to the bridge (approx. 70 degr.), the concrete was cracked, and holes developed. At 9m to both sides there were cracks between the bottom plate and the walls. Cracks developed in the walls, and the corner of the box-section was destroyed. Due to the shock, the concrete around the prestressing anchorages was knocked off. No damages were observed in the top plate. The bridge was not closed, and the repair was done in steps. First a 1m section of the hole in the bottom web was repaired to secure the carrying capasity. Then the damaged concrete was removed and replaced. Epoxy injection was used for the cracks, and glassfibers and epoxy was used approx. 10m on the bottom side for protection. No injection of the cracks in the bottom plate was done.

2.5 Gisund Bridge

During construction, the Bailey platform used for the construction of one of the main foundations for this free cantilever construction, was hit by a ship. Damages made it necessary to replace the platform. The requirement for lighting and other navigation directions had been followed, and thus the shipowner had to pay the bill.

2.6 Drammen Bridge

This motorway bridge was finished in 1975. It is a concrete box-section construction with spans around 50m. Close to the bridge is a quay in use for larger ships. In 1978 a ship of 4572 dwt was not able to reverse the engine. However, by very good seamanship the ship was grounded after manouvering between two columns. The superstructure of the ship only caused minor damages to the edges of the box-section. Fig. 8.

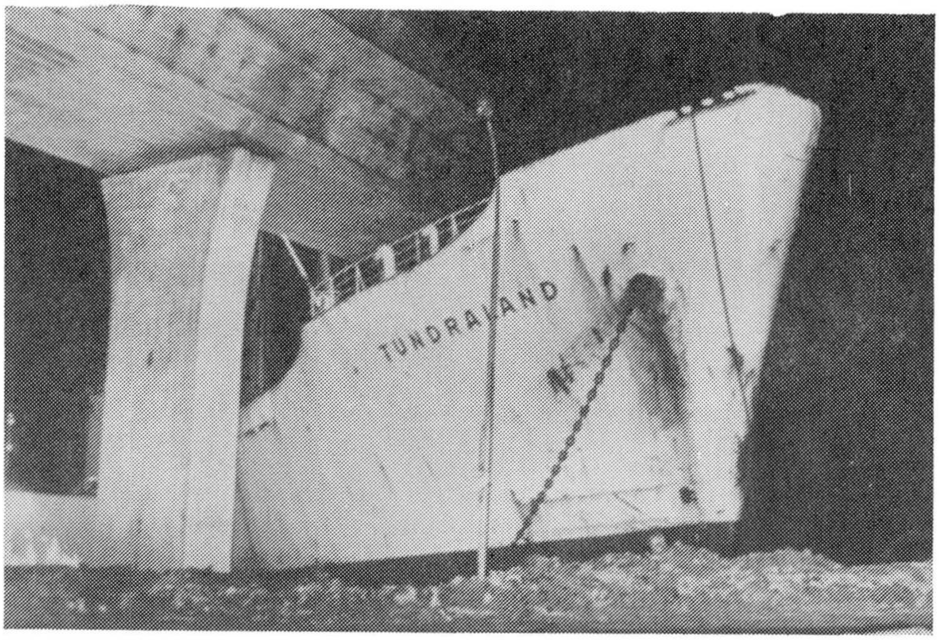


Fig. 8 Drammen Bridge; Nearly catastrophe

3. THE VULNERABILITY OF NORWEGIAN BRIDGES ACROSS CHANNELS
A SUMMARY OF THE REPORT DATED JULY 1982 (4)

The question of safety with respect to the Norwegian channel bridges was brought up by the Tjörn bridge collapse in Sweden, January 1980.

Shortly afterwards the Norwegian Public Roads Administration, through its Bridge Division, prepared a preliminary survey on bridges which were supposed to be classified as a channel crossing. The actual size of the ships which possibly could pass through the waters - and their frequency - was not taken into consideration on this stage of the proceedings.

The list of the 102 bridges thus brought forward was based on selections made by the local road authorities in the coastal counties concerned.

Fairly early in the subsequent examination of the listed bridges it became evident that a realistic number of vulnerable constructions was much smaller when importance was attached to the following conditions:

- Vulnerability of piers and superstucture against collision.
- Expected size of ships and traffic intensity through the channel.
- Intensity of motor traffic and pedestrians across the bridge.

The report was only aiming at different means of secureing ships and structures by improving navigational conditions and pier protection in the main channel area. A reinforcement of bridge structures outside this area even though spanning across navigable waters, has been ignored from technical and economical reasons. The safety of these structures has been taken care of we believe by the road-traffic warning system recommended in the report.

The navigational conditions at the bridges in question were reviewed by the Coast Directorate. Their evaluation of the naval problems together with conclusions drawn up by the Bridge Division led to the presentation of the final report containing 20 presumably vulnerable bridges. The report states that increased safety can be achieved by applying one or more of the suggested improvements listed below:

I Better pier protection by reducing sailing depths, i.e. a filling up zone around main foundations to an acceptable level.
Alternatively - construction of separate fenders. (4 bridges).

II Installation of radar echo equipment along the main channel (on buoys or skerries), (6 bridges).

III Installation of navigation lamps and/or improving existing lighting systems on the bridge. (13 bridges).

IV Installation of special warning devices to stop all the traffic across the bridge in case of serious damage to the structure. (8 bridges).

Though the existing procedures for designing adequate pier protection - as well as positioning of structure according to navigational requirements - appears well established, we believe that this report will pinpoint new aspects of the question of safety for channel crossings.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

1. Lastbestemmelser for vegbruer Nordisk Vegteknisk Forbund; Rapport nr. 4: 1980.
2. Ostenfeld, Chr.: "Shipcollisions Against Bridge Piers", IABSE Publications, twenty-fifth, volume, Zürich 1965.
3. Arild, Arnulf: "Beskyttelse av bropilarer mot kollisjon med større fartøyer", Public Roads Administration, Bridge Division, Oslo, June 1966.
4. "Rapport om utsatte bruer i skipsleder", Public Roads Administration, Bridge Division, Oslo, July 1982.