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Autor(en): **Frandsen, Aksel G. / Fujii, Yahei / Olsen, Dan F.**

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Ship Collision Studies for the Great Belt East Bridge

Etudes sur la collision de bateaux pour le Pont Est du Grand Belt

Studien zum Schiffsanprall für die Ostbrücke der Grossen Belt-Verbindung

Aksel G. FRANDSEN
Consulting Engineer
COWIconsult
Copenhagen, Denmark

Aksel G. Frandsen, born 1924, got his M.Sc.C.E. degree at the Technical University of Denmark in 1948. In COWIconsult since 1949 he has been responsible for some of the firm's advanced bridge projects.

Yahei FUJII
Traffic Researcher
Taiyo Musen Co. Ltd.
Tokyo, Japan

Yahei Fujii, born 1926, got his physics degree at the Tokyo University. Ph.D., D.Sci, E.Eng and FRIN. He is involved in electronic navigation and traffic studies.

Dan F. OLSEN
Consulting Engineer
COWIconsult
Copenhagen, Denmark

Dan F. Olsen, born 1945, M.Sc.C.E. 1970, Ph.D. 1973 from the Technical University of Denmark. In COWIconsult since 1977 he has been working on risk analysis, especially on ship collision with bridges.

Soeren SPANGENBERG
Project Manager
Great Belt Link Ltd.
Copenhagen, Denmark

Soeren Spangenberg, born 1950, M.Sc. in structural engineering 1976 from the Technical University of Denmark and B.Com. His main subject is design philosophy and structural analysis of ships and offshore constructions. Since 1987 project manager with the Great Belt Link Ltd.

SUMMARY

The paper summarizes some of the results obtained from the ship collision study for the East Bridge of the Great Belt Link. The study included collecting data of vessel traffic, evaluating the effect of the planned bridge structures on the navigation conditions and evaluating the risks and consequences of vessel collisions with the bridge.

RESUME

L'article présente quelques résultats des études sur la collision de bateaux pour le Pont Est sur le Grand Belt. Les études comprennent la saisie de données du trafic de bateaux, l'évaluation de l'effet des structures de pont projetées sur les conditions de navigation et l'évaluation des risques et des conséquences de collisions de bateaux avec le pont.

ZUSAMMENFASSUNG

Dieser Beitrag fasst einige Ergebnisse der Schiffsanprallstudie für die Ostbrücke der Grossen Belt-Verbindung zusammen. Die Studie umfasste das Sammeln von Daten über Schiffsverkehr, Bewertung von Wirkungen der geplanten Brückenkonstruktionen auf die Navigationsverhältnisse sowie der Risiken und Folgen von Schiffsanprallungen mit der Brücke.

1. Introduction

The Great Belt Strait has a width of approximately 18 km. and divides Denmark into two parts, and the population into nearly two halves. By connecting the two main islands of Zealand and Funen - Funen is already connected to Jutland by bridges - a fixed link will be made between Copenhagen, the capital of Denmark, the main land of Jutland and the continent.

An international shipping route passes through the Eastern part of the strait and is the only deep water route connecting the Baltic Sea with the North Sea. The traffic flow is approximately 20,000 vessels/year. At the moment there is intensive ferry traffic across the strait (a total of approximately 50,000 movements per year), most of which is likely to disappear after the Fixed Link is completed.

The Fixed Link consists of three parts. The Western part of the link will be a combined rail and road bridge. The Eastern Channel crossing will consist of a bored tunnel for train traffic and a suspension bridge (the East Bridge) for motor vehicles. The East Bridge will have a number of piers located in navigable water and thus exposed to the risk of vessel collisions.

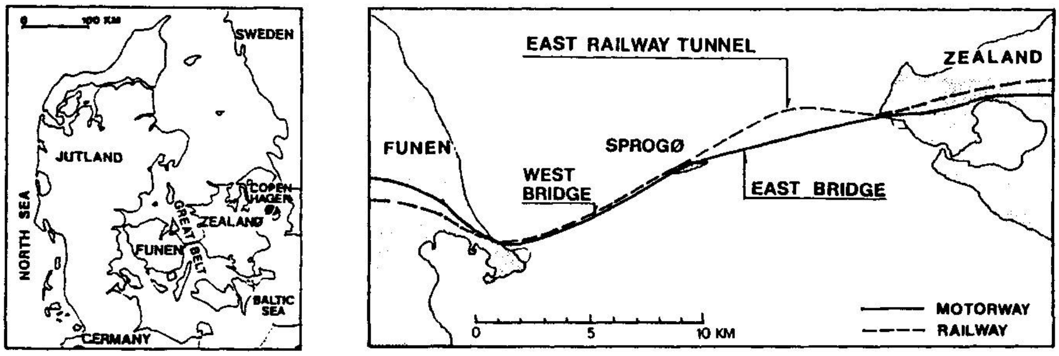

Fig. 1. Map of Denmark showing the position of the Great Belt Link.

Preliminary investigations for a fixed link were carried out already in 1977 to 1979, including a study of the risk of vessel collision [1]. In 1989 the Great Belt Link Ltd. asked COWIconsult to undertake a new comprehensive investigation of the interaction between vessel traffic and the planned bridge structures across the Eastern Channel.

The investigation included collecting data on the existing conditions for the vessel traffic in the Great Belt, forecasting expected traffic development [10], collecting vessel accident statistics and data on environmental conditions, evaluating the effect of the planned bridge structures on the navigation conditions, and evaluating risks of collisions as well as predicting potential consequences of the possible collisions. The results of the investigations have formed the basis for a new, improved vessel/bridge collision model.

Methods of reducing the risk of vessel collisions have been investigated. A conceptual design of a Vessel Traffic Service system has been made in cooperation with representatives from the Danish Navy and the Danish Maritime Authorities.

The objectives of the ship collision study have been to give requirements for the design of the East Bridge against ship impact. Two main types of requirements have been established:

- The opening of the East Bridge shall be so large that ship collision with the bridge structure will be likely to occur only as a result of navigation errors and technical failures on board, and not because of increased navigational difficulties due to the bridge.

- The ship impact resistance of the bridge structure shall be so large that the estimated frequency of disruption for more than one month shall not exceed 0,04 per 100 years cf. [9].

This paper summarizes some of the results obtained by the ship collision study for the East Bridge of the Great Belt Link.

2. NAVIGATION SPAN WIDTH OF THE EAST BRIDGE

The navigation span opening has proved to be one of the most important design parameters for the design of the East Bridge. Two different methods have been applied to evaluate the effect of the span opening on the navigation conditions. The first method was computer based manoeuvring simulations and the second method was utilization of ship domain theory.

Manoeuvring Simulations

Computer based manoeuvring simulations were carried out in cooperation with experienced Great Belt Pilots at the Danish Maritime Institute, the Copenhagen School of Navigation and the Naval Tactical Trainer at Frederikshavn Naval Base. These analyses were of significant importance in the clarification and verification of the effect of different navigation span openings and different changes of the navigation route under normal as well as adverse weather conditions. The simulations have shown that it is important to perform the investigation at an early stage of the bridge design process as the result may influence the overall design of the bridge. It also provided an idea of optimum arrangement of bridge line and navigational route which formed the basis for decisions of possible dredging. The fact that professional pilots were conning the simulator ships, that the crucial man-machine interaction aspects were represented in the simulator system, and that the investigation was carried out in a cooperation between bridge designers and maritime authorities and organizations ensured that convincing and reliable results were obtained. Fig. 2 illustrates the simulator at the Danish Maritime Institute showing digital instrument screen (left), control stand (middle), track plotter (right) and visual display (background). Furthermore fig. 2 shows one trajectory plot of the used navigation procedure. The manoeuvring simulations are described in more detail in [2].

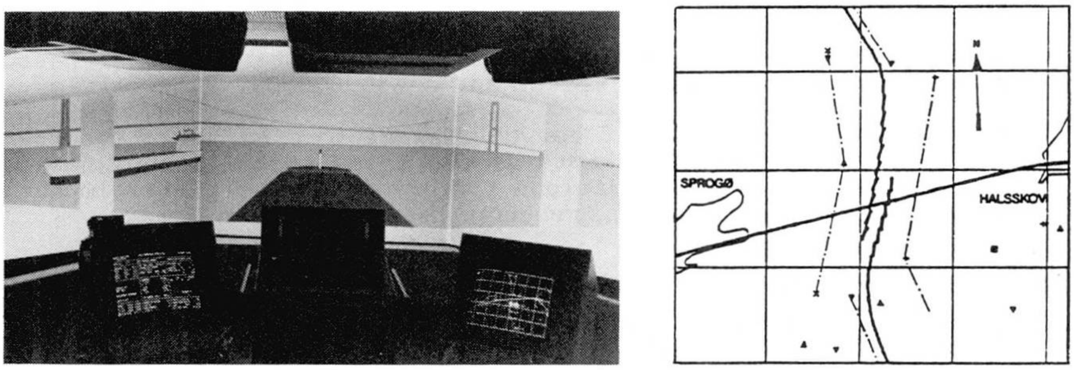

Fig. 2: View of the simulator and a trajectory plot.

Ship Domain Theory

As the resulting span opening requirement from the manoeuvring simulations surpassed earlier estimates, it was found advisable to try to verify this result by an alternative method. The alternative method was based on experience of vessel behaviour and vessel collision records from large bridges worldwide. The method offers empirical rules for estimating the minimum span opening. More detailed information of the background for the empirical rules are described in [3] and [4]. Fig. 3 shows the principle of the empirical rule for two way traffic.

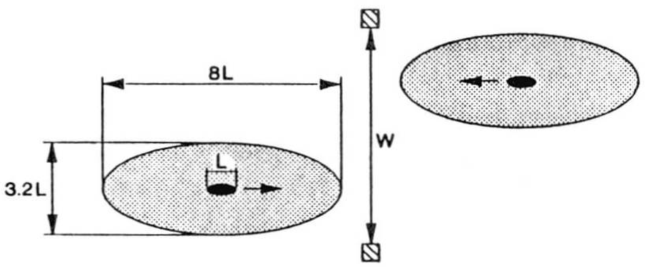

Fig. 3: Principle of the empirical rule for minimum span width assuming that vessels travel on service speed.

3. SHIP IMPACT LOADS

Impact loads due to ship collision to bridge structures have been studied by means of a literature review and analysis of ship impact loads by calculation.

Literature Review

Literature on full-scale observations, laboratory tests and analytical calculations has been reviewed. For small ships (< 10,000 DWT) the collision force seems to be very dependent on the construction of the ships. It was difficult to generalize, but use may be made of Minorsky's empirical formula [5]. For bigger ships (40,000 DWT and above) the Woisin results obtained during the 70'es seemed to provide reliable results. However, only the average impact force is estimated by Woisin [6]. It was concluded, that literature did not provide sufficient and reliable information necessary for the design of the Great Belt connection. However, valuable information on the subject and information of importance for the interpretation of the EDP results calculated by Det Norske Veritas, DnV, described below, have been found.

Pier Impact Load Calculations

The impact load calculations were carried out by DnV [11]. It was decided that impact loads should be expressed as time histories and dynamic bridge response should be considered in the design. The investigation included analysis of impact loads due to bow collisions and broadside collisions. Both global and local loads have been assessed. The majority of the considered cases refer to bow collisions. Analyses of bow collisions have been made to study the effects of ship size, ship speed, bow profile, full forepeak tanks, collisions angle, step in piers, width of piers and eccentric impacts.

In the bow collision study two ship sizes typical for the Eastern Channel have been investigated, a 40,000 DWT container vessel and a 150,000 DWT bulk carrier.

Examples of the DnV calculation in case of bow collisions for the two ships are given in fig. 4. Both examples assume 10 knots as the speed at collision. Based on these results simplified analytical equations for prediction of global impact loads due to both bow and broadside collisions have been developed.

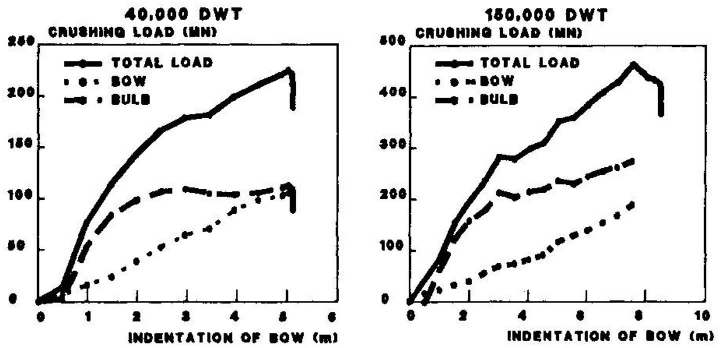

Fig. 4: Calculated impact loads from a loaded 40,000 DWT ship and 150,000 DWT ship

4. SHIP COLLISION RISK MODEL

Description of Ship Collision Risk Model.

To investigate if the acceptance criterion for disruption risk for the East Bridge tender design was fulfilled and hereby to optimize the arrangement of the approach span piers, a ship collision risk model was needed. In this model the total disruption risk is calculated as the sum of disruption risks for a number of categories, each representing a certain phenomenon.

Analysis of grounding events has shown that the main contributions to the disruption risk came from two categories:

CAT. I: Ships following the ordinary, straight route with normal speed.

CAT. II: Ships which fail to change course at the turning point close to the bridge.

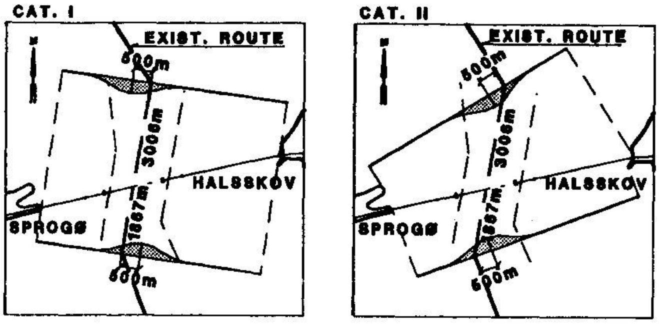

Fig. 5: Principle of the two categories, CAT. I and CAT. II.

Parameters of the Ship Collision Risk Model

Besides the more well defined data about the bridge, data about the water depths, position of lanes and ship traffic, the collision risk model is based on the following parameters:

- The causation probability i.e. the rate of failure to avoid an obstacle on the navigation course due to causes such as human error and technical failure.
- The ship track distribution, i.e. the transverse distribution of ships in a navigation channel, has been found by means of radar observations and by comparison with results from other straits.
- The ship traffic data, i.e. characteristics such as number of movements, length, breadth, airdraft, displacement for the ships in different ship size classes, have been collected.
- The Heinrich function, i.e. the ratio of severe collisions to all collisions, has been investigated based on collision data from Japan [7].

The causation probability was estimated based on data on grounding events in Japanese Straits [8], where the largest number of observations have been found. The estimate was adapted to the Great Belt navigation and environmental conditions resulting in values of approximately 3.2 10^{-4} for ships without pilot and 1.1 10^{-4} for ships with pilot on board.

Grounding events and lighthouse collisions registered in the period 1974 - 1989 at different locations in the Great Belt have been used in order to verify the estimate of the causation probability for the East Bridge. Fig. 6 shows grounding and collisions at Halsskov Rev/Sprogø Rev which is near the East Bridge alignment.

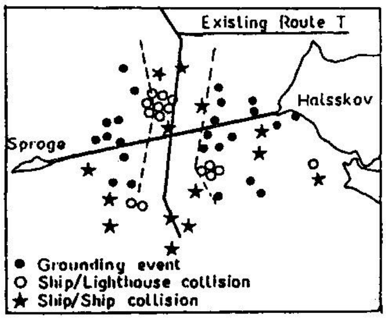

Fig. 6 Registered grounding events and lighthouse collisions at Halsskov Rev/Sprogø Rev.

By application of a modified version of the ship collision risk model, derived for the East Bridge, to the grounding events at Halsskov Rev/Sprogø Rev, the calculated number of groundings in the study period was found approximately equal to the observed number of grounding events. This result indicate that the estimate of the causation probability used in the ship collision risk model is of the right order of magnitude.

5. CONCLUSION

The comprehensive ship collision study for the East Bridge of the Great Belt Link has given valuable information and a better understanding of the interactions between vessel traffic and bridges crossing navigable waters. The study has proven that the necessary navigation span width of bridges crossing navigable waters can be estimated by use of manoeuvring simulations and empirical rules based on ship domain theory. Furthermore the study has given new information of ship collision forces and showed the importance of collecting experience from other bridges and grounding/collision data in order to develop and calibrate a suitable ship collision risk model.

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