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Ship Collision Analysis for the Westerschelde Crossing

Analyse des collisions de bateaux pour la jonction sur le Westerschelde

Analyse der Kollision von Schiffen für die Verbindung über die Westerschelde

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SUMMARY
The paper describes the selection of a tunnel-bridge connection. It also explains why a suspension bridge minimizes the results of a ship-pier collision for this situation. The advantages and disadvantages of several bridge types are mentioned. To learn the risks of a collision with the stiffening truss of the bridge a risk analysis was done. Damage levels are used to judge the design.

RÉSUMÉ
L'article décrit la procédure de sélection d'un pont-tunnel. Un pont suspendu diminue les conséquences d'une collision d'un bateau contre un pilier dans cette situation. Les avantages et désavantages de plusieurs types de ponts sont donnés. Une analyse des risques a été entreprise pour le cas d'une collision contre les poutres de rigidité du pont. Des niveaux de dégâts sont utilisés pour juger le projet.

ZUSAMMENFASSUNG
Der Artikel beschreibt das Selektionierungsverfahren einer Tunnelbrücke. Eine Hängebrücke vermindert die Folgen einer Kollision eines Schiffes mit einem Pfeiler in dieser Situation. Die Vorteile und Nachteile mehrerer Brückentypen werden erwähnt. Um die Risiken einer Kollision mit dem Versteifungsträger zu schätzen, wurde eine Risikoanalyse gemacht. Schadenniveaus werden gebraucht, um das Projekt zu beurteilen.

1. GENERAL ABOUT THE PROJECT

1.1 Introduction

In 1978 the province Sealand decided to start with the preparations to change the present ferry connection over the Westerschelde by a fixed link under and across the river. The decision was based on promises done by the Dutch Government, that was asked to support the project.

The realisation and future control should be done by a limitid liability company. The province Sealand should hold 99% of the shares.

Income should be guaranteed by toll income. Further the Central Government promised to furnish the amount of money presently paid to cover the losses of the ferry connection in service nowadays. These losses are 70% of the operating costs. The Central Government should also furnish the amount of money necessary to realise a new ferry harbour in case no fixed crossing is realised.

Financial considerations required to have an impression of the financial risks. For this reason it was important to know the risk of a ship collision with the result no possibility to use the bridge and consequently no toll income. Together with insurance companies was looked for the costs to insure the risk, also is examined the advantages of an energy absorbing construction to reduce risks and possible insurance costs.

1.2 Location of the planned crossing

The location of the proposed bridge is in the South-West of the Netherlands across the Westerschelde estuary. The Westerschelde estuary is the only estuary which is not closed as a result of the Delta Works (These works have the purpose to defend the South-West of the Netherlands against the sea). Closing of this estuary by a dike is partly not possible and partly not allowed. Partly not possible, because the estuary is the entrance to the harbours of Antwerp, Terneuzen and Gent. Partly not allowed because the Netherlands promised Belgium an open connection with the sea in the past.

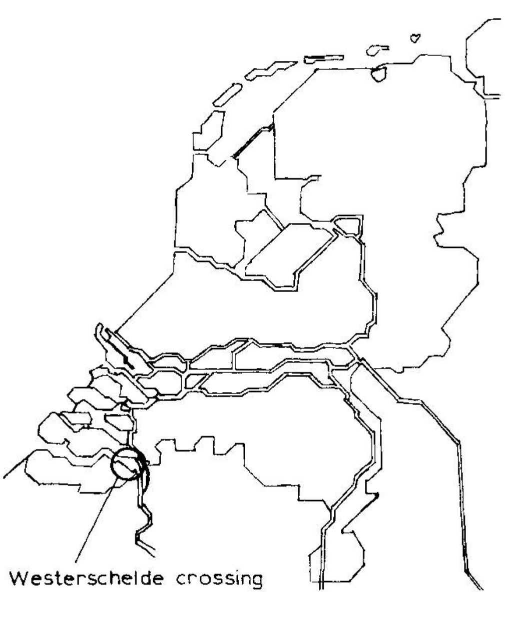

Fig. 1 Location of the bridge marked on the map of the Netherlands

1.3 Situation of the location

The location of proposed crossing has two shipping lanes. The main lane called the 'Zuidergat' and the minor lane called the 'Schaar van Ossenisse'. The minor lane is used by smaller ships to avoid busy traffic close to the locks of Hansweert, once the entrance of the bussiest canal of Europe. In the main lane big ships need relative high speed, because of the strong curvature of the lane at the location. Also for this reason the smaller ships choose for the minor lane. The plans for the crossing consist of a tunnel underneath the main channel and a suspension bridge across the subchannel. Selecting a tunnel has to do with the earlier mentioned open connection with the sea.

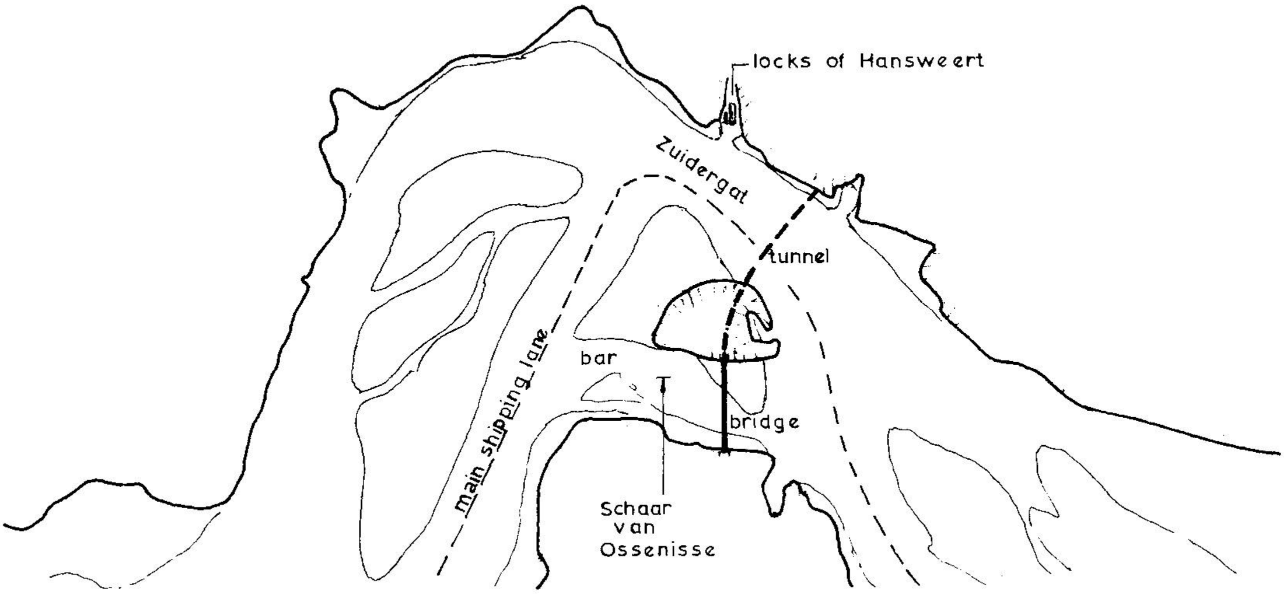

Fig. 2

1.4 General arrangement

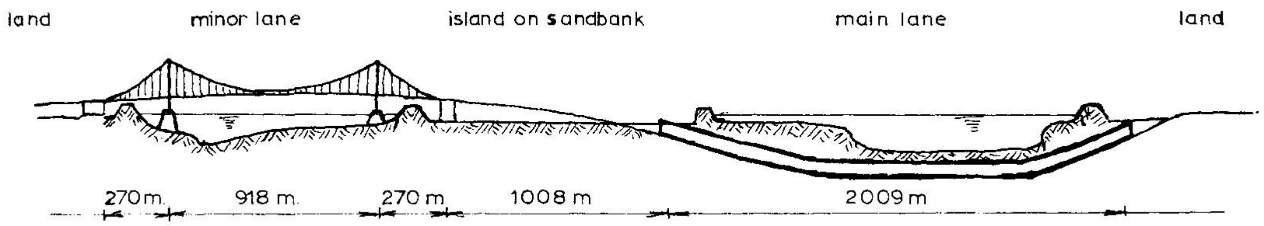

Fig. 3

To cope with the described conditions the general arrangement of figure 3 was developed.

1.5 Design

The Lock and Weir Department of the Ministry of Transport operates as the consulting engineering department for the tunnel crossing. The Bridge Department for the suspension bridge.

2. SCOPE OF THE STUDY

The Dutch Government has guaranteed in the past the Belgium Government a free connection with the sea. Free connection means also free clearance in hight. For this reason was the only possible solution a more expensive tunnel underneath of the main shipping lane. For the other less important shipping lane the link can be realised by a bridge.

With this design we got a rather unique situation. The bridge across the minor lane does not require a big clearance. Critical is the situation of a low bridge with big ships passing through the main lane very close to the bridge.

The first idea about the design was a bridge on more supports. The water depth under the bridge varies between 2 - 12 metres. A pier protection for the smaller ships was felt necessary. To the smaller ships we had also to include push barges. In the future push barges can be built together to the number of 6. Nowadays is the number 4. The weight of 6 barges can be approximately 12,000 tons. For this reason a protection is mandatory. For the protection artificial islands were selected. It became clear that because of the equilibrium of the gullies a bridge with piers with artificial islands needs bigger spans. The area is very sensitive for distrubances. The tide moves mainly through the main lane (gully) and it has to stay that way, this because it is not possible to predict what the new equilibrium is.

Bigger main spans brought two types of bridges in view, namely the stay bridge and the suspension bridge. A stay bridge in this particular situation was not in favour. This because of the big ships in the neighbourhood. A collision with the stay bridge close to the pier means the lost of a big part of the bridge. This as a result of the axial force in the deck.

As result of the mentioned considerations one choose for a suspension bridge:
- big span means fewer piers.
- fewer piers results in less artificial islands which means little hydraulic disturbance.
- with a suspension bridge the piers can be located such that they are located in shallow water.
- the deck construction is not the main construction element in regard to strength of the whole construction. Damaged areas are relatively easy to repair.

After all these considerations one question remained unanswered. What is the chance with the big ships in the neighbourhood in the main lane of a collision with the bridge deck. The study undertaken was a risk analysis of the deck construction as designed. One was not only interested in damage yes or no, but also in the change of a certain level of damage. The possible damages were differentiated in classes. Smaller damages are acceptable for the exploitation of the bridge and bigger are not. To make clear which levels were choosen, first a description of the considered deck construction. A cross section is shown in figure 4.

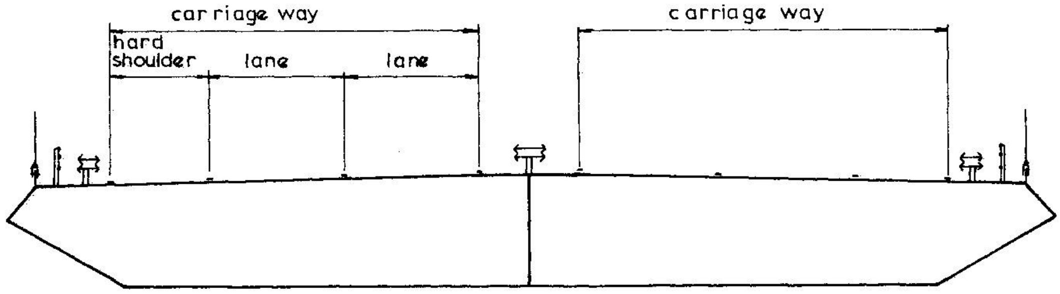

Fig. 4

The design of the crossing consists of a dual carriage way with two lanes and one hard shoulder in each direction.

The considered levels of damage are
1. scratch of dent in box girder, no consequences for the traffic
2. damage of the box edge, no consequences for the traffic
3. damage of the hard shoulder and one lane, delay in one direction
4. damage of one carriage way, delay in both directions
5. damage of total box girder, no traffic possible

3. THE STUDY

The study undertaken was concentrated on the risk values of the mentioned damage levels. To answer this it was also necessary to know what type ship or what type of collision gives what level of damage. The study is done for the bridge with the described general arrangement. Clearance in the middel of the main span is 19.935 m, near the pylons 16.067 m.

3.1 Causes

Damage of the roaddeck can only be caused by a ship which actually only can sail in the main shipping lane, because of height. The next two cases mentioned are recognized to be able to cause a collision with the deck.

a. accidently: a sea-ship of the main lane (tunnel lane) comes in the minor shipping lane (bridge lane) as result of
- a give way situation
- an accident
- a technical break down.

These situations can cause a collision if:
- it is not possible to stop in time or
- the captain thinks wrongly he can continue his trip through the minor lane.

b. wrong decision: the captain erroneously (tries a short cut) uses the minor lane 'het Schaar van Ossenisse' to reach his destination.

3.2 Institutes concerned with the study

The study is done by the Dutch Physical Laboratory TNO, the University of Delft and the Ministry of Transport (Rijkswaterstaat Bridges Department).

3.3 Method of investigation

The analysis is done by using the technique of fault tree analysis. This fault tree is built up with events which leads to the top event of a collision with the bridge. To enable the calculation of the change of the top event one must know the change of the basic events.
To know which basis events cause the top event a fault tree has to be constructed. The circumstances which have an influence on the chance of occurence of the basis event must be known.
Because certain circumstances have an influence on more events it is prefered to make a circumstance matrix of all the circumstances of influence on the fault tree.

3.4 Fault tree

3.4.1 Main fault tree

The main purpose of the study was to determine the odds of the top event e.g. a collision with the bridge. Being interested in different levels of damage there are actually more top events. In the fault tree we make also difference between a collision on the west-side and the east-side, because the circumstances are different for both sides. On the west-side the time in the tide is important. With low water a number of ships is not able to pass the bar in the sailing lane on the west-side. Also difference is made between a collision with the mast or the derricks or with the wheel house. This is done because a mast can break down before the total energy is absorbed.

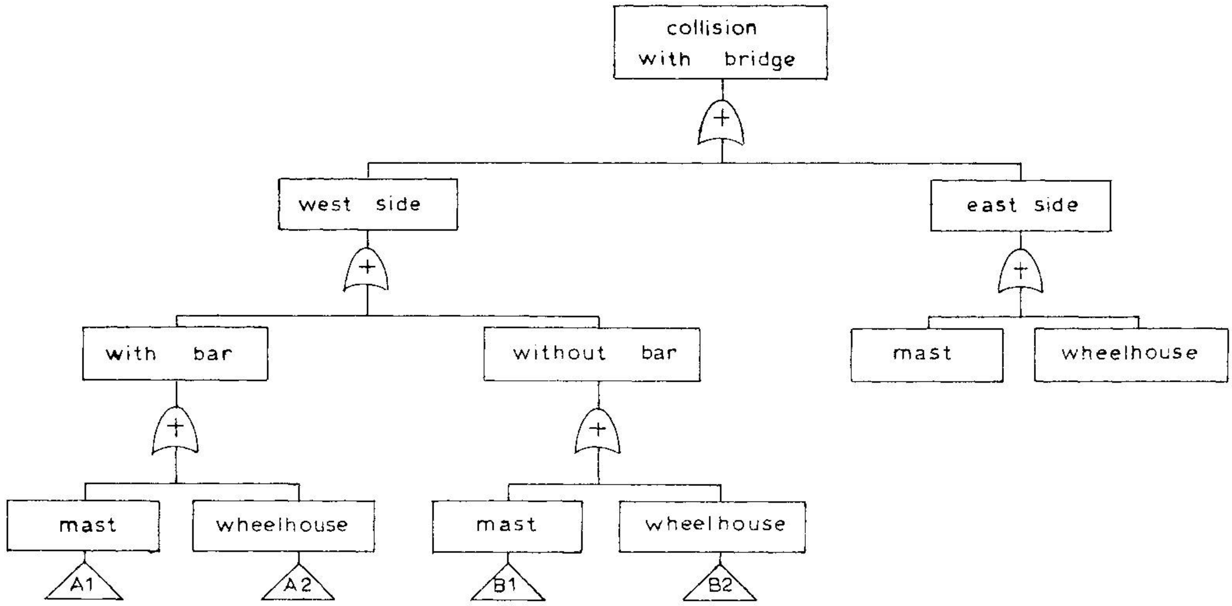

Fig. 5

3.4.2 Sub fault tree

The events, which cause the basic events of the main tree, are described with the sub trees A1, A2, B1, B2, C1 and C2. As an example fig. 6 describes a sub tree. In the subtrees A and B it is believed that a ship with a break down situation does not reach the bridge. This because the minor lane on the west-side is long and winding. The basic events are:

a. A sea going ship sailing in the main lane comes after an accident in the main lane in the minor lane as result of
   1. wrong human acting
   2. give way situation
   3. technical break down of steering equipment or engines

b. The captain thinks erroneously that he has sufficient head room to sail through the minor lane.

In a number of cases which can cause a collision it is believed that it is possible after realising the danger to make an emergency stop.

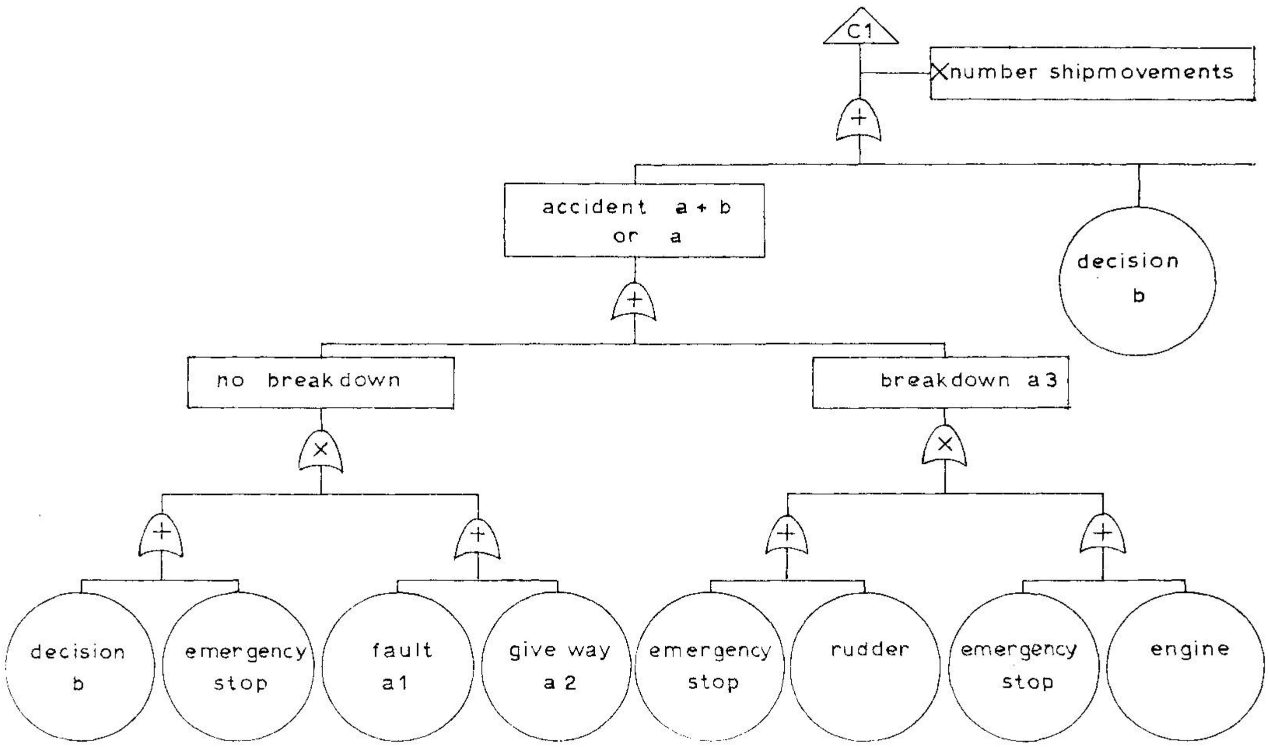

Fig. 6 Sub fault tree C1

3.5 Circumstance matrix

Circumstances of interest are:

1. type of sea going ship
2. presence of pilot
3. water depth in the lane (dependent of time)
4. day or night
5. visibility
6. weather conditions

3.6 Determination of the chance of occurence of a basic event

Chance of basic event = number of ship movements x frequence of accident

The number of ship movements is determined with the occurence matrix. The frequence of an accident is determined with information from the registration of ships which stranded. The frequence is determined by counting all the run on shore situations in the Westerschelde river and to devide them with the coast length (= 63 km). So we got the number of strandings by unit of length. The number must be multiplied by the length of the entrance of the minor lane.

3.7 Chance of top event of fault tree

The calculated chances of a collision with the bridge in the period of 10, 50 and 100 years, based on average expectation, are mentioned in tabel 1.

collision	period		
	10 years	50 years	100 years
with mast west	0.008	0.039	0.077
with mast east	0.040	0.185	0.336
with wheel house east	0.001	0.005	0.01
total	0.05	0.23	0.42

Tabel 1

3.8 Level of damage

To know the level of damage of a certain added energy we have to determine the penetration of the mast or the wheel house in the bridge deck. The penetration is calculated with the plasticity theory. The deck construction consists of a steel box girder with trough stiffeners and diaphragms. In a collision the side of the bridge acts like a membrane. The different levels of damage in which we are interested are mentioned in chapter 2. The necessary energy to cause these damages is listed below.

level 1	scratch or dent (by masts)	$E < 2$ MJ
level 2	box edge (not possible with strongest mast)	$2\text{ MJ} \leq E < 13$ MJ
level 3	hard shoulder + one traffic lane	$13\text{ MJ} \leq E < 53$ MJ
level 4	one carriage way	$53\text{ MJ} \leq E < 90$ MJ
level 5	total box girder	$90\text{ MJ} \leq E$

The change for the different levels is mentioned in tabel 2.

	total	level 1	level 2	level 3	level 4	level 5
mast west	0.077	0.031	0.046	-	-	-
mast east	0.336	0.134	0.202	-	-	-
wheel house east	0.010	-	0.008	0.002	0.0005	-

Tabel 2

The study included also an analysis of the advantages of an energie absorbing structure on the edge of the box girder.

4. CONCLUSION

On the bases of the results of this study the risks, in regard to a collision, were thought to be acceptable. For this reason the fender structure was not in favour. A fender is mostly an open structure and for this reason expensive in maintenance. The insurance companies gave no reduction on the premium in case of a fender structure.