# SAGGING OF A BARGE
Sagging and partial sinking of a barge on 5 July 2004 in the Middensluis lock of IJmuiden

The Hague, July 2006

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## THE DUTCH SAFETY BOARD

The Dutch Safety Board has been established with the responsibility to investigate and establish what the causes or probable causes are of individual or categories of incidents in all sectors. The sole aim of such an investigation is to prevent future accidents or incidents and if the results of this should give cause to do so, to attach recommendations to this. The organization consists of a Board with five permanent members and has a number of permanent committees. Specific advisory committees are formed for specific investigations. A staff that comprises investigators and secretarial reporters as well as a support staff support the Dutch Safety Board.

The Dutch Safety Board is the legal successor to the Dutch Transport Safety Board. The present investigation is initiated and partly carried out by the Transport Safety Board but published under the auspices of the Dutch Safety Board.




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|---|---|---|---|
| Address: | Anna van Saksenlaan 50<br>2593 HT The Hague | Postal address: | PO Box 95404<br>2509 CK The Hague |
| Telephone: | +31 (0)70 333 7000 | Fax: | +31 (0)70 333 7077 |
| Internet: | www.safetyboard.nl | | |

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N.B:
This report is published in the Dutch and English languages.
In the event of conflict in interpretation, the Dutch text will be deemed binding.

## LIST OF ABBREVIATIONS AND CONCEPTS

| | |
|---|---|
| Barge | A barge is an engine-powered cargo ship that is specially built for transporting sand (wet or dry) and gravel |
| Bending moment | Combination of forces on a joist, which causes the joist to bend |
| BPR | Binnenvaartpolitiereglement [national inland navigation police regulations] |
| BSB | Binnenschepenbesluit [national inland navigation vessels decree] |
| BSW | Binnenschepenwet [national inland navigation vessels act] |
| CCR | Central Commission for Navigation on the Rhine [Centrale Commissie voor de Rijnvaart] |
| Classification Society | The expert organisation recognised by the Transport and Water Management Inspectorate which carries out activities for the certification of vessels (including the assessment of drawings and calculations in the case of new construction, rebuilding, and major repairs) |
| Coaming | A raised section on a ship designed to deflect or prevent entry of water in cargo holds / wells |
| CvO | Certificaat van Onderzoek [certificate of inspection] |
| Design tools | Tables, diagrams, etc., which were created based on the results of systematic calculations for clearly defined cases and on the basis of a limited number of parameters (such as length, block coefficient and relative hold length) and a set of assumptions (such as the ship's weight distribution and stocks present). These diagrams and tables can be used when designing vessels to simplify complex calculations such as that of the bending moment. Due to the limitations of the assumptions and parameters, however, the results generated in this manner are only estimates of the values achieved based on the full calculations. |
| Drawing assessment | Using drawings (and calculations) to determine whether the vessel to be built complies with the relevant laws and regulations |
| Extrapolate / extrapolation | To estimate something unknown from facts or information that are available; to continue a series on this basis |
| Floor | A vertical plate that is installed for reinforcement in the athwartship direction of a ship's hull |
| Fore-and-aft strength | The lengthwise strength of a vessel |
| Gangway | The lengthwise walkway of a ship |
| Hull | Body of the ship |
| IACS | Association of Classification Societies |
| IVW/DS | The Transport and Water Management Inspectorate, Shipping Inspectorate (Inland) |
| KLPD | National Police Services Agency |
| NAP | Normaal Amsterdams Peil [normal Amsterdam water level] |
| OvV | Dutch Safety Board |
| ROSR | Reglement Onderzoek Schepen op de Rijn 1995 [regulations for the inspection of vessels for the Rhine Navigation] |
| RPR | Rijnvaartpolitiereglement 1995 [Rhine navigation traffic regulations] |
| RvTV | Dutch Transport Safety Board |
| Sagging | The bending of a ship due to excess stress, resulting in a permanent distortion or collapse of the ship |
| Ton | 1000 kg |
| Wvb | Wet vervoer binnenvaart [national inland water transport act] |

## CONSIDERATION

On 5 July 2004 at approximately 10:45 am, a new barge folded in half lengthwise and partially sunk in the Middensluis lock of IJmuiden. The new vessel had been delivered on 9 June 2004 and was carrying out its third trip with a load. During this serious accident, everyone on board was able to escape without injury. The lock, however, was closed for a longer period.

During the investigation by the Dutch Safety Board[1], it soon became clear that the sagging of the vessel could not be attributed to conditions in the lock or an excessive load. Instead, there was a structural defect resulting from an improper design, which took insufficient account of the loads that the barge would potentially be transporting. The vessel was not designed for the stress to which it could be exposed. This emerged from both the check calculations from the Transport and Water Management Inspectorate, Shipping Inspectorate (Inland)(IVW/DS), and the calculations of the Safety Board. The lack of fore-and-aft strength was such that the only conclusion possible was that this had been the cause of the accident.

Subsequently, the Safety Board's investigation was aimed at determining the factors that could have led to this situation occurring. In the investigations of the Safety Board, the question of who was to blame (legally or otherwise) and any legal relationships between the parties are not taken into consideration, in accordance with regulatory requirements. Designations and definitions in the reports that relate to the parties are used exclusively to provide clarity about the parties' identity. The sole objective of the investigations and the studies is to learn from the incidents that do occur and, where possible, to prevent accidents in the future.

Based on the investigation into the accident with the barge, the Safety Board has come to the following conclusions:

**None of the parties involved were sufficiently critical**
The design of the barge in question was different from existing barges, but the existing design tools were used. The fact that the size and ratios were non-standard was not given sufficient attention by any of the parties. The accepted design tools (including diagrams and tables which provide for simplified and rapid calculations) were used, without a sound analysis being carried out of whether these were sufficient. If full and extensive calculations for the construction of the vessel had been carried out (instead of only simplified calculations), it would have been possible to determine that the barge was not strong enough.

**The design tools used were not applied correctly**
Both the designers of the vessel and the supervisory body nearly always use design tools which can determine such aspects as the bending moment (the combination of powers on a joist, which causes this joist – in this case, the barge – to bend*)* and the permissible tensions in certain construction components. These design tools are drawn up by Classification Societies[2]. This working method was developed before the computer age, when it was still labour intensive to complete the underlying calculations.

For this barge, the design tools were used outside the validity area for which they were established in the past. These tools are commonly used in the sector to design inland navigation vessels. The ratio of the hold length to the ship's length for this vessel, however, deviated significantly from the ratios for which the formulas were drawn up.

The Safety Board's investigation revealed that, when these commonly used design tools are applied for the vessel type in question – even within the validity range of these formulas – the resulting calculation generates a bending moment that is far too low. As a result, the vessel can fold when carrying a load.

1 The Dutch Safety Board was established on 1 February 2005. Prior to this, the Dutch Transport Safety Board was responsible for independent investigations into accidents in inland navigation. The investigation into this accident was therefore commenced under the responsibility of the Dutch Transport Safety Board and completed under the responsibility of the Dutch Safety Board.

2 Classification Societies are expert organisations recognised by the Transport and Water Management Inspectorate which carry out activities for the certification of vessels (including the assessment of drawings and calculations in the case of new construction, rebuilding, and major repairs).

In other words: even if the design tools are used correctly, the result may be an overly weak ship design.

This was reason for the Safety Board to put forward a recommendation to the inspector general of the Transport and Water Management Inspectorate. This recommendation was as follows:

> We recommend to the inspector general of the Transport and Water Management Inspectorate that further investigation be carried out into the construction strength of well vessels (>80 metres and/or with a non-standard length/width ratio) which have not received the Certificate of Inspection on the basis of full calculations.

The division of responsibility between the various parties involved in the design was unclear. The process took place as follows:

- The first drawings of the midship frame and the general plan of the hull were made by a draughtsman as commissioned by the developer/shipbuilder. The future owner, however, found the hull construction too heavy and therefore too expensive. The costs of the new barge were strongly influenced by the amount of steel needed for the construction.
- The developer/shipbuilder then took the information to another calculation and draughting agency to determine whether the weight of the barge could be reduced.
- Ultimately, this other agency performed calculations that resulted in a lighter hull. Contacts were made by this calculation and draughting agency with the IVW/DS to have the vessel approved.
- The IVW/DS approved these construction drawings and calculations.
- Ultimately, it was revealed that the tests and assessments carried out by the IVW/DS did not offer sufficient safeguards. However, in practice, the inland navigation sector assumes this is the case.
  This was revealed based on the following and other conditions:
  - The file received by the IVW/DS was not complete or sufficient in terms of content; however, IVW/DS did not comment on this situation.
  - The check calculations performed by the IVW/DS were primitive and incomplete.

In addition, the Board believes that the IVW/DS was not sufficiently critical with respect to its own role. As such, the IVW/DS did not conduct a thorough basic analysis of the design, nor did it recognise that the increase in scale could produce unexpected effects.

**Conclusion**

The inland navigation sector still relies heavily on the traditional approach, without considering whether this approach is actually sufficient for the current situation. Now that the scale of designs is being increased even further, the question remains whether the traditional approach can still be used. The use of design tools in general, and in particular for designing vessels with non-standard ratios and/or dimensions, is highly undesirable. Certainly now that it is possible to perform full calculations of the options present in a vessel using computers, it is the Safety Board’s opinion that it is vital that all designs are fully calculated using state-of-the-art methods, as is already common practice in the maritime sector.

Furthermore, the inland navigation sector should provide better checks and balances of its own role. The Safety Board believes that measures should be taken to better monitor developments and analysis them in more detail. This can be achieved in a variety of ways.

Examples could include:

- The improved recording and checking of design tools with attention paid to the range of use and the development of other reliable design tools.
- The improvement of the tests conducted by the sector itself and those performed by government-related bodies.
- The clarification of the responsibilities of the various parties.

With respect to this problem, the Dutch Safety Board considered it necessary to issue a recommendation to the inspector general of the Transport and Water Management Inspectorate. This recommendation is as follows:

> We recommend to the inspector general of the Transport and Water Management Inspectorate that, for the new construction or major renovations of inland navigation vessels, the applicant is required to demonstrate the construction strength of the vessel based on full calculations, before the Certificate of Inspection is issued.

Moreover, lessons can be learned from the assessment process of the construction of other types of vessels, such as vessels which transport hazardous substances and seagoing vessels.

- Inland navigation vessels which transport hazardous substances are always built "under classification", which means that a Classification Society checks the entire design and construction process.
- Seagoing vessels have also long been built "under classification". For new seagoing vessels, it is common practice that the shipyard bears full responsibility for the end product, and therefore is also liable for this. The shipyard is the point of contact for the IVW/DS and the Classification Society.

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| Prof. Pieter van Vollenhoven | Ms. M. Visser |
| Chairman of the Board | General Secretary |

## GENERAL VESSEL AND ACCIDENT INFORMATION

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|---|---|
| Location accident | : IJmuiden - Middensluis lock |
| Date of accident | : 5 July 2004 |
| Time of accident | : 10:45 am (local time) |
| Type accident | : Sagging and partial sinking |
| Type of vessel | : Engine-powered barge |
| Vessel number | : 2326544 |
| Total crew | : 4 crew members + 1 passenger |
| Power | : 2 x 1300 hp |
| Cargo | : Wet sand |
| Visibility | : Good |
| Wind | : West, 3 Beaufort |
| Tide | : None |
| Cloud density | : Light cloud |
| Water level | : Outer 0.28 m + NAP (sea side)<br>Inner 0.42 m – NAP (Noordzeekanaal) |

# 1 FACTS AND BACKGROUND INFORMATION

This chapter contains the facts and background information concerning the sagging of a new barge in the Middensluis lock of IJmuiden on 5 July 2004. Chapter 1 sets out the facts and relevant information about the accident. Chapter 2 of this report contains the relevant legislation and regulations. Chapter 3 provides a summary of the parties involved. The analysis of the direct cause and the underlying factors of this accident are presented in chapter 4.

The identities of some of the parties in this report have been made anonymous, in accordance with the policy of the Dutch Safety Board. Company names and names of "individuals" have been left out, except for the so-called "public parties" (such as government bodies) and/or companies which have already been named in reports from the Safety Board (which, incidentally, was not the case for the accident).

## 1.1 DESCRIPTION OF CONDITIONS SURROUNDING THE ACCIDENT

On Monday morning 5 July 2004, a new barge first folded and then partially sank in the Middensluis lock in IJmuiden, the Netherlands. The Middensluis lock connects the Noordzeekanaal with the IJmuiden outer harbour.

*Figure 1: Folded vessel in the Middensluis lock of IJmuiden*

The vessel was put into commission in late June 2004. The construction and taking into service of this vessel was big news in the world of inland navigation, because the dimensions of this vessel (110m x 11.4m x 3.9m) were larger than usual for well vessels. In addition, it was a multifunctional vessel which allowed for the transport of sand and other bulk materials (such as polluted sludge and ore), in addition to containers.

The vessel departed on Monday morning 5 July 2004 at approximately 7:30 am from the Middensluis lock in IJmuiden, in the direction of Fort Island (*Forteiland*) to pick up a load of sand. The sand was loaded on the vessel by the Weesperkaspel sand dredger, located at Fort Island in the outer harbour area of IJmuiden.

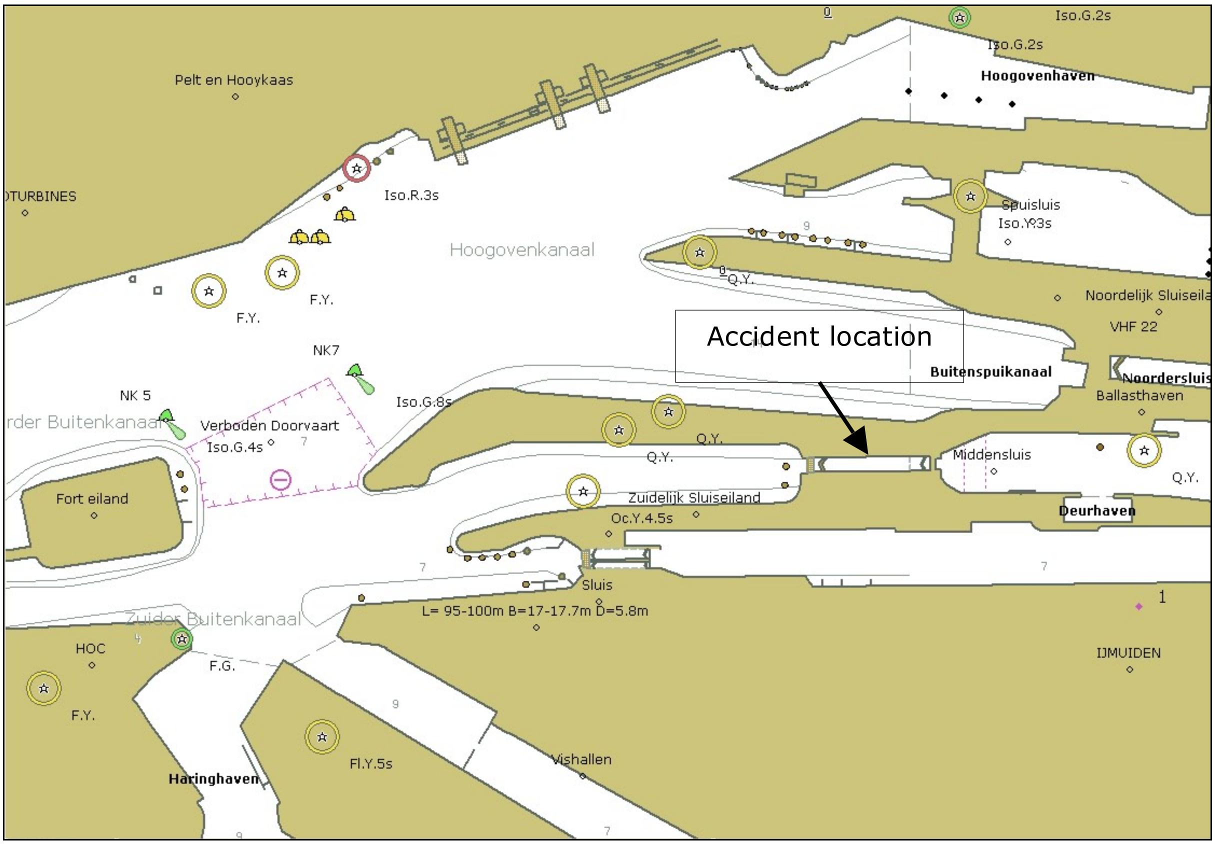


*Figure 2: Location of the accident (Map: Navigis)*

After the vessel had sailed away from the sand dredger, the skipper reported the vessel to the lock service for passage through the locks from the outer harbour area towards the Noordzeekanaal (from the sea side towards the inland in the direction of Amsterdam). In view of the fact that the Middensluis lock was not yet ready for the passage, the vessel sailed very slowly to the lock, where it arrived at approximately 10:30 am. The vessel moored portside to the Middensluis lock (on the north side) and was the only vessel in the lock.

The skipper was on the gangway on the starboard side when he saw that the well wall of the vessel on the port side was starting to warp. The skipper immediately understood that something was wrong. Muffled thuds were also audible. The skipper sent the helmsman to the front of the vessel, where the forward accommodation was located, to warn the crewmember and his girlfriend. The skipper went to get his wife who was in the accommodation at the stern.

When the skipper and his wife came on deck, the midship section was already completely underwater. They managed to get onto the quay, and were able to assist the three other people and the dog off of the fore part of the ship.

After a certain amount of time, when the skipper realized that the situation was still dangerous, but stable, he climbed back on the stern of the vessel and turned off the engines. The generator cut out a while later, after having produced black smoke for several minutes. It was not possible to turn off the generator because it was too dangerous.

No one was hurt in this serious accident. However, the Middensluis lock in IJmuiden was closed for a longer period, and the vessel had to be repaired and reinforced before it could be put back into service.

## 1.2 DEVELOPMENT AND CONSTRUCTION OF THE VESSEL

This section provides further details about the development and construction of the vessel in question. This includes the commission for the construction, the design process, the main characteristics of the design of the vessel, the construction, inspection and certification and the taking into service of the vessel. The owner did not submit a request to the IVW/DS[3] for construction under classification.

### *1.2.1 Commissioning of the construction*

The owner of the folded barge had plans to bring a new and larger vessel into service at the end of 2001. To this end, a conversation took place on 17 December 2001 between the skipper/owner and the developer/ shipbuilder. During this conversation, it was decided that the developer/shipbuilder would develop the hull (= the body of the vessel without equipment) based on a new barge concept. The hull would then be built. This was recorded in a letter from the developer/shipbuilder. A purchase contract signed by both parties was never drawn up.

### *1.2.2 The design process*

The initial drawings of the midship frame and the general hull plan were made by a draughtsman as commissioned by the developer/shipbuilder. From conversations with the shipbuilder/developer, it was clear that calculations had been performed that demonstrated that the vessel would weigh approximately 850 tons and would comply with the criteria used by the Transport and Water Management Inspectorate[4]. It had also been established based on calculations that this design would have sufficient fore-and-aft strength.

The commissioning party asked the shipbuilder to research whether it would be possible to make the hull lighter. This was to reduce the costs of the amount of steel needed, and also because the weight of the vessel influences the load size that can be transported. In response, the developer/shipbuilder took the information to calculation and draughting agency (to be referred to hereinafter as calculation and draughting agency B) to determine whether it was possible to reduce the weight of the vessel.

The calculation and draughting agency B performed calculations which resulted in a lighter vessel with the same overall dimensions. The calculation and draughting agency B initiated contact with the IVW/DS concerning the Drawing Assessment (see also section 1.2.5). The developer/ shipbuilder was no longer directly involved in this process, but this party was kept abreast of the situation through a staff member of the developer/ shipbuilder. The IVW/DS approved the construction drawings. After this, the developer/shipbuilder did not conduct any additional check of the midship frame/construction drawings.

### *1.2.3 Characteristics of the design*

The design of the vessel was quite different from conventional well vessels in a number of aspects. For example, at present, a standard large barge has a length of approximately 80 m. The design of the folded barge, however, had a length of 110 m. This is an increase of 40% compared to the standard well vessels. Because the width and height were also included in the scaling, the size of the vessel was increased by a factor of 2 to 3. This can be described as a substantial increase in scale compared to existing well vessels.

Another noticeable aspect is the propulsion mechanism, which is located at the very back and equipped with two retractable rudder propellers. This makes it possible to ensure sufficient water is supplied to the screw propellers even in very shallow water (this is essential to ensure proper manoeuvring of the vessel).

Compared to normal dry cargo inland navigation vessels, this barge only used a relatively small part of the vessel as the hold. The location of the hold areas means that the load is concentrated at the middle of the vessel. This is disadvantageous in terms of the distribution of forces exerted on the vessel.

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3 Building under classification means that the entire design and construction process is checked by a certified Classification Society.

4 See chapter 2 of this report for a further explanation of these criteria. See chapter 3 for further details concerning the duties of the the Transport and Water Management Inspectorate, Shipping Inspectorate (IVW/DS).

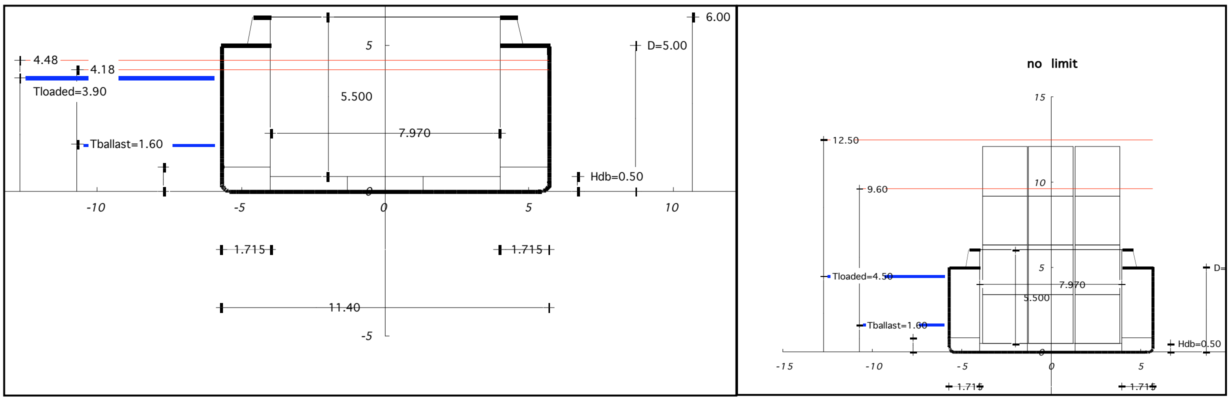



*Figure 3: Cross sections of the barge*

- The vessel has this design (among other reasons) such that the shape of the hold can also transport other cargo (general cargo and, in particular, containers). The width of the hold is large enough to place three containers next to each other). In addition, a choice was made for a relatively small hold, to create more space for the accommodations.

### *1.2.4 Construction*

Ultimately, the construction of the hull shell was outsourced to a shipyard in the Ukraine based on the drawings approved by the IVW/DS. The developer/shipbuilder made small detail changes to the vessel during the construction of the hull and gave these to the shipyard. The hull was then transported to the Netherlands for further construction.

### *1.2.5 Inspection and certification process*

The inspection and certification was performed by the IVW/DS. On the application form, the developer/shipbuilder indicated that the vessel had to be suitable for international navigation on the Rhine. For this reason, assessment took place based on the requirements as stated in the Inspection Regulations for Vessels on the Rhine (ROSR).

A calculation for the fore-and-aft bending moment and a midship frame drawing were submitted to the IVW/DS for inspection. The calculation submitted shows that use was made of extrapolated instructions from one of the certified Classification Agencies. The vessel was designed based on these formulas and tables. The Classification Society itself was *not* involved in performing the calculations.

After the inspection of the midship frame drawing, additional construction drawings were submitted for inspection by the developer/shipbuilder, independently of the calculation and draughting agency B. These were based on the approved midship frame drawing and calculation. These drawings were assessed by the IVW/DS, and returned with the inspectorate’s stamp.

After this, the construction of the vessel was supervised by an external organisation. The commissioning party made use of the option to have part of the supervision performed by a Classification Society. This concerns the inspections during the construction of the hull in the Ukraine. On 30 May 2003, the Classification Society issued a survey report that indicated that the activities were being performed properly and in accordance with the drawings.

After the hull arrived in the Netherlands, an additional visit was paid to the vessel by an expert from the IVW/DS to assess whether the hull had arrived undamaged. During this inspection, it was revealed that the vessel had been slightly damaged in transport, and that this damage was already being repaired. Furthermore, the IVW/DS reported that additional other minor damage also needed to be repaired. During completion, the vessel was inspected various times by experts from the IVW/DS. The goal of these inspections was to verify whether the vessel complied with the statutory requirements with respect to layout and equipment.

Based on the above statement from the Classification Society and the results from the IVW/DS inspection, the IVW judged that the hull was built according to the approved drawings. Inspection reports were drawn up for all of the stated inspections.

In June 2004, the IVW/DS issued a Certificate of Inspection (CvO) and the vessel was subsequently taken into service.

### 1.2.6 *Taking into service*

The owner applied for the tonnage certificate. In addition, at the owner's request, a draught limitation was issued for the vessel, which was stricter than the depth limitation calculated based on the design. The skipper/owner undertook this course of action for economic reasons. The amount of the levies and charges, such as port dues, can be determined by the depth of the vessel.

## 1.3 CONDITIONS DURING THE ACCIDENT

For the facts concerning the conditions surrounding the accident, please refer to section 1.3.1. In addition, it can also be stated that the weather conditions on 5 July 2004 were good and that the vessel was not too heavily loaded. In their statements, two witnesses said that they thought that the skipper/owner could have taken on even more cargo, because the hold was not yet full. After the incident, a determination was made of the stress and depth of the load, based on a photograph taken immediately after loading (made available by the skipper/owner[5]).

In this context, it is important to state that the level of the white paint of the load lines was incorrect (the level was too high). The National Police Services Agency (KLPD) conducted a criminal investigation into this situation, because there were signs that this was an economic offence. In the context of the investigation, the actual loading condition was of great importance. However, it was determined that the vessel was not overloaded at the time of the accident. In view of the fact that these incorrectly located load lines played no role whatsoever in the occurrence of the accident, this aspect was not taken into further account in the Safety Board's report.

*Figure 4: Photo of the barge soon after loading (photo taken by the owner)*

[5] Based on such evidence as the KLPD's report and the witness statements, the Safety Board finds that there is sufficient evidence that the cargo indicated on the photo represents the actual loading condition at the time of the accident.

## 1.4 INVESTIGATION AFTER THE ACCIDENT

### *1.4.1 Investigations*

In response to this accident, a number of other authorities besides the Safety Board carried out various investigations. Examples of these are as follows:

- An investigation by the IVW/DS, which also reviewed the entire certification process.
- An investigation commissioned by the IVW/DS and the insurance company, and conducted by independent experts into the physical characteristics of the steel used. In addition, an investigation into the possible overloading of the vessel was performed after the accident by a loss adjustment agency, commissioned by the abovementioned insurance company. An investigation was also carried out after the accident into the bending moments and the resulting tensions by a loss adjustment agency, commissioned by the insurance company.
- An investigation ordered by the National Police Services Agency (KLPD).

### *1.4.2 Findings of the IVW investigation*

After the accident, an investigation was carried out by the IVW/DS into the cause of the incident. The IVW/DS came to the following conclusions:

- The vessel was built based on the drawings approved by the IVW/DS.
- The materials used had been approved.
  The investigation conducted by independent experts into the physical characteristics of the steel in question revealed that the material used complied with the legal standards.
- The calculations of the fore-and-aft strength were performed by the designer based on the standards from a certified Classification Society. The tables were extrapolated for this purpose. While extrapolation of the tables used is not uncommon, in this case, however, insufficient account was taken of the validity of the formulas used. The designer's assumption with regard to the calculation for the vessel construction was incorrect. Therefore the vessel was not designed for the stresses to which it could be exposed.
  *"The only possible conclusion is that this was the cause of the accident."* (Report on the Investigation into the accident with the inland navigation vessel "No Limit", IVW/DS, 10 September 2004).

With regard to this last point, the IVW/DS performed a number of check calculations which took into consideration the actual load and position of the vessel during the accident. The formulas from two other Classification Societies were also used in this process. In addition, a rough calculation was performed based on basic shipbuilding principles. The IVW/DS's conclusion made from all of these separate calculations is that the vessel's fore-and-aft strength was insufficient. This lack of fore-and-aft strength was such that, in the IVW/DS's opinion, there is no doubt that this was the cause of the accident.

After the accident, the IVW/DS investigated whether there were similar vessels in existence for which such an accident could also occur as a result of overly weak construction. This investigation was carried out based on the data available in the IVW/DS databases. According to the IVW/DS, the investigation revealed that this is not the case.

Furthermore, the IVW/DS investigated whether the certification process should be changed. For this purpose, it was taken into consideration that, each year, an average of a hundred newly built vessels are certified, which involves the approval of many thousands of drawings and calculations. This leads on a regular basis to comments that result in modifications to vessel construction and other aspects. Until now, there has been no evidence that such a design error has gone undetected. Due to the random character of this situation, the IVW/DS therefore determined that it is not necessary to fundamentally change the inspection process.

This accident, however, did demonstrate that the assumptions concerning the Classification Society's standards were not checked in the correct manner by the IVW/DS. In response, the IVW/DS has indicated that it will undertake action to prevent such mistakes from occurring in the inspection process in the future. A supplemental letter from the IVW/DS to the Safety Board stated that these measures would consist of tightening up the peer assessment by the IVW/DS.

*1.4.3 Inspection by TNO*

The report from Netherlands Organisation for Applied Scientific Research (TNO) indicated that, on Wednesday 7 and Thursday 8 July 2004, observations were carried out of the folded barge. At that point, the vessel was located in a dry dock in Amsterdam. On Wednesday 7 July, the vessel was inspected before and during the draining of the dock. On Thursday 8 July, an additional inspection of the exterior was conducted.

The following comments were made:

"1. ….. It is striking that the dent line is not located crossways on the vessel. It was also observed that the front part shifted slightly crossways after the ship was unbent. The dent shape is therefore clearly asymmetrical.

2. The folds in the sidewall were shaped like a pair of trousers.

3. Initially, the vessel was bent, but it gradually straightened out in dry dock when the vessel was fully above water. This process was accompanied by popping noises." (*TNO report*)


*Figure 5 and 6: Photos of the sagging of the side of the ship*

# 2 LEGISLATION AND REGULATIONS

In a general sense, inland navigation is governed by two sets of regulatory rules: Dutch legislation and legislation for the navigation on international waters (the Rhine). A summary of the legislation and regulations relevant for this investigation is provided below.

## 2.1 NATIONAL LEGISLATION AND REGULATIONS

The Inland navigation vessels Act (BSW - *Binnenschepenwet*) and the Inland navigation vessels Decree (BSB - *Binnenschepenbesluit*).
These relate to:

- The seaworthiness, design and equipment of the vessel
- The safety, health and well-being in connection with the work carried out on board
- The knowledge, competence and physical condition of the skipper.

*Measurement decree for inland navigation vessels (Metingbesluit binnenschepen) (1978)*
This decree makes it mandatory to keep a valid tonnage certificate on board. The tonnage certificate is the result of the measurement conducted periodically by the Ship Measurement Service (*Scheepsmetingsdienst*). Aspects measured include the cargo capacity and the engine power. The measurement data serves, for example, as the basis for determining the level of the levies and charges.

*Inland Navigation Transport Act* (*Wvb - Wet vervoer binnenvaart*)
The Wvb focuses on ensuring that operations are conducted properly for the transport of goods and passengers by inland navigation vessels. The Wvb is responsible for the access to the profession for the company/business owner and the access to the market for vessels. The Act contains rules with which the organisation must comply to be eligible for a permit to participate in the shipping profession or to register for 'own transport'. Each of the company's vessels is required to have a permit or registration papers in order to transport cargo. This is only granted if the vessel possesses, among others, a valid Certificate of Inspection (CvO).

## 2.2 INTERNATIONAL LEGISLATION AND REGULATIONS

### *2.2.1 Inspection Regulations for Vessels on the Rhine (ROSR* - Reglement Onderzoek Schepen op de Rijn*) 1995*

The ROSR is managed by the Central Commission for Navigation on the Rhine (CCR) (Mannheim Convention) and sets out regulations for the construction design and crew for ships that sale on the International Rhine. A large number of Dutch vessels have a Certificate of Inspection (CvO) and must comply with the rules in the ROSR.

The legislation that is applicable to a new ship to be built is provided by the developer/shipbuilder of the new vessel. To this end, the intended sailing range of the vessel is indicated on the application form. On the application form for the new barge in question, the developer/shipbuilder indicated that the vessel had to be suitable for international navigation on the Rhine. As such, the vessel had to comply in full with all of the requirements as set out by the ROSR.

Part II chapter 3 article 3.02 of the ROSR explains the criteria with which the strength of the ship's hull must comply. This states the following:

> "*Article 3.01 – General rule*
> *Vessels must be built according to proper shipbuilding practices.*
>
> *Article 3.02 – Strength and stability*
> 1. *The strength of the ship's hull must be such that it is adequate for the stresses to which the hull is exposed to under normal conditions.*
>    a. *For new vessels and for renovations by which the strength of the vessel can be affected, calculations must be provided to demonstrate that the ship's hull is sufficiently strong. This is not necessary if a classification certificate or a statement from a certified Classification Society is submitted.*
>    b. *For investigations as referred to in article 2.09, the minimal thicknesses of the*

*bottom, bilge and side plating of the ship's shell must be checked in accordance with the following method:*
…..” (see Appendix 3 for the accompanying formulas)

## 2.3 CURRENT STANDARDS AND GUIDELINES –CLASSIFICATION SOCIETY GUIDELINES

In addition, in the inland navigation sector, it is common practice to use the tools drawn up by Classification Societies for the design process. These tools consist of guidelines, design tables, design diagrams and approximation formulas. These design tools are not checked by other agencies or bodies. These tools have gained their authority through years of use and the fact that they originate from certified agencies and that they are accepted by the IVW/DS. IVW recognises the Classification Societies that are affiliated with the International Association of Classification Societies (IACS). A further explanation of the design tools used is included in Appendix 2.

# 3 SUMMARY OF THE PARTIES INVOLVED AND THEIR RESPONSIBILITIES

Many parties with different roles were involved in the construction and inspection process. The sections below provide a summary of the various parties.

## 3.1 Skipper/owner

The skipper/owner was the commissioning party for the construction of the vessel. During the first meeting, it was agreed that the skipper/owner and the developer/shipbuilder would remain the joint owners of the hull until one of the two existing ships belonging to the skipper could be sold. The drawings of the new design would remain the property of both the developer/shipbuilder and the skipper, at least according to the meeting report. When the vessel was taken into service, one of the two ships had already been sold, and the skipper therefore became the sole party entitled to the design of the new barge. The skipper was also the owner of the vessel and the party who applied for the tonnage certificate.

## 3.2 Developer/shipbuilder

The contractor for the construction of the vessel was a Dutch shipbroker and shipbuilder, who was the commissioning party for:

- A calculation and draughting agency that prepared the first general plan and the first midship frame design (to be referred to hereinafter as: calculation and draughting agency A),
- A second calculation and draughting agency (to be referred to hereinafter as: calculation and draughting agency B),
- The shipyard in the Ukraine, which built the hull.

## 3.3 Calculation and draughting agency B

This calculation and draughting agency performed calculations commissioned by the developer/shipbuilder. The developer/shipbuilder also instructed calculation and draughting agency B to make contact with the IVW/DS in connection with the Drawing Assessment. At this point, the developer/shipbuilder was no longer directly involved, but was aware of this process.

## 3.4 Transport and Water Management Inspectorate Shipping Inspectorate (Inland)(IVW/DS)

The IVW/DS is the inspection and certifying institute, and has the following mission statement:
"…*The Transport and Water Management Inspectorate (IVW) aims to ensure maximum safety on Dutch inland waterways. To achieve this goal, the IVW supervises compliance with the legislation and regulations. The IVW focuses on the inland navigation profession, certified Classification Societies, surveyors, the crew of vessels, and companies that are involved in the transport of hazardous substances.*
*The following activities are undertaken for this purpose:*

- Registration of the inland navigation fleet
- Testing and inspection of vessels and ship equipment
- Issuing of permits to business owners
- Supervision of the transport of hazardous substances
- Checks of crew strength and compliance with sailing and rest times
- Registration and control of the qualifications of each crew member
- Issuing of the Rhine Navigation Certificate (*Rijnvaartverklaring*), the service book and the sailing hours book.

*On Dutch inland waterways, there are many inland navigation vessels which sail under foreign flags and which are owned by foreign companies. This transport also falls under the responsibility of the IVW."*

This responsibility is put into practice based on the provisions in chapter 2 of the ROSR. This states that a vessel must be investigated by the Committee of Experts before it can be taken into service. In the Netherlands, the IVW/DS has been appointed as the Committee of Experts. The Committee of Experts can waive this inspection in whole or in part, as stated in article 2.12 of the ROSR, if a statement is provided by a certified Classification Society that the vessel complies with the established provisions.

## 3.5 CERTIFIED CLASSIFICATION SOCIETY

The Classification Society had a double role in the construction of this vessel:
In the past, a Classification Society drew up the design tools that were used by the designer and by the IVW/DS. The Classification Society was not consulted on this subject. The abovementioned Committee of Experts (see party IVW/DS in section 3.4) may, as stated in article 2.12 of the ROSR, waive, in whole or in part, the inspection of a vessel to determine whether it complies with the construction and design and equipment requirements, in the case that a certified Classification Society has provided a statement that the vessel complies with the established provisions. The commissioning party made use of the option to have a Classification Society carry out part of the supervision of the construction. This concerns the inspections during the construction of the hull at the shipyard in the Ukraine, based on the approved drawings. The vessel was not built under classification, nor was the design of the vessel assessed by a Classification Society.

## 3.6 OTHER PARTIES

In addition to the above, a number of other parties were involved in the construction of the vessel and in the accident:

*Calculation and draughting agency A*
This agency prepared the first general plan and the first midship frame design, and made detailed drawings and cross sections.

*National Police Services Agency (KLPD)*
After the vessel folded, this party took statements from several witnesses to discover the facts concerning the sagging of the vessel, and also to determine whether the higher placement of the painted load lines than specified in the tonnage certificate was permitted. The fact that these painted load lines were moved concerns a possible economic offence, and is not of importance for the Safety Board's investigation. However, the loading condition was involved in the investigation.

*Lenders*
The documentation did not reveal if the vessel has any other co-owners. Only the first meeting report refers to the presence of one bank staff member.

*Insurance companies and legal service providers*
Insurance companies and legal service providers played a role after the accident occurred. Their role will not be examined further (see also footnote 6).

*Investigation by agencies*
Furthermore, after the accident, a number of agencies conducted investigations into the circumstances surrounding the incident. Supplemental calculations were also carried out with respect to the strength of the vessel.

# 4 ANALYSIS OF THE DIRECT CAUSE AND UNDERLYING FACTORS

## 4.1 Structural analysis

This chapter contains the analysis of the direct cause and the underlying factors of the sagging and partial sinking of the barge on 5 July 2004.

The investigation of the Safety Board focused on the presence and effectiveness of safety measures.

In this chapter, the Safety Board indicates how it came to the conclusion that the fore-and-aft strength was the direct cause (section 4.2.1) of the accident and which factors contributed to the late realisation that the design was not strong enough (section 4.3 to section 4.5). In addition, the Safety Board will explain how it came to the conclusion that the direct cause of the accident can be attributed to the insufficient strength of the vessel, and not to other factors (section 4.2.2).

## 4.2 Determination of direct cause; insufficiently strong design

The section below first describes the direct cause of the accident (section 4.2.1). Other possible causes are then briefly addressed (section 4.2.2).

### *4.2.1 Direct cause*

Calculations were performed by the Safety Board to determine the tensions during the sagging of the vessel in the lock (see Appendix 2). The observations of the maximum permissible tensions are such that the only possible conclusion was that the strength of the vessel was insufficient due to poor design.

The compressive stresses in the entire coaming amounted to double the permissible tensions, while the tensile stress in the bottom was very close to the permissible limit. The fact that the vessel was able to sail for any distance at all is probably due to the incredible resilience of the steel constructions, which can distort up to 20% without breaking, and, if they do break, can absorb double the design load.

Due to the alarming findings of the first calculations, the Safety Board determined that performing additional calculations was essential. These revealed that the strength of the first design, which was extrapolated by calculation and draughting agency A, was also insufficient. Compared to the vessel actually built, the first proposal used approximately 10% more steel in the construction, but this also created approximately 15% more compressive stresses than the allowable tensions at certain locations. As such, the poor designs do not seem to be random in nature. In the analysis into the underlying factors which contributed to the late discovery of the fact that the design was not strong enough, the non-random nature of the designs is examined in more detail.

### *4.2.2 Other possible causes*

The Safety Board also examined other possible causes which could have caused the vessel to fold:

- Insufficiently strong construction due to errors in the construction work
  From the documents made available for the investigation, including the results from the investigation after the accident, there was no indication that the vessel was not built in accordance with the approved drawings.
  - The Safety Board therefore finds that there is sufficient evidence that the construction of the vessel took place in accordance with the drawings.

- Insufficiently strong construction due to poor material used for the construction
  The investigation conducted by independent experts into the physical characteristics of the steel in question revealed that the materials used complied with the legal standards.
  - The Safety Board therefore finds that there is sufficient evidence that the sagging of the vessel was not caused by the use of the materials.

- The vessel was overloaded when it sailed
  After the incident, a determination was made of the stress and depth resulting from the load, based on such aspects as various statements from witnesses, information from the KLPD's report, and a photograph taken immediately after loading (made available by the skipper/owner).

It was possible to conclude on this basis that the vessel was not overloaded.
- The Safety Board therefore finds that there is sufficient evidence that the vessel was not overloaded.

- External factors such as bad weather, conditions in the lock
  The weather conditions on 5 July 2004 were good and no particular incidents were reported in or near the lock. The Safety Board did not investigate in further detail why the vessel folded specifically in the lock.
  - The Safety Board therefore considers it very unlikely that the specific location played an active role in the occurrence of the accident.

The Safety Board therefore finds that there is sufficient evidence that the accident was exclusively and solely due to insufficient construction strength in the basic design.

## 4.3 UNDERLYING FACTOR: USE OF INADEQUATE DESIGN TOOLS WITHOUT A CRITICAL ANALYSIS OF WHETHER THIS IS POSSIBLE

Both the designers of the vessel and the supervisory body IVW/DS nearly always use design tools, such as rough estimate formulas, to determine the strength a vessel should have for a particular design. As a result, the underlying calculations (which are complex and time-consuming) do not have to be performed. This practice was developed before the computer age, when the completion of such calculations was a very time-consuming job.

These design tools were drawn up by specialised agencies which, over time, became recognised as Classification Agencies.

For this vessel, both the ship's designers and the supervisory body IVW/DS used diagrams and rough estimate formulas from a certified Classification Society. The Classification Society was not consulted on this matter and did not play a role in this process.

When drawing up the construction calculations, it was assumed that the vessel fell within the basic conditions established in the guidelines. In view of the ratios between the cargo hold and the other parts of the vessel, the design deviates from the "standard vessels" [6] for which the standards were drawn up. In addition, extrapolation took place beyond the limits of the design tools used.

The sections below addresses the inadequate design tools (section 4.3.1) and analyses the consequences of using these tools without a critical analysis of whether this is possible.

### *4.3.1 Inadequacy of design tools*

The design tools were examined in further detail by the Safety Board. Diagram 1 shows the deviations that were observed. The calculations that form the basis for this diagram were performed for the depth at which the vessel fractured: 3.90 m with a load volume of approximately 3.495 tons (see also Appendix 2).

In the diagram, the prediction made by the tool used can be extrapolated beyond the area of validity. In addition, calculated values based on the data of the folded barge are presented. This illustrates the following:

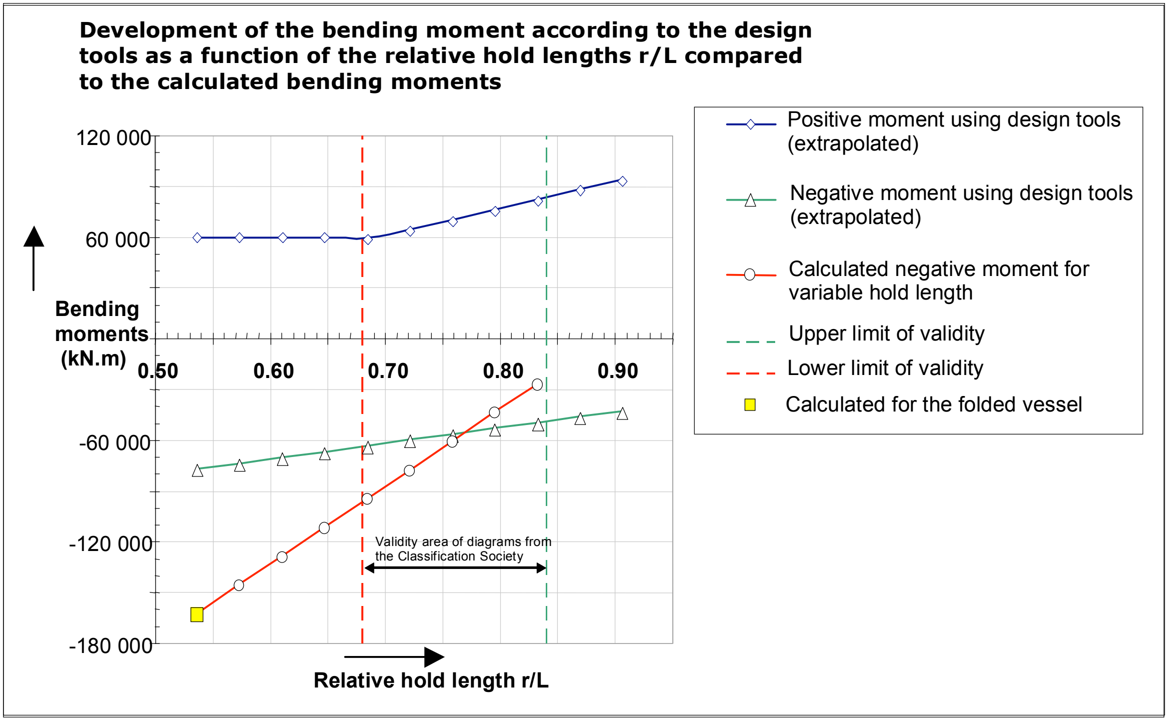
- The formula corresponds with the actual situation on only one point.
- For short holds, it becomes clear that the calculated values are already significantly higher than the values determined using the design tools.

- At the limit of the diagram's validity as indicated (a hold length of 68%), the deviation amounts to 90 000/60 000=1.50; in other words, 50%.
- In the design of the folded vessel (for which the hold length amounts to 55%), the deviation is even higher: a factor of 2 (165 000/80 000=2.00).

[6] The ratio between the hold and ship length of a standard vessel is 0.80, while the ratio of the vessel involved in the accident was 0.55.

It has emerged from the Safety Board's calculations that the design tools are not satisfactory. For the type of vessel in question, these tools indicate a bending moment that is far too low, also within the validity range of the design tools.

*Diagram 1: Development of bending moment according to the design tools compared to the calculated bending moments*




### 4.3.2 *Lack of critical analysis concerning whether the use of the design tools is possible*

The fact that the vessel was non-standard was not recognised by any of the parties. The normal design tools were used, without a critical analysis being made of whether this was sufficient.

From an analysis of the documentation and the interviews, it emerged that the use of rough estimate formulas is very common, and that this was the reason it was not discussed. It did not occur to any of the parties that the design deviated from the standard.
In addition, it is possible to establish that the calculations contained errors. This became clear from the following and other points:

- The calculations provided by the designer/shipbuilder to the IVW/DS were incomplete in their execution.
- Certain other crucial calculations were missing (for example: calculation of the negative bending moment, direct calculation of the bending moment, no calculation of the resistance moment of the floors).
- No critical reflection took place with respect to the results of the calculations performed (for example: it was revealed that large transverse forces were present in front of and behind the hold, but no further research was conducted on how to absorb these).
- None of the parties recognised the limitations of the rough estimate formulas.

### 4.3.3 *In conclusion*

None of the parties recognised the fact that the design deviated from existing well vessels, and existing methods were relied upon as a result. No critical analysis took place to determine whether the design tools could actually be used for this purpose.

It emerged from the Safety Board's calculations that the design tools were not satisfactory. These tools predicted a bending moment that was far too low for the vessel type in question, both outside the validity area (as was the case here) and within the validity range of the design tools.

## 4.4 Underlying factor: Duties not performed adequately by the IVW/DS

This section examines in further detail the role of the IVW/DS. The first subsection takes a closer look at how the inspection process took place, and the second subsection provides a number of considerations with respect to this inspection process by the IVW/DS. These first two subsections contain some information that has also been addressed in other sections of this chapter. These subsections should be read as an introduction to the third subsection in which the conclusions of the analysis are drawn. Finally, the fourth subsection examines the IVW/DS investigation after the accident.

### *4.4.1 Inspection process*

The internal procedures of the IVW/DS describe various primary processes which relate to the certification of vessels. For this accident, the process of "drawing assessment" is important.

This process took place as follows:

- On the application form, the developer/shipbuilder indicated that the vessel had to be suitable for international navigation on the Rhine. For this reason, the design was assessed based on the requirements as stated in the ROSR. This states that, in general, the strength of the vessel must correspond with the stresses to which the hull is exposed under normal conditions. Sub a of this article indicates that this must be demonstrated by means of calculations, unless a classification certificate or statement can be provided by a certified Classification Society. In this case, the commissioning party chose to submit calculations.
- A calculation for the fore-and-aft bending moment and a midship frame drawing were submitted to the IVW/DS for inspection. The calculation submitted revealed that use was made of instructions from one of the certified Classification Agencies.
- In the assessment of the calculation, it was observed that, if the formulas and tables submitted are used as a basis, for the type of vessel, extrapolation must take place in of one the tables. It is common practice to regularly extrapolate in these tables during the design stage. To this end, it must continually be assessed whether the extrapolation is justified. The IVW/DS implicitly assumed that the calculation and draughting agency B had correctly performed this extrapolation. Assuming the validity of the extrapolation, the calculation submitted was correctly performed according to the IVW/DS.
- After the inspection of the midship frame drawing, the developer/ shipbuilder submitted additional construction drawings for inspection, independently of the calculation and draughting agency B. These drawings were based on the approved midship frame drawing and calculation. These drawings were assessed by the IVW/DS and returned with the inspectorate's stamp.

### *4.4.2 Considerations*

Based on an analysis of the available documents, the Safety Board has derived the following considerations with respect to this IVW/DS inspection process:

- The calculations from the calculation and draughting agency B for the IVW/DS were incomplete and primitively calculated. For example, an important calculation (calculation of a negative bending moment) was not submitted. The IVW/DS did not react to this situation.
- In the Board's opinion, the way in which the IVW/DS approved the calculations must also be characterised as inadequate.
  Examples are as follows:
  - The input for the check calculation shows two significant errors.
  - The outcome does not correspond with the calculation submitted by the calculation and draughting agency B. However, this was not reason enough for this agency to request new calculations (including bending moments).
  - The check calculation of the IVW/DS was also not checked (or at least visibly checked) by a colleague or supervisor.
  - The basic assumptions were not stated clearly or at all.
- Because the IVW/DS works with a spreadsheet with built-in extrapolations, the inspection process does not involve a visual confrontation with the underlying diagrams. This led to an extrapolation taking place far outside the validity range of the diagrams.
- There was no evidence of critical consideration on the part of the IVW/DS with respect to the design of the vessel: the short hold, the lack of a cross bulkhead, and the lack of a longitudinal frame system.

#### *4.4.3 The IVW/DS investigation after the accident*

After the accident, the IVW/DS investigated whether it was necessary to modify the certification process.

According to the IVW/DS, the inspectorate came to the conclusion that, in view of the random[7] nature of the accident, it is not necessary to fundamentally change the inspection process.

However, this accident did indeed demonstrate that the use of this type of general design tools by the IVW/DS for the assessment of the drawings and calculations for such non-standard vessel designs is not adequate. For this reason, the IVW/DS indicated that it would undertake action that is aimed at preventing similar errors from occurring in the inspection process in the future.

The Safety Board does not endorse these conclusions. In the Safety Board's opinion, the IVW/DS was not sufficiently critical of its own role.

### 4.5 Underlying factor: Unclear allocation of responsibility[8]

An analysis of the documentation revealed that many parties were involved in the design, and that the allocation of roles among these parties was not always clearly specified. The Safety Board considers the most important factor to be that too much trust was placed in the IVW/DS inspection, as also discussed in the previous section. This will be examined in more detail in section 4.5.1. In addition, two separate subsections are dedicated to the influential role of the skipper/owner in the design process in relation to the associated cost incentive, and the role of the extra calculation and draughting agency B.

#### *4.5.1 Too much trust was placed in the IVW/DS inspection (see also the section on the IVW/DS)*

The expectations with regard to the inspection role of the IVW/DS compared to the inspections that the designer/shipbuilder performed himself (or had performed), do not seem to correspond. Consequently, this led to a situation in which it was not clear what had been inspected and what had not; this turned out to be a disastrous working method, especially with regard to the ability to apply basic assumptions.

In general, the inland navigation sector relies heavily on the inspection of the calculations by the IVW/DS and thus runs a risk, in view of the fact that this concerns difficult assessments and calculations. In the Safety Board's opinion, the inland navigation sector should take more own responsibility in this regard. The IVW/DS is only the inspection institute that should function as the last safety net. That is also a more suitable role for an institution that aims to reduce its direct involvement in the sector.

#### *4.5.2 Role of the designer/shipbuilder in the design process*

After the first drawings of the midship frame and the general plan of the hull were made by calculation and draughting agency A, the future skipper/owner asked whether it was possible to construct a lighter version of the vessel. The reason for this was that the costs[9] for the new vessel were strongly influenced by the amount of steel needed for the construction and also because the load capacity would be influenced as a result.
To this end, the developer/shipbuilder commissioned another calculation and draughting agency (calculation and draughting agency B) to determine whether it was possible to reduce the weight of the vessel.

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[7] For this purpose, it was taken into consideration that, each year, an average of a hundred newly built vessels are certified, which involves the approval of many thousands of drawings and calculations. This leads on a regular basis to comments that result in modifications to vessel construction and other aspects. Until now, there has been no evidence that such a design error has gone undetected.

[8] For all of the Safety Board's investigations, the question of who was to blame (legally or otherwise) is not taken into consideration. The sole purpose of the investigations and studies is to learn from the incidents and to prevent, where possible, such situations from occurring in the future. As such, the elaboration of the investigation focuses mainly on the factors that can be controlled. Being focused on these factors means that the primary aim is to find actions, measures and rules that can improve the safety level.

[9] The price of the new hull would apparently consist of the cost price of the vessel (price for materials, labour, etc.) plus an agreed fixed amount, the brokerage fee.

### *4.5.3 Calculation and draughting agency B*

Ultimately, this agency performed calculations that resulted in a lighter vessel. Contacts were made by calculation and draughting agency B with the IVW/DS to have the vessel approved. The developer/shipbuilder was still indirectly involved in this process, but no longer personally checked any of the calculations for the main construction.

## 5 THE ACCIDENT IN A BROADER PERSPECTIVE

Section 4.3.1 states that supplemental calculations revealed that the design tools are not satisfactory. These tools predicted a bending moment that was far too low for the vessel type in question, also within the validity range of the design tools. This gives rise to the question of whether this incident was an accident, or whether such a situation could occur on a more frequent basis. It is unclear what this means for well vessels that are currently in service. The Safety Board believes that further investigation should take place on this matter.

This sector often relies on tradition, without any consideration of whether this is sufficient. Now that designs are being further increased in scale, the question arises of whether this is justified. The Safety Board believes that it is undesirable to design vessels based on general design tools. Certainly now that computers make it possible to complete full and extensive calculations for a vessel, the Safety Board considers it vital that all designs are realised on the basis of full calculations.

It is also clear that the sector should carry out improved internal checks and balances. It is the Safety Board's opinion that measures should be taken to better monitor developments and to analyse them more thoroughly. This could take place in a variety of ways. Examples could include:

- The improved recording and checking of design tools with attention paid to the range of use and/or the development of other reliable design tools
- The improvement of the inspections carried out by the sector itself and those conducted by government-related institutions
- The clarification of the responsibilities of the parties involved.

Furthermore, lessons can be learned from the inspection process for the construction of other types of vessels.

- Inland navigation vessels which transport hazardous substances are built "under classification". This means that a Classification Society checks the entire design process.
- Seagoing vessels have also long been built "under classification". For new seagoing vessels, it is common practice that the shipyard bears full responsibility for the end product, and therefore is also liable for this. The shipyard is the point of contact for the IVW/DS and the Classification Society.

Section 1.4.2 states that, after the accident, the IVW/DS investigated whether there were similar vessels in existence for which such an accident could also occur as a result of overly weak construction. According to the IVW/DS, this investigation revealed that this is not the case. Additionally, the IVW/DS believes that this accident was random in nature, based on the fact that, until now, there has been no evidence that such a design error has gone undetected. Therefore, as such, the inspectorate does not find it necessary to fundamentally change the inspection process. It is the Safety Board's opinion that the IVW/DS should reconsider this conclusion.

# 6 CONCLUSIONS

Based on the previous chapters, the Safety Board has drawn the following conclusions.

- The vessel was not designed for the stress to which it could be exposed. This emerged from both the check calculations from the IVW/DS and the calculations of the Safety Board. The lack of fore-and-aft strength was such that the only conclusion possible was that this had been the cause of the accident.

- This situation was based on a number of factors, such as:

  - **Insufficiently critical attitude**
    None of the parties recognised the fact that the design deviated from existing large well vessels, even though existing methods were relied upon. No critical analysis took place to determine whether the design tools could also be used for this non-standard vessel.

  - **The design tools were not sufficient**
    The Safety Board's calculations revealed that the design tools used were not sufficient. These tools predicted a bending moment that was far too low for the vessel type in question, both outside the validity area (as was the case here) and within the validity range of the design tools. It is unclear what this means for the inland navigation vessels that are currently in service.

  - **The design tools used were not applied correctly**
    For this vessel, formulas were used outside of the validity area for which they were originally created.

  - **The IVW/DS assessment provides inadequate safeguards**
    The assessments and inspections performed by the IVW/DS did not provide adequate safeguards. Those directly involved in the practical situation seem to assume that these safeguards are sufficient.

  - **Unclear allocation of responsibility**
    The allocation of responsibility among the parties involved in the design was not clear. As a result, it was not clear what had been inspected and what had not; this turned out to be a disastrous working method, especially with regard to the ability to apply basic assumptions.

# 7 RECOMMENDATIONS

1. We recommend to the inspector general of the Transport and Water Management Inspectorate that, for the new construction or major renovations of inland navigation vessels, the applicant is required to demonstrate the construction strength of the vessel based on full calculations, before the Certificate of Inspection is issued.

2. We recommend to the inspector general of the Transport and Water Management Inspectorate that further investigation be carried out into the construction strength of well vessels (>80 metres and/or with a non-standard length/width ratio) which have not received the Certificate of Inspection on the basis of full calculations.

Administrative bodies to which a recommendation is directed are required to submit to the minister involved, within six months of the publication of this report, a statement of position with regard to the follow-up to this recommendation. Non-administrative bodies or persons to whom a recommendation is directed are required to submit to the minister involved, within one year of the publication of this report, a statement of position with regard to the follow-up to this recommendation. A copy of this response must be submitted at the same time to the Chairman of the Dutch Safety Board and the Minister of the Interior and Kingdom Relations.

## APPENDIX 1: JUSTIFICATION OF THE INVESTIGATION

The Dutch Transport Safety Board (RvTV), the predecessor of the Dutch Safety Board, decided to conduct an investigation into the accident with the engine-powered barge due to the seriousness of the situation and the conditions under which the accident took place. The accident involved the bending of the nearly new engine-powered barge, under the weight of its own load, while moored in the Middensluis lock in IJmuiden, during its third trip transporting cargo. The vessel was not overloaded and there were no external influences that played a role.

Soon after the accident was reported, the Board commenced the investigation into the surrounding circumstances. The investigation that followed focused primarily on the certification process and the basic design of the vessel, due to the fact that the accident involved a recently constructed barge.

In its investigation, the Board focused significant attention on *how* and *why* the accident occurred. Furthermore, the Board investigated the underlying structural factors during the construction and certification process.

**Investigation organisation**
The investigation was conducted by a project team from the Board's bureau. The investigation consisted of various parts, for which internal and external experts were engaged.

**Parts of the investigation**
The investigation focused on answering the following two questions:

- The direct cause: what was the primary cause of the accident?
- The indirect factors: which factors indirectly contributed to the occurrence of the accident or to the situation that resulted in the bending of the vessel under normal operational conditions?

To determine the cause of the accident, the Board used the information from its own investigation in addition to information it was able to obtain from documents from nearly all the organisations directly involved in the accident, in a variety of areas. In addition, an extensive investigation was conducted and calculations performed by the Board's bureau staff members, who were assisted by external experts commissioned by the Board.

**The final report of the Dutch Safety Board**
After the abovementioned parts of the investigation were completed, the draft final report was drawn up under the responsibility and supervision of the Shipping Committee.

The report was submitted for inspection to the parties involved on 24 June 2005. The responses received were assessed and incorporated in the draft report which was submitted to the Board on 18 April 2006. The report was adapted following the comments from the Board.

In 2005, the investigation was transferred in connection with the dissolution of the Dutch Transport Safety Board and the transfer of its duties to the Dutch Safety Board on 1 February 2005.

The composition of the Dutch Transport Safety Board and the Shipping Committee is set out below.

Composition of the Dutch Transport Safety Board and the Maritime Committee (dissolved with effect from 1 February 2005)

**Board**

| | |
|---|---|
| Chairman: | Prof. Pieter van Vollenhoven |
| | F.W.C. Castricum |
| | J.A.M. Elias |
| | B.M. van Balen |
| | A.H. Brouwer-Korf |
| | D.M. Dragt |
| | J.A.M. Hendrikx |
| | K. Nije |
| | Prof. U. Rosenthal |
| | F.R. Smeding |
| | D.J. Smeitink |
| | J.P. Visser |
| | G. Vrieze |
| | Prof. W.A. Wagenaar |

**Maritime Committee**

| | |
|---|---|
| Chairman: | J.A.M. Elias |
| | D.M. Dragt |
| | A. Aalbers |
| | B.C. De Savornin Lohman |
| | K.J. van Dorsten |
| | G.A. Egas Repáraz |
| | P.M.J. Kreuze |
| | M.J. Torpstra |
| | H.J.G. Walenkamp |
| | L.P.A. de Winter |
| Secretary: | H.J.A. Zieverink |

## APPENDIX 2: ANALYSES AND CALCULATIONS EXECUTED BY THE BOARD

[NO ENGLISH TRANSLATION AVAILABLE]

## 1 GEGEVENS VAN HET SCHIP

In de navolgende tabel zijn de hoofdgegevens weergegeven, zoals deze konden worden afgeleid uit het beschikbare materiaal.

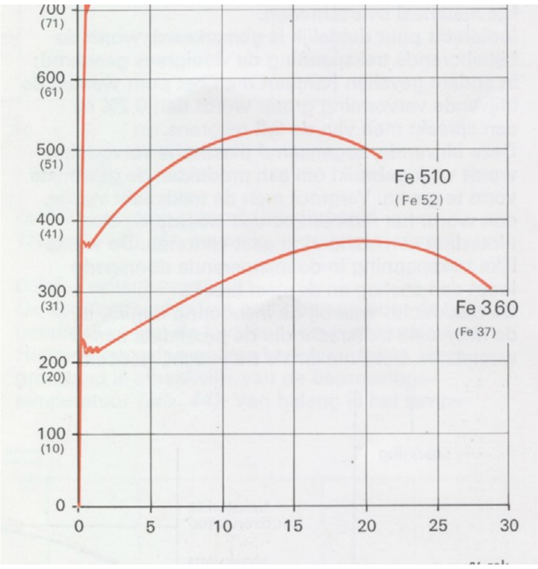
| | | | | opmerking |
|---|---|---|---|---|
| 1 | Lengte over alles | m | 110.00 | ijklengte |
| 2 | Lengte over alles, gemald | m | 109.05 | algemeen plan |
| 3 | Lengte voorsteven tot roerkoning | m | 108.10 | loodlijn lengte |
| 4 | Lengte voor scantlings | m | 107.30 | volgens midship section 22-07-02 |
| 5 | Lengte op ontwerpwaterlijn 3.90 | m | 109.75 | |
| 6 | Lengte over alles maal 0.97 | m | 106.70 | 97% van ijklengte |
| 7 | Te rekenen lengte definitie Germanischer Lloyd | m | 108.10 | grootste van 108.10 en 106.70 |
| | Breedte op buitenkant spant | m | 11.40 | |
| | Holte, midscheeps, gemald | m | 5.00 | |
| | Holte, kleinste | m | **4.52** | volgens meetbrief |
| | Diepgang, meetbrief | m | **3.90** | |
| | Draagvermogen diepgang 3.90 | t | 3495 | |
| | Diepgang, sterkte berekeningen | m | **4.85** | volgens midship section 22-07-02 |
| | Draagvermogen op diepgang 4.85 | t | 4684 | |
| | Diepgang, keur algemeen plan | m | **4.45** | goedgekeurd SI d.d. 8-8-02 |
| | Leeg scheepsgewicht | t | 1016 | berekening consultant consortium |
| | Zwaartepunt in lengte leeg schip | m | 53.80 | |
| | Zwaartepunt in hoogte leeg schip | m | 2.76 | |
| | Voortstuwingsvermogen | kW | 2x956 | |
| | Snelheid | km/h | 21.4 | op diepgang 3.90 m |
| | Soortelijk gewicht van de lading | t/m$^3$ | 1.600 | rekenwaarde ontwerp constructie |
| | Soortelijk gewicht droog spuitzand | t/m$^3$ | 1.626 | meting na ongeval |
| | Soortelijk gewicht nat spuitzand | t/m$^3$ | 1.880 | meting na ongeval |
| | Ruimlengte | m | 59.0 | |
| | Ruimlengte t.o.v. scheepslengte | - | 0.546 | =59.0/108.10 |
| | Ruimhoogte tot bovenkant beun | m | 5.50 | |
| | Ruiminhoud tot bovenkant beun | m$^3$ | 2576 | 2576x1.88 = 4843 t; 2576x1.626 = 4189 t |
| | Diepgang met droog zand, 100% fuel | m | **4.57** | deadweight = 4189+150 = 4339 t |
| | Diepgang met nat zand, 100% fuel | m | **5.10** | deadweight = 4843+150 = 4993 t |
| | Hoogte in ruim tot hoogste overvloei | m | 3.68 | |
| | Ruiminhoud tot hoogste overvloei | m$^3$ | 1723 | 1723x1.88 = 3239 t; 1723x1.626 = 2801 t |
| | Diepgang met droog zand, 100% fuel | m | **3.45** | deadweight = 2801+150 = 2951 t |
| | Diepgang met nat zand en 100% fuel | m | **3.81** | deadweight = 3239+150 = 3389 t |
| | Hoogte tot laagste overvloei | m | 3.38 | |
| | Ruiminhoud tot laagste overvloei | m$^3$ | 1583 | 1583x1.88 = 2976 t; 1583x1.626 = 2574 t |
| | Hoogte lading ten tijde ongeval | m | 4.17 | |
| | Ruiminhoud ten tijde ongeval | m$^3$ | 1951 | 1951x1.88 = 3668 t; 1951x1.626 = 3172 t |
| | Diepgang met droog zand, 100 % fuel | m | **3.75** | deadweight = 3172+150 = 3322 t |
| | Diepgang met nat zand, 100 % fuel | m | **4.15** | deadweight = 3668 +150 = 3818 t |
| | Brandstof capaciteit | m$^3$ | 154 | 50 voor, 104 achter |
| | Zoetwater capaciteit | m$^3$ | 20 | |
| | Diverse tanks | m$^3$ | | |
| | Vaargebied | | 2,3,4 | |

## 2 ACHTERGROND VAN STERKTEBEREKENINGEN

### 2.1 ALGEMEEN: SPANNING, MOMENT, TRAAGHEID, WEERSTAND

#### *2.1.1 Toelaatbare spanning*

**Trekspanning.** De toelaatbare trekspanning van een materiaal wordt doorgaans vastgesteld op basis van een trekproef van een proefstaafje uit het te gebruiken materiaal.




**Grafiek 2: Spanning op basis rek van twee staalsoorten**

In bijgaande grafiek[10] zijn de trekkrommen van twee staalsoorten gegeven, één van een standaard scheepsbouwstaal, Fe 360, en één van een hoogwaardiger staal met een hogere treksterkte, Fe 510. In de grafiek is op de horizontale as de rek van het staafje aangegeven als percentage van de oorspronkelijke lengte en verticaal is aangegeven de spanning in N/mm$^2$.

Kenmerkende punten in de grafiek zijn: het punt waar voorbij het materiaal vloeit en blijvende vervorming optreedt.

Dat punt wordt de vloei- of rekgrens genoemd (yield stress, Fliessgrenze). In het voorbeeld van Fe360 (het staal gebruikt voor het beunschip) bedraagt de vloeigrens ongeveer 240 N/mm$^2$. Het tweede kenmerkende punt is het hoogste punt van de trekkromme, dit wordt de treksterkte genoemd (tensile strength, Zugfestigkeit). In dit geval is dat 360 N/mm$^2$. Een staal wordt dus aangeduid met zijn treksterkte.

Er kan geen hogere spanning op het materiaal worden uitgeoefend, daarboven bezwijkt het materiaal.

Opgemerkt moet worden, dat het vloeien optreedt bij een rek van ongeveer 0.2%, terwijl het materiaal pas definitief bezwijkt na een vervorming van 20% bij het standaard scheepsbouwstaal Fe360 en 15% bij het hoogwaardiger staal Fe 510.

Omdat niet alleen de sterkte van de constructie gewaarborgd moet zijn, maar ook de vormvastheid, zullen de spanningen die in constructies mogen optreden lager moeten zijn dan de vloeispanning.

Omdat er ook nog een veiligheidsfactor in acht moet worden genomen voor b.v. dynamische effecten, niet perfecte lassen en niet voorziene belastingen, wordt er in het geval van een binnenschip door Germanischer Lloyd een spanning toegelaten van maximaal 160 N/mm$^2$. Dat is 2/3 van de vloeispanning, of een veiligheidsfactor van 1.50. Lloyd's Register of Shipping laat toe137 N/mm$^2$, een veiligheidsfactor van 1.75.

[10] Beknopte staalkennis, Stichting Staalcentrum Nederland, Publicatie nr 102, oktober 1972.

**Drukspanning.** In het bovenstaande wordt het materiaal beoordeeld op grond van de *trek*spanningen. Het gedrag van een constructie onder invloed van *druk*spanningen kan hiervan niet worden afgeleid. Toelaatbare *druk*spanningen van materialen die plat zijn in de drukrichting zijn hoger dan de toelaatbare *trek*spanning van hetzelfde materiaal. Wordt echter de hoogte/dikte verhouding[11] van het beproefde stuk materiaal hoger dan 5 à 6, dan treedt het fenomeen knik op. Dat is het aanvankelijk elastisch uitknikken van de staaf, waarna de staaf onmiddellijk onderworpen wordt aan buigende momenten, waaraan de staaf uiteindelijk bezwijkt.

*De kniklast op een enkelvoudig constructiedeel:*

$$F_k = \frac{\pi^2 \cdot E \cdot I}{l_k^2}$$

*Dit leidt tot de knikspanning:*

$$\sigma_k = \frac{F_k}{A} = \frac{\pi^2 \cdot E \cdot I}{A \cdot l_k^2}$$

*met* :

$l_k$ = *kniklengte*

*I = axiaal traagheidsmoment*

*E= elasticiteitsmodulus*

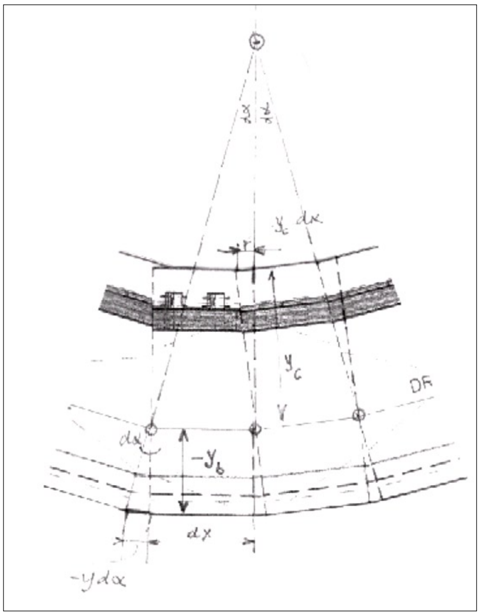
*A= dwars oppervlak*

Euler heeft voor de toelaatbare kniklast de nevenstaande formule opgesteld. Experimenten met een slanke stok die ieder wel eens heeft uitgevoerd, leiden tot de conclusie dat een kleine ondersteuning halverwege de stok, al kan leiden tot een grote toename van de draagkracht van de stok. Dat komt ook naar voren in de kwadratische term van de kniklengte in de noemer van de formule.

De klassenbureaus hebben ook voor samengestelde constructies zoals de dwarsdoorsnede van het schip, dergelijke formules opgesteld. Het voldoen van de knikvoorwaarde is vooral een kwestie van verstandig construeren met voldoende langsscheeps materiaal. Dit leidt doorgaans tot het construeren met langsspanten voor schepen die onderworpen worden aan grote langsscheepse buigende momenten.

### *2.1.2 Buigend moment, weerstandsmoment en spanning*

We nemen twee mootjes uit het schip met een totale lengte van *2 dx.* In onbelaste toestand zijn die moten rechthoekig. We gaan het schip nu belasten en we kunnen dan constateren dat de moten gaan vervormen, en dat de doorsneden roteren over een hoek $d\alpha$.
We kunnen ook constateren dat de onderste vezels van de doorsnede langer zijn geworden, en dat de bovenste vezels korter zijn geworden.
Ergens tussenin zal er daarom een vezel te vinden zijn die even lang is gebleven. We kiezen nu de oorsprong van ons assenstelsel in die vezel[12], die op een nog onbekende afstand van de basis van de constructie is gelegen.




11 Winkler, J., Technische Mechanik, VEB Fachbuchverlag Leipzig,1987
12 Den Hartog, J.P., Sterkteleer, Het Spectrum, Utrecht/Antwerpen,1977

**Figuur 7: Toelichting op krachten bij buiging**

De onderste vezel bijvoorbeeld van het linker mootje, ligt op een afstand *-y* vanaf de oorsprong van ons zelf gekozen, maar nog onbekende nulpunt. Deze vezel had een lengte *dx*, maar wordt door de belasting verlengd met een stukje ter grootte van *-y* $d\alpha$. De rek die deze vezel ondergaat is dan:

$$rek = \varepsilon = -\frac{y \cdot d\alpha}{dx}$$

Nu geldt verder, volgens de wet van Hooke, dat de spanning recht evenredig is met de rek (althans tot de vloeigrens, zie eerdere figuur):

$$\sigma = E \cdot \varepsilon$$

*met*

$\sigma$ = *spanning = kracht per oppervlakte eenheid in* $kN/cm^2$

*E = elasticiteitsmodulus van het materiaal in* $kN/cm^2$

*E = 21 000* $kN/cm^2$ *voor staal*

$\varepsilon$ = *specifieke verlenging of rek in cm/cm*

*waarmee:*

$$\sigma = -E \cdot y \cdot \frac{d\alpha}{dx}$$

Aangezien er geen horizontale krachten in de scheepsmoot werkzaam zijn, moet er gelden dat de som van alle krachtjes in de doorsnede gelijk aan nul is. Dit wordt omdat het een oppervlak betreft, aangeduid met een dubbel integraalteken, wat niets anders is dan een symbool voor de *som* van zeer veel, zeer kleine krachtjes:

$$F = \iint_A \sigma \, dA = 0$$

*omdat* :

$$\sigma = -E \cdot y \cdot \frac{d\alpha}{dx}$$

*kunnen we F schrijven als:*

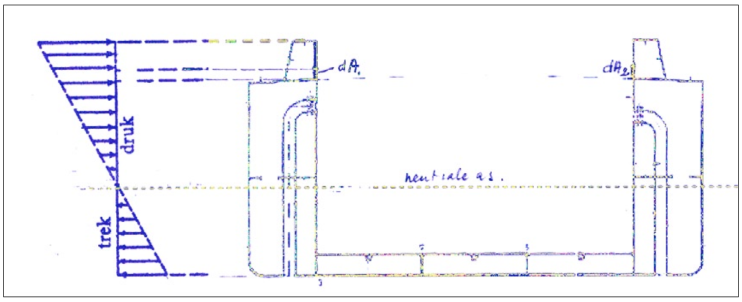
$$F = -\iint_A E \cdot y \cdot \frac{d\alpha}{dx} \cdot dA = 0$$

$$F = -E \cdot \frac{d\alpha}{dx} \iint_A y \cdot dA = 0$$

*Dit is het geval als:*

$$\iint_A y \cdot dA = 0$$

In de laatste uitdrukking herkennen we de definitie van het geometrische zwaartepunt van de doorsnede. Hieruit kunnen we concluderen dat kennelijk de vezel waarin geen rek optreedt, loopt door het zwaartepunt van de dwarsdoorsnede.




**Figuur 8:** Bepalen van zwaartepunt van de dwarsdoorsnede

Vervolgens kunnen we het moment gaan bepalen ten opzichte van ons zojuist gevonden zwaartepunt:

*De kracht op een elementair oppervlakje dA bedraagt:*

$f = \sigma \cdot dA$

*Het moment van dit krachtje t.o.v. van het zwaartepunt bedraagt:*

$f \cdot y = \sigma \cdot dA \cdot y$

*Het totale moment dat in de doorsnede wordt uitgeoefend is:*

$$M = \iint_A y \cdot \sigma \cdot dA$$

$$M = -\iint_A y \cdot E \cdot y \cdot \frac{d\alpha}{dx} \cdot dA = -E \cdot \frac{d\alpha}{dx} \iint_A y^2 dA$$

*In de laatste factor herkennen we de uitdrukking voor het oppervlakte traagheidsmoment van de doorsnede I*

*Zodat we kunnen schrijven:*

$$M = -E \cdot I \cdot \frac{d\alpha}{dx}$$

We kunnen vervolgens in zowel de uitdrukking voor het moment als in de uitdrukking van de spanning, eenzelfde factor identificeren, namelijk $d\alpha/dx$, de verandering van de hoek per lengte eenheid.

Dit stelt ons in staat een link te leggen tussen het moment en de spanning als volgt:

$$M = -E \cdot I \frac{d\alpha}{dx} \Rightarrow -E \cdot \frac{d\alpha}{dx} = \frac{M}{I}$$

*en*

$$\sigma = -E \cdot y \frac{d\alpha}{dx} \Rightarrow -E \cdot \frac{d\alpha}{dx} = \frac{\sigma}{y}$$

*ofwel:* $\frac{\sigma}{y} = \frac{M}{I}$

*waarmee:*

$$\sigma = \frac{M}{I} \cdot y$$

Dit is een erg eenvoudige maar ook zeer belangrijke formule in de sterkteleer. De formule laat zien dat de spanning toeneemt als:

- het moment $M$ toeneemt
- de afstand $y$ van het beschouwde element verder afligt van het zwaartepunt
- het traagheidsmoment $I$ van de hele doorsnede afneemt

De spanning is het hoogst waar y het grootst is, dus op de grootste afstand van het zwaartepunt. Of dat in de coaming is of in de bodem, hangt af van de ligging van het zwaartepunt. Ligt dat laag, dan zal het dek de hoogste spanning vertonen, ligt dat hoog dan zal de bodem de hoogste spanning vertonen.

De hoogste spanning waarmee een constructie reageert op een zeker moment M, kan worden gekarakteriseerd door de factor y/I uit bovenstaande formule. Als we voor y de maximum afstand in de constructie tot het zwaartepunt invullen, $y_{max}$, dan geeft $y_{max}/I$ de vermenigvuldigingsfactor waarmee het moment moet worden vermenigvuldigd om de maximale spanning in de constructie te bepalen.

De inverse van deze factor wordt het weerstandsmoment van de constructie genoemd:

$$W = I/y_{max}$$

# 3 HET CONSTRUEREN VAN HET GROOTSPANT

## 3.1 CONSTRUEREN VOOR TREK- EN DRUKSPANNINGEN IN DEK EN BODEM

Het ontwikkelen van het ontwerp van een constructie begint met het schatten van het maximale buigende moment die op het schip kan werken. Daarmee wordt een voorlopige constructie opgezet, en met het daarmee te bepalen constructiegewicht kan nagegaan worden of de eerste schatting van het moment klopte. Vervolgens zal er gezocht moeten worden naar die beladingconditie die het grootste buigende moment oplevert. Van te voren staat niet vast in welke beladingstoestand dat zal zijn en of dat een hogging moment is (leidend tot een kattenrug) of een sagging moment (leidend tot een paardenrug).

Doorgaans zal er gekeken worden naar een toestand waarbij het schip leeg is en een toestand waarbij het schip vol beladen is.

Uiteindelijk zullen er vier condities zijn waarop de constructie gedimensioneerd zal worden:

| | Buigend moment | |
|---|---|---|
| aard: | maximaal positief | maximaal negatief |
| benaming:<br>verschijning:<br>Spanning in dek:<br>Spanning in bodem: | hogging<br>kattenrug<br>**1. trek in dek**<br>**3. druk in bodem** | sagging<br>paardenrug<br>**2. druk in dek**<br>**4. trek in bodem** |

In ieder van deze vier gevallen wordt, met het beschikbare weerstandsmoment, de optredende spanning bepaald met de formule:

$$\sigma_{bodem} = \frac{M}{I} \cdot y_{bodem} = \frac{M}{W_{bodem}}$$

$$\sigma_{dek,coaming} = \frac{M}{I} \cdot y_{dek,\ coaming} = \frac{M}{W_{dek,coaming}}$$

Vervolgens wordt dan beoordeeld of deze spanningen lager zijn dan de toelaatbare spanningen, zoals die door het klassenbureau zijn vastgesteld. Is dat niet het geval, dan zal de constructie moeten worden verzwaard en opnieuw moeten worden doorgerekend.

Er bestaan dus vier stappen bij het dimensioneren en beoordelen van een grootspantsconstructie:

- zoeken naar de maximale positieve en negatieve momenten die op kunnen treden in enige operationele conditie van het schip
- construeren van het grootspant en het bepalen van het weerstandsmoment van dek en bodem
- bepalen van de optredende maximale druk- en trekspanningen
- beoordelen of deze spanningen acceptabel zijn

Alle berekeningen die hierbij aan de orde komen zijn niet moeilijk. Het grootste probleem schuilt in het identificeren van die twee beladingstoestanden waarbij respectievelijk het hoogste hoggingmoment optreedt en het hoogste saggingmoment optreedt.

## 3.2 HET SCHATTEN VAN HET MAXIMAAL OPTREDENDE BUIGENDE MOMENT

Om aan dit probleem van het identificeren van de ongunstigste belasting tegemoet te komen, hebben de klassenbureaus in het verleden systematische berekeningen uitgevoerd naar de optredende momenten die zowel in een leeg schip kunnen optreden, maar vooral ook tijdens het laden en lossen.

Het klassenbureau Germanischer Lloyd onderscheidt bij de schatting van de buigende momenten voor droge lading motorschepen, twee typen op grond van de wijze van laden en lossen:

Type A: Schip wordt beladen in een heen- en weergaande beweging: achterin beginnend, naar voren en dan weer naar achteren. Lossen in de zelfde volgorde: ook achterin beginnend.

Type B: Schip wordt in één gang beladen, achterin beginnend. Het schip wordt ook in één gang gelost , maar dan voorin beginnend

Met deze ladingswijzen zijn systematische berekeningen uitgevoerd. Voorbeelden zijn in de onderstaande figuur afgebeeld[13]. Op de horizontale as staat de ruimlengte afgebeeld, op de verticale as het buigende moment. Overigens worden deze schepen kennelijk in drie gangen beladen. Te zien is dat bij het beladen van het schip er aanvankelijk een positief buigend moment is, dat naarmate het schip voller beladen wordt, lager wordt en afhankelijk van de volheid van het schip, ook negatief kan worden. Ook is te zien, bijvoorbeeld aan de hand van de Kahn, δ=0.92, dat er op driekwart van het beladen er een buigend moment ontstaat, dat hoger is dan het moment in de eindtoestand van de belading. Zou de ontwerper alleen de eindtoestand hebben beoordeeld, dan zou hij een te laag moment in rekening hebben gebracht.

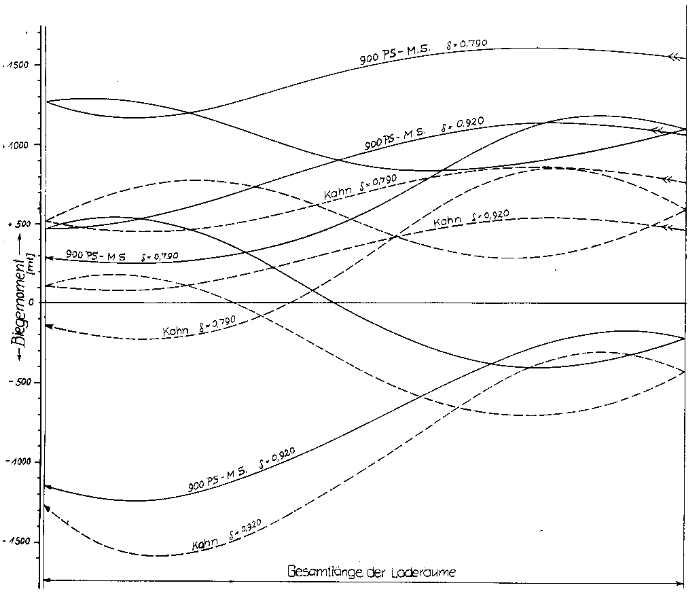


Bild 1 Längsbiegemoment während des Beladens

Een tweede voorbeeld van een dergelijke systematische zoektocht naar het grootste moment biedt de volgende figuur van een schip met een lengte van 95.0 m en een diepgang van 4.0 m. De aanduiding M1 etc slaat op de onderscheiden beladingstoestanden. Hier zien we tijdens het beladen het moment veranderd van 50 000 kNm positief, via 55 000 kNm negatief, tot uiteindelijk 28 000 kNm negatief in de eindtoestand.

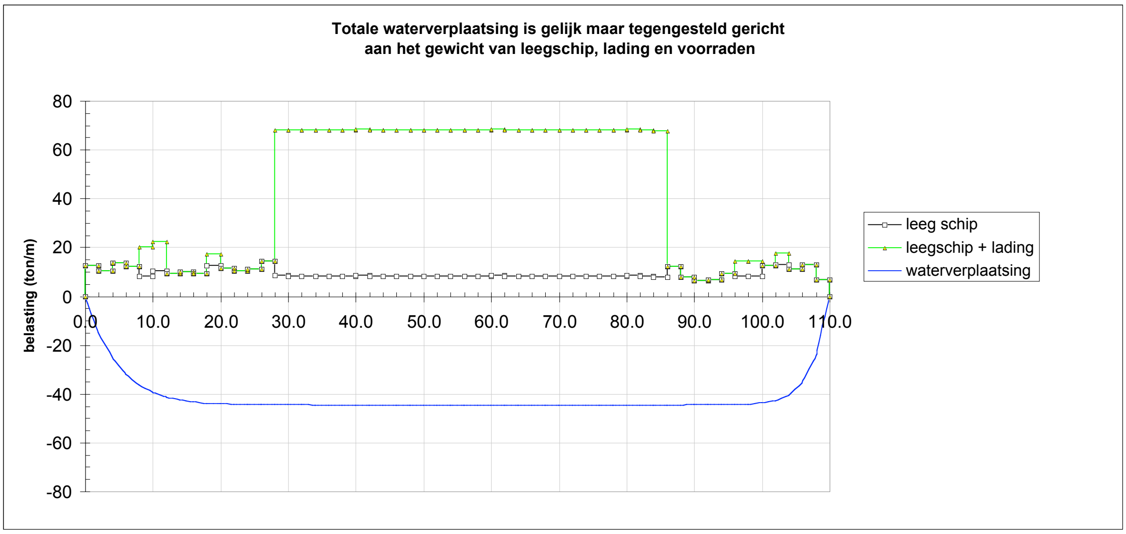
## 3.3 Het rechtstreeks berekenen van het buigend moment

### *3.3.1 De verdeling van neerwaartse en opwaartse krachten*

Een buigend moment berekening zal moeten beginnen met een gewichtsberekening van het schip, zodat het gewicht en de verdeling van het gewicht van het lege schip over de lengte bepaald kan worden. Vervolgens wordt de verdeling van de lading over de lengte bepaald, inclusief de gewichten van brandstof en andere voorraden. Hiermee zijn de neerwaartse krachten bepaald en verdeeld over de lengte. Gebruikelijk is het om het schip in moten te verdelen met een niet te grote lengte ten opzichte van de scheepslengte, in dit geval bijvoorbeeld 2 meter.

Dat is te zien in onderstaande grafiek, waarbij in zwart de gewichten per meter zijn aangegeven van het lege schip. Daarbovenop is dan geplaatst het gewicht van de lading en de voorraden in groen, ook in tonnen per meter scheepslengte.

[13] Schellenberger, K.-H., Einiges über die Festigkeit der Binnenschiffe, Schiffstechnik Bd. 3 (1955/56).



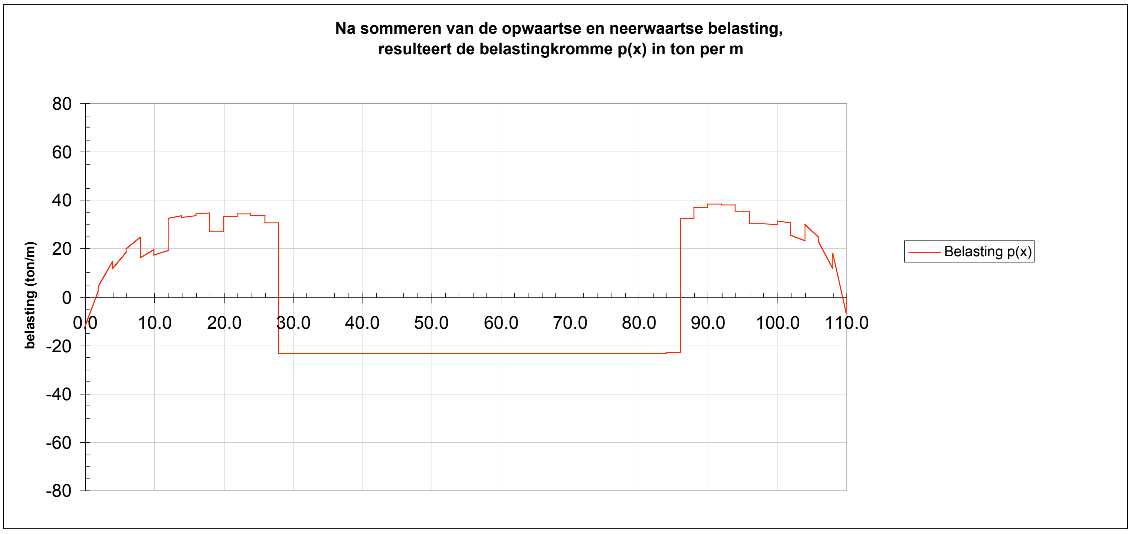

**Grafiek 3:** Neerwaarts gericht gewicht van het schip en opwaartse waterdruk

Vervolgens worden de opwaartse krachten op het schip bepaald volgens de wet van Archimedes. De verdeling van de opwaartse krachten over de lengte van het schip verloopt volgens de zogenaamde kromme van spantoppervlakken. Deze is in blauw aangegeven.

Er is natuurlijk evenwicht tussen de opwaartse en neerwaartse krachten en tussen het moment van deze krachten.

### *3.3.2 De bepaling van de belasting op het schip*

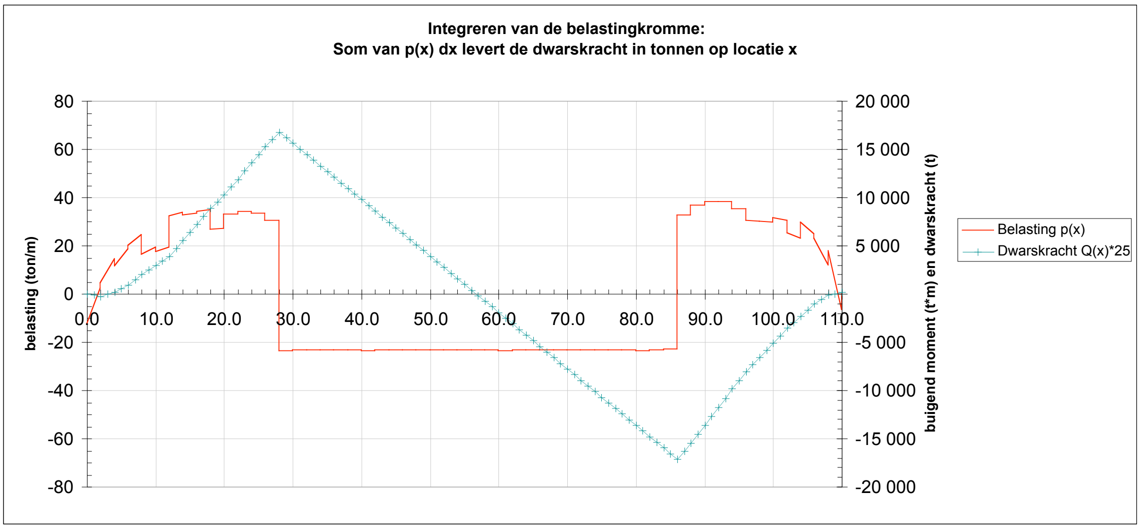
Door per moot van 2 meter het verschil te bepalen tussen de opwaartse en neerwaartse kracht, ontstaat de belasting p in ton per m op het schip. Dat is geïllustreerd in onderstaande figuur. Duidelijk is te zien dat de lading van het schip als het ware is opgehangen tussen het achterschip en het voorschip, omhoog gehouden moet worden door het achter- en voorschip.




**Grafiek 4:** Opwaartse en neerwaartse belasting gesommeerd

### *3.3.3 De bepaling van de dwarskracht op het schip*

Vervolgens wordt bepaald welke dwarskrachten er optreden in de diverse dwarsdoorsneden van het schip. Hierbij wordt beginnend achteraan met stappen van, in dit geval 2m, een knip te maken in het schip en alle verticale krachten te sommeren. Per doorsnede wordt dan de kracht gevonden die je moet uitoefenen om het schip in evenwicht te houden als je het zou doorknippen in die doorsnede. De verdeling van die dwarskrachten zien we in de volgende grafiek:

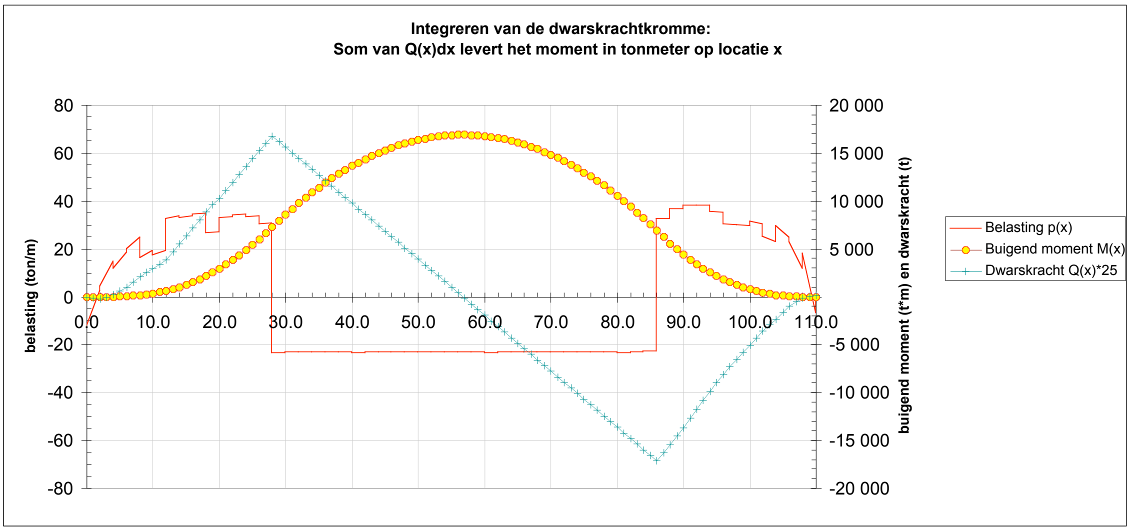



**Grafiek 5:** Som belastingen en dwarskracht

### *3.3.4 De bepaling van het buigend moment op het schip*

Tenslotte kan het buigende moment voor iedere doorsnede van het schip bepaald worden door het sommeren van de dwarskrachten over de lengte. Het is duidelijk dat er in dit geval een buigend moment optreedt dat het schip in het midden wil doen doorzakken: het schip krijgt een doorgezakte paardenrug. Germanischer Lloyd duidt dit moment aan met een positief moment. Een positief moment resulteert in horizontaal gerichte drukkrachten in het dek en de coaming van het schip en in horizontale trekkrachten in de bodem van het schip. Zou het schip een kattenrug vertonen, dan is er sprake van een negatief moment en dan zullen er trekkrachten optreden in dek en coaming, maar drukkrachten in de bodem.

In het algemeen treedt een paardenrug op bij geladen schepen en een kattenrug bij lege schepen.




**Grafiek 6:** Som belastingen, dwarskracht en buigend moment

Het interessante mechanisme is dat de verticale krachten van gewicht en opdrijvende kracht, via dwarskracht en buigend moment weer omgezet worden in horizontale krachten in de constructie: namelijk trek en druk krachten in dek en bodem.

### 3.3.5 *Het berekenen van het weerstandsmoment*

Het weerstandsmoment wordt in een aantal stappen bepaald.

- vaststellen welke verbanddelen bijdragen aan de langsscheepse sterkte: alleen langsscheeps en over de gehele beschouwde lengte doorlopend materiaal mag worden meegeteld
- vaststellen in een tabellarische berekening van het oppervlak, het zwaartepunt, het traagheidsmoment van de individuele oppervlakken en het totale oppervlak, het totale zwaartepunt en het totale traagheidsmoment van de totale constructie van het grootspant ten opzichte van de basislijn.
- vervolgens kan na vaststellen van het zwaartepunt het traagheidsmoment ten opzichte van een as door het zwaartepunt worden vastgesteld.

Als voorbeeld hierbij de bepaling van de eigenschappen van de doorsnede van de constructie aan de hand van de tekening van het beunschip, als ingediend ter keur bij IVW.

We zien in de linkerkolom de omschrijving van de langsscheepse constructiedelen, vervolgens wordt aangegeven of het betreffende element horizontaal of verticaal loopt. Dan volgt de lengte van het element en de plaatdikte van het element en de afstand tot de gekozen basislijn, meestal het vlak. Op grond van de oriëntatie verticaal of horizontaal, wordt vervolgens bepaald of het element in de breedte of in de hoogte moet worden genomen bij de bepaling van het eigen traagheidsmoment van het element, dat immers bedraagt:

$$I_{eigen} = \frac{1}{12} \cdot h^3 \cdot b$$

| Keurtekening d.d. 22-07-02 /goedgekeurd d.d. 8-8-02 | direc-tion | length | thickness | lever z to basis | breadth | height | Area | Moment | A z² | I element |
|---|---|---|---|---|---|---|---|---|---|---|
| | - | cm | cm | m | cm | cm | $cm^2$ | $cm^2$ x m | $cm^2$ x $m^2$ | $cm^4$ |
| bottom | h | 510.0 | 1.0 | -0.005 | 510.0 | 1.0 | 510 | -3 | 0 | 43 |
| bilge 1 | h | 25.0 | 1.3 | -0.006 | 25.0 | 1.3 | 33 | 0 | 0 | 5 |
| bilge 2 | v | 56.0 | 1.3 | 0.103 | 1.3 | 56.0 | 73 | 7 | 1 | 19025 |
| bilge 3 | v | 22.5 | 1.3 | 0.463 | 1.3 | 22.5 | 29 | 14 | 6 | 1234 |
| sideshell | v | 393.7 | 0.9 | 2.544 | 0.9 | 393.7 | 354 | 901 | 2293 | 4576753 |
| sheerstrake | v | 50.0 | 2.5 | 4.762 | 2.5 | 50.0 | 125 | 595 | 2835 | 26042 |
| deck | h | 171.5 | 1.2 | 5.032 | 171.5 | 1.2 | 206 | 1036 | 5211 | 25 |
| coaming OUTside | v | 98.1 | 0.8 | 5.521 | 0.8 | 98.1 | 78 | 433 | 2392 | 62938 |
| coaming top | h | 60.0 | 1.0 | 6.005 | 60.0 | 1.0 | 60 | 360 | 2164 | 5 |
| coaming hp top | v | 10.0 | 0.6 | 5.950 | 0.6 | 10.0 | 6 | 36 | 212 | 50 |
| coaming hp side | h | 10.0 | 0.6 | 5.521 | 10.0 | 0.6 | 6 | 33 | 183 | 0 |
| coaming INside | v | 145.0 | 1.2 | 5.275 | 1.2 | 145.0 | 174 | 918 | 4842 | 304863 |
| stringer plt | h | 32.0 | 0.8 | 2.254 | 32.0 | 0.8 | 26 | 58 | 130 | 1 |
| stringer fb | v | 10.0 | 2.5 | 2.254 | 2.5 | 10.0 | 25 | 56 | 127 | 208 |
| long bhd | v | 450.0 | 1.0 | 2.300 | 1.0 | 450.0 | 450 | 1035 | 2381 | 7593750 |
| tank top | h | 124.0 | 1.2 | 0.506 | 124.0 | 1.2 | 149 | 75 | 38 | 18 |
| tank top | h | 248.0 | 1.2 | 0.506 | 248.0 | 1.2 | 298 | 151 | 76 | 36 |
| side girder | v | 40.0 | 0.8 | 0.250 | 0.8 | 40.0 | 32 | 8 | 2 | 4267 |
| hp deck | v | 10.0 | 1.2 | 4.967 | 1.2 | 10.0 | 12 | 60 | 296 | 100 |
| | | 2465.8 | max: | 600.5 | | | 2645 | 5773 | 23189 | 12589362 |

**Tabel 1:** Eerste overzicht met resultaten voor het berekenen van het weerstandsmoment

Merk op dat de eenheden cm en m per kolom kunnen verschillen, dit wordt gedaan om niet te grote getallen te krijgen. De tabel geldt voor de halve doorsnede en ten opzichte van de basis van de doorsnede.

| | | | |
|---|---|---|---|
| Keurtekening d.d. 22-07-02 /goedgekeurd d.d. 8-8-02 | | | |
| A: Area cross section | $cm^2$ | 5290 | |
| Mass/m | ton/m | 4.23 | |
| Moment A w.r.t. baseline | $cm^3$ | 1 154 669 | |
| C.O.G. $_{basis}$ | cm | 218 | |
| Moment of inertia A $z^2$ | $cm^4$ | 463 771 478 | 0.95 |
| I individual elements | $cm^4$ | 25 178 724 | 0.05 |
| I total basis | $cm^4$ | 488 950 202 | 1.00 |
| | | | |
| $I_{yy}= I_{basis} - ZP_{basis}{}^2 \times A$ | $cm^4$ | 236 931 226 | |
| | | | |
| Z top from basis | cm | 600.5 | |
| Z deck from basis | cm | 500 | |
| $W_{bottom}=I_{zp}/z$ | $cm^3$ | 1 085 542 | |
| $W_{deck} = I_{zp}/(deck-z)$ | $cm^3$ | 840 959 | |
| $W_{coaming}=I_{zp}/(top-z)$ | $cm^3$ | 619 851 | |
| | | | |
| Bending moment calculated | kNm | -180 000 | sagging |
| | | | |
| $\sigma_{bottom}=M/W$ | $N/mm^2$ | 166 | trek in bodem |
| $\sigma_{deck}=M/W$ | $N/mm^2$ | -214 | druk in dek |
| $\sigma_{coaming}=M/W$ | $N/mm^2$ | -290 | druk in coaming |

**Tabel 2:** Tweede overzicht met resultaten voor het berekenen van het weerstandsmoment

Vervolgens wordt in een tweede tabel achtereenvolgens het zwaartepunt van de doorsnede bepaald, het totale traagheidsmoment ten opzichte van basis en vervolgens ten opzichte van het zwaartepunt. Vervolgens wordt het weerstandsmoment bepaald van bodem, dek en coaming, of andere gewenste locaties. Door introductie van het eerder gevonden buigende moment kunnen tenslotte de optredende spanningen worden bepaald.

De laatste actie is dan om de hoogte van de spanningen te beoordelen.

Daarbij dient onderscheid gemaakt te worden tussen drukspanning en trekspanning. De toelaatbare spanningen worden gegeven door het klassenbureau.

# 4 BEREKENING MET ONTWERPHULPMIDDELEN VAN KLASSENBUREAUS

## 4.1 INLEIDING

De regels van Germanischer Lloyd zijn de meest toegepaste voorschriften in de Europese binnenvaart (was ook bij dit schip het geval). Ook Lloyd's Register of Shipping en Bureau Veritas hebben dergelijke voorschriften.

We volgen in dit hoofdstuk de voorschriften van Germanischer Lloyd om zowel de ontwerp buigende moment te bepalen, als om de toelaatbare spanningen te vinden in de belangrijkste constructiedelen.

Volgens de hoofdwet van de sterkteleer leidt de kennis van de toelaatbare spanning en de op te leggen momenten tot de vereiste weerstandsmomenten:

$$\sigma_{bodem} = \frac{M}{I} \cdot y_{bodem} = \frac{M}{W_{bodem}}$$

$$\sigma_{dek,coaming} = \frac{M}{I} \cdot y_{dek,\ coaming} = \frac{M}{W_{dek,coaming}}$$

## 4.2 DE FORMULES EN DIAGRAMMEN VAN GERMANISCHER LLOYD

*Geldigheid (B. Gültigkeit)*

De voorschriften gelden onder aanname van het uitgangspunt, dat de schepen bij het laden en lossen en bij de vaart in ballast, niet hoger worden belast dan bij de volgende laad- en los procedures:

A. Laden en lossen bij een heen- en teruggang.14
Bij motorschepen met motorkamer in het achterschip wordt ervan uitgegaan dat het laden en het lossen in het achterschip wordt aangevangen.

B. Laden en lossen in een gang.
Bij motorschepen met machinekamer achter, dient het laden achterin het ruim te beginnen, terwijl het lossen voorin moet beginnen.

*Dit is een belangrijke ontsnappingsclausule voor de geldigheid van deze formules, omdat deze aanname alleen kan worden aangetoond door de buigende momenten te berekenen, en dan heb je de formules sowieso niet meer nodig.*

*Uitzonderingen (D. Sonderregelungen)*

Als het voornemen bestaat het schip anders te beladen of te lossen dan volgens B, dan moet er een langs- en dwars sterkte berekening gemaakt worden.

## 4.3 DE GEHANTEERDE FORMULES

Abschnitt 2 Bemessungsgrundlagen
A. Allgemeines
B. Längsbiegemomenten
De te hanteren ontwerp buigende momenten worden als volgt berekend voor laadvolgorde A, voor laadvolgorde B moet het positieve moment met 8% vergroot worden, het negatieve moment is gelijk aan dat bij A.:

14 Dit impliceert dat de helft van de lading van achter naar voor wordt neergelegd, en de andere helft bovenop de eerste laag bij de teruggang van de laad/los inrichting (kraan, transportband etc)

**Het positieve moment**, dat trek in het dek en druk in de bodem veroorzaakt, (rug als boze kat) bedraagt:

$$(+M) = \lambda \cdot B \cdot H \cdot L^2 \quad [kNm]$$

**Het negatieve moment**, dat druk in het dek en trek in de bodem veroorzaakt, (rug als oud paard) bedraagt:

$$(-M) = \lambda_1 \cdot B \cdot H \cdot L^2 \cdot (1.45 \cdot \frac{T}{H} - 0.45) \quad [kNm]$$

Waarbij:

$\lambda$ = *coefficent af te lezen in diagram 1*
$\lambda_1$ = *coefficent af te lezen in diagram 2*
$L$ = *Lengte*
$B$ = *Breedte*
$H$ = *Holte*
$T$ = *Diepgang*

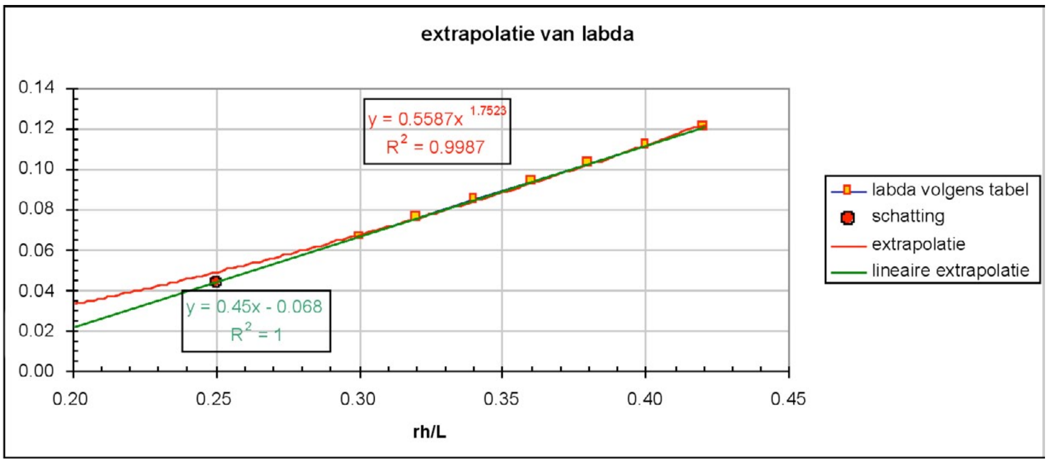
*Deze formules geven benaderingen voor het buigend moment, als men dit niet wenst of niet kan uitrekenen en als er sprake is van een gewoon schip.*

*Bepaling positieve moment bij toepassen van de formules en extrapolatie in de diagrammen:*

$(+M) = \lambda \cdot B \cdot H \cdot L^2 \quad [kNm]$
*met :*

*B=11.40 m*
*L=108.10 m*
*H=5.00 m*

*volgt:*
$(+M) = \lambda \cdot 11.40 \cdot 5.00 \cdot 108.10^2$
$(+M) = \lambda \cdot 666\ 080$




*De coëfficiënt $\lambda$ wordt bepaald op basis van de factor $r_h/L$. $r_h$ is de afstand tussen het MK schot en de halve lengte van het schip. De achtergrond daarvan is dat hoe verder het MK en daarmee het MK gewicht naar achteren is gelegen, des te hoger zal het positieve, hogging moment uitvallen. Een rechtlijnige extrapolatie leidt tot een $\lambda$ van 0.045.*

$$(+M)=\lambda \cdot 666080$$

$$(+M)=0.045 \cdot 666080=29\ 974\ kNm$$

*Dit moment mag nog verkleind worden als de blokcoëfficiënt groter is dan de normwaarde, dat is hier het geval. Echter het positieve moment mag volgens B5 nooit kleiner gekozen worden dan dat wat optreedt bij het lege schip:*

$$(+M)=0.090 \cdot B \cdot H \cdot L^2$$

$$(+M)=0.090 \cdot 666080=59\ 947\ kNm$$

*De ontwerpbelasting op grond van de benaderingsformules dient dus te zijn 59 947 kNm, en treedt op in lege toestand.*

Er wordt vanuit gegaan dat de lading ongeveer gelijkmatig is verdeeld over de laadruimlengte. Is dat niet het geval, of bij andere beladingswijzen als A. of B., dan moet het langsbuigend moment op andere wijze berekend worden.

*Uitwerking negatieve moment volgens voorspelling:*

$$(-M) = \lambda_1 \cdot B \cdot H \cdot L^2 \cdot (1.45 \cdot \frac{T}{H} - 0.45)$$

$B=11.40\ m$

$H=5.00\ m$

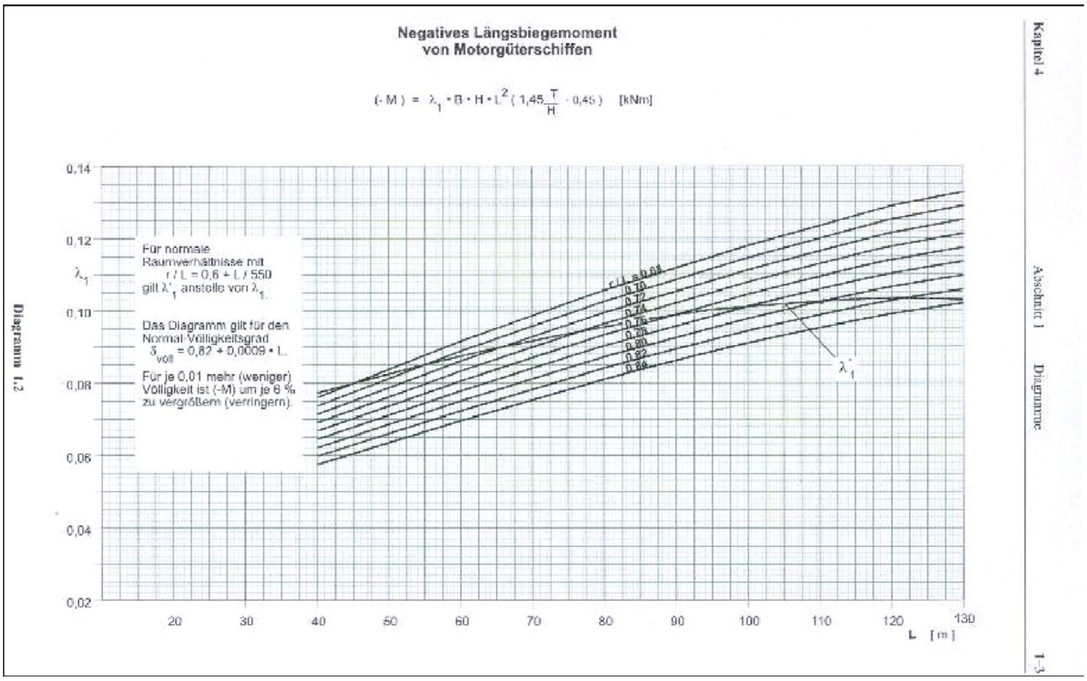
$L=108.10\ m$

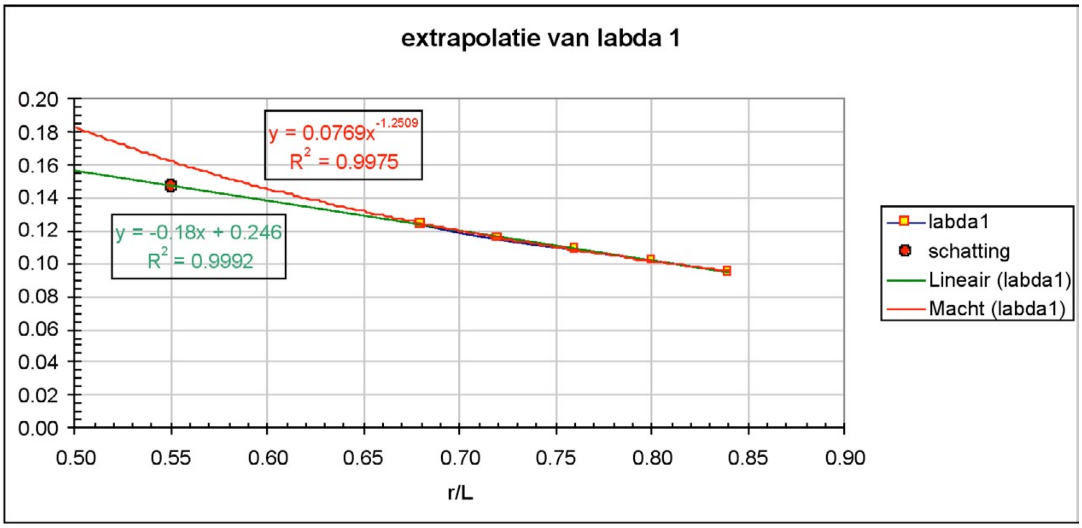
$T=4.85\ m$

$$(-M)= \lambda_1 \cdot 11.40 \cdot 5.00 \cdot 108.10^2 \cdot (1.45 \cdot \frac{4.85}{5.00} - 0.45)$$

$$(-M)= \lambda_1 \cdot 11.40 \cdot 5.00 \cdot 108.10^2 \cdot (1.45 \cdot \frac{4.85}{5.00} - 0.45)$$

$$(-M)= \lambda_1 \cdot 666\ 080 \cdot 0.957= \lambda_1 \cdot 637\ 438$$




*$\lambda_1$ wordt bepaald op basis van r/L, waarbij r de ruimlengte is, uit diagram 2.*

*Extrapolatie leidt tot een $\lambda_1$ van 0.147 (tot 0.162). En daarmee het moment (-M) = 93 703 kNm.*

*Echter, de blokcoëfficiënt is met 0.940 groter dan de norm van 0.82+0.0009L=0.917. Het moment moet vergroot worden met 6% per 0.01 overschrijding van de normblok: (1.06/0.01)x(0.940-0.917)=2.4%.*

*In te zetten negatief moment wordt dan: 95 952 kNm.*

## 4.4 TOELAATBARE SPANNINGEN (D. ZULÄSSIGE SPANNUNGEN)

*We passen de formules uit de rules direct toe op de constructie zoals die is ingediend door de bouwer bij IVW DS.*

**1**. In geen geval mag een normaalspanning van 160 N/mm$^2$ overschreden worden. De gecombineerde spanning langs- dwars- en lokaal mag niet hoger zijn dan 200 N/mm$^2$
**2**. Bij schepen met dwarsspanten mag de drukspanning in de huid en het dek niet hoger zijn dan:

$$ó_d = c \times \left(\frac{100 \times t}{a}\right)^2 \times \left[1 + \left(\frac{a}{u}\right)^2\right]^2 \qquad \left[N/mm^2\right]$$

*met:*

*$ó_d$=drukspanning*

*c=16 voor huidplaten*

*c=20 voor dekplaten*

*t=plaatdikte*

*a=wrang- of dekbalken afstand*

*u=afstand tussen langsverstijving*

*Voor het hoofddek:*

$$ó_d = 20 \times \left(\frac{100 \times 12}{500}\right)^2 \times \left[1 + \left(\frac{500}{572}\right)^2\right]^2 = 358 \qquad \left[N/mm^2\right]$$

*met:*

*c=20 voor dekplaten*

*t=plaatdikte = 12 mm*

*a=wrang- of dekbalken afstand = 500 mm*

*u=afstand tussen langsverstijvingen=572 mm*

*Deze spanning is niet toegestaan, omdat de spanning nooit hoger dan 160 $N/mm^2$ mag bedragen.*

*Voor de bodembeplating:*

$$\acute{o}_d = 16 \times \left(\frac{100 \times 10}{500}\right)^2 \times \left[1 + \left(\frac{500}{2666}\right)^2\right]^2 = 68 \quad \left[N/mm^2\right]$$

*met:*
*c=16 voor huidplaten*
*t=plaatdikte = 10 mm*
*a=wrang- of dekbalken afstand = 500 mm*
*u=afstand tussen langsverstijvingen=8000/3=2666 mm*

*Dit is een erg lage toegelaten belasting, als gevolg van de zeer grote afstand tussen het langsmateriaal in de bodem, dat zijn de zaathouten en het ruimlangsschot.*

**4**. De druk- en trekspanning in de bovenkant van de coaming mag niet hoger zijn dan:

$$\acute{o}_d = 115 + 0.2 \cdot L \quad \left[N/mm^2\right]$$

*Met L=108.10 m leidt dit tot een toelaatbare druk- en trekspanning van 136.6 N/mm$^2$ in de bovenkant coaming of dennenboom.*

**5**. De drukspanning op halve coaminghoogte mag niet hoger zijn dan:

$$\acute{o}_d = 65 \times \left(\frac{100 \times t}{h}\right)^2 \quad \left[N/mm^2\right]$$

*met:*
*$\acute{o}_d$=drukspanning*
*t=plaatdikte*
*h=afstand coaming verstijving tot gangboord*

*Dit leidt voor de buitenkant van de coaming tot:*

$$\acute{o}_d = 65 \times \left(\frac{100 \times 8}{516}\right)^2 = 156 \quad \left[N/mm^2\right]$$

*met:*
*$\acute{o}_d$=drukspanning*
*t=plaatdikte=8 mm*
*h=afstand coaming verstijving tot dek = 516 mm*

*Dit leidt voor de binnenkant van de coaming tot:*

$$\sigma_d = 65 \times \left(\frac{100 \times 12}{942}\right)^2 = 105 \qquad \left[N/mm^2\right]$$

*met:*

*$\sigma_d$=drukspanning*

*t=plaatdikte=12 mm*

*h=afstand coaming tot dek = 942 mm*

## 4.5 SAMENVATTING

Indien gekozen wordt voor de toepassing van de formules van Germanischer Lloyd, voorbijgaande aan het zelf uitrekenen van de buigende momenten op directe wijze, dan zou dat geleid moeten hebben tot de volgende uitgangspunten voor de bepaling van de constructie:

| | Buigend moment | |
|---|---|---|
| aard: | maximaal positief | maximaal negatief |
| welke conditie: | leeg schip conditie | tijdens laden/lossen[15] |
| benaming: | hogging | sagging |
| verschijning: | kattenrug | paardenrug |
| grootte bepaald met $\lambda$ c.q. $\lambda_1$:<br>grootte met factor 0.09: | 29 974 kNm<br>59 947 kNm | -95 952kNm |
| **ontwerpwaarde:** | **59 947 kNm** | **-95 952 kNm**[16] |
| Spanning in dek: | **1. trek in dek** | **2. druk in dek** |
| Spanning in bodem: | **3. druk in bodem** | **4. trek in bodem** |

| | Toelaatbare spanningen | |
|---|---|---|
| aard: | maximaal positief | maximaal negatief |
| welke conditie: | leeg schip conditie | tijdens laden/lossen |
| benaming: | hogging | sagging |
| verschijning: | kattenrug | paardenrug |
| grootte bepaald met $\lambda$ c.q. $\lambda_1$:<br>grootte met factor 0.09: | 29 974 kNm<br>59 947 kNm | -95 952 kNm |
| **ontwerpwaarde:** | **59 947** kNm | **-95 952** kNm |
| | | |
| Spanning bovenkant coaming | **trek: 137** N/mm$^2$ | **druk: -137** N/mm$^2$ |
| Spanning binnenkant coaming | **trek: 160** N/mm$^2$ | **druk: -105** N/mm$^2$ |
| Spanning buitenkant coaming | **trek: 160** N/mm$^2$ | **druk: -156** N/mm$^2$ |
| Spanning in dek: | **trek: 160** N/mm$^2$ | **druk: -160** N/mm$^2$ |
| Spanning in bodem: | **druk: -68** N/mm$^2$ | **trek: 160** N/mm$^2$ |

15 Dus niet noodzakelijkerwijs het buigende moment in de volbeladen conditie, zoals b.v. bepaald voor de conditie tijdens het breken. Niet uitgesloten kan worden dat bij bijvoorbeeld start beladen in voor- of achterschip er nog hogere buigende momenten gevonden worden.

16 Dit is voor een diepgang van 4,85 m; dit in afwijking van de andere berekeningen die gemaakt zijn voor de diepgang tijdens het breken van abt 3,90 m.

Voorbeeld van de variatie van het buigend moment tijdens het laden en lossen.

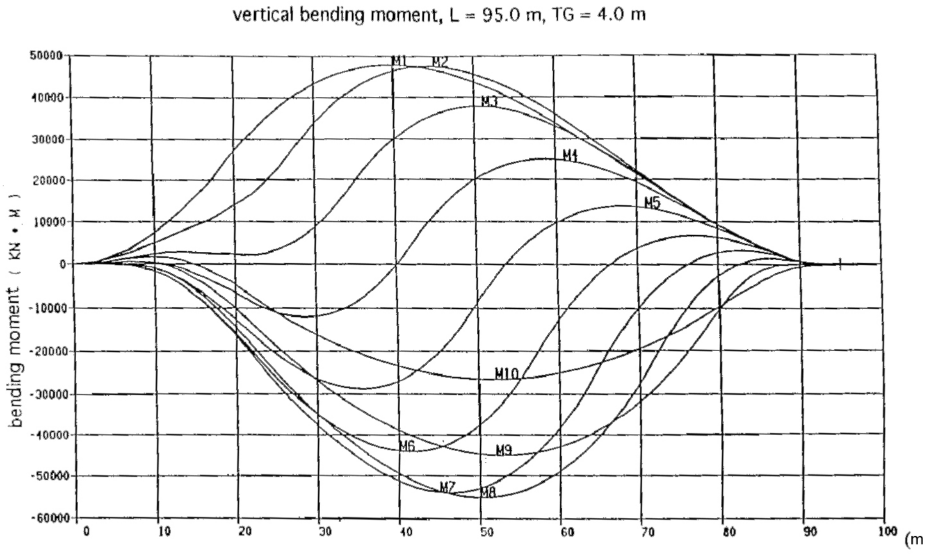



Fig. 2: Distribution of longitudinal bending moment for 10 loading conditions (M1-empty Ship with 50% supply, M10-full ship) from /7/

## 5 NADER ONDERZOEK BUIGEND MOMENT

### 5.1 INLEIDING

Omdat hier sprake is geweest van een sterke extrapolatie buiten het door de diagrammen beschreven gebied, komt de vraag op of de formules wel juist voorspellen binnen de geldigheid van de diagrammen.

Het probleem heeft zich ten minste voorgedaan met de voorspelling van het negatieve buigende moment of sagging moment.

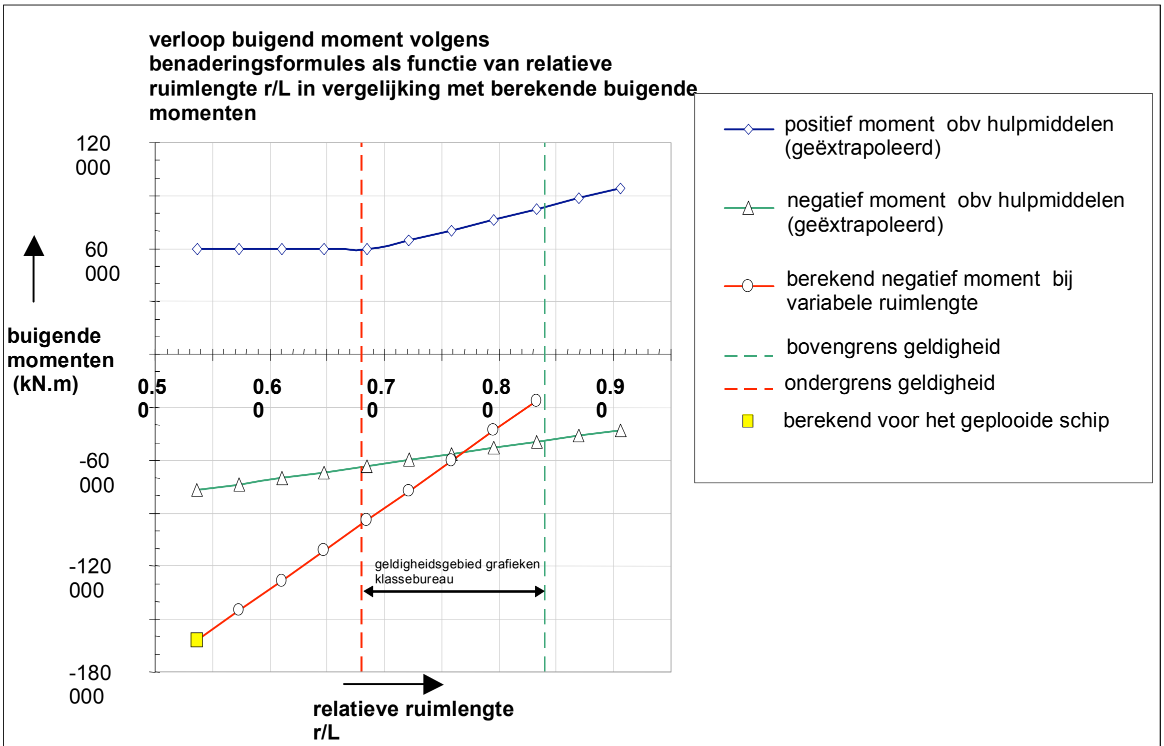
De formule bevat een factor $\lambda_1$ die een functie is van de verhouding van de ruimlengte tot de scheepslengte. Deze verhouding bedraagt normaal meer dan 70%, terwijl dit bij het beunschip 55% bedraagt. Dit leidt tot een geconcentreerdere belasting op de scheepslengte, en daarmee tot hoge buigende momenten.

De diagrammen dekken een bereik van de relatieve ruimlengte r/L tussen 68% en 84% en voorzien in dit gebied de voorspelling van het tijdens het laden en lossen maximaal te verwachten buigende moment. Dit buigende moment treedt namelijk niet noodzakelijkerwijs op aan het einde van de belading. Zie figuur in paragraaf 3.1.4.

Daarom is het ruim in stappen van 4m langer gemaakt en is de lading vervolgens uitgesmeerd over de lengte van het ruim.

### 5.2 RESULTATEN

De berekeningen zijn uitgevoerd voor de diepgang van 3.90 m (diepgang ten tijde van het ongeval), met een ladinghoeveelheid van 3468 ton.




| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ruimlengte (m) | 58 | 62 | 66 | 70 | 74 | 78 | 82 | 86 | 90 |
| berekend negatief moment in ton x m | -16901 | -15169 | -13437 | -11704 | -9972 | -8239 | -6506 | -4773 | -3045 |
| relatieve ruimlengte (-) | 0.537 | 0.574 | 0.611 | 0.648 | 0.685 | 0.722 | 0.759 | 0.796 | 0.833 |
| berekend negatief moment bij variabele ruimlengte | -165799 | -148808 | -131817 | -114816 | -97825 | -80825 | -63824 | -46823 | -29871 |

In het diagram zijn weergegeven de voorspelling van de formule, die buiten het geldigheidsgebied lineair is geëxtrapoleerd. Daarnaast zijn de berekende waarden op grond van de gegevens van het beunschip weergegeven en opvallend is dat de formule slechts op een punt overeenstemt met de werkelijkheid. Beneden een ruimlengte van 75% blijkt dat de berekende waarden beduidend hoger uitpakken dan de geschatte waarden van de formule.

Op de grens van de geldigheid van het diagram, een ruimlengte van 68%, bedraagt de afwijking 90 000/60 000=1.50. Bij 55% ruimlengte bedraagt de afwijking : 165 000/80 000=2.00.

## 5.3 CONCLUSIE

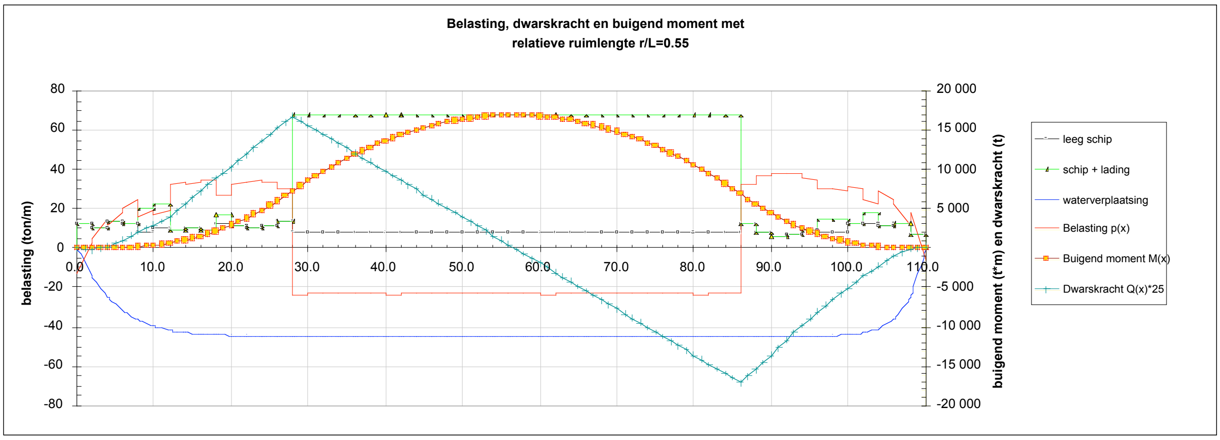
Uit bovenstaande blijkt dat de benaderingsformules uit de voorschriften voor een dergelijk type schip ook binnen het geldigheidsbereik van de diagrammen een onjuist buigend moment voorspellen.

Zeker voor beunschepen zal daarom altijd met directe berekeningen het buigend moment moeten worden bepaald.

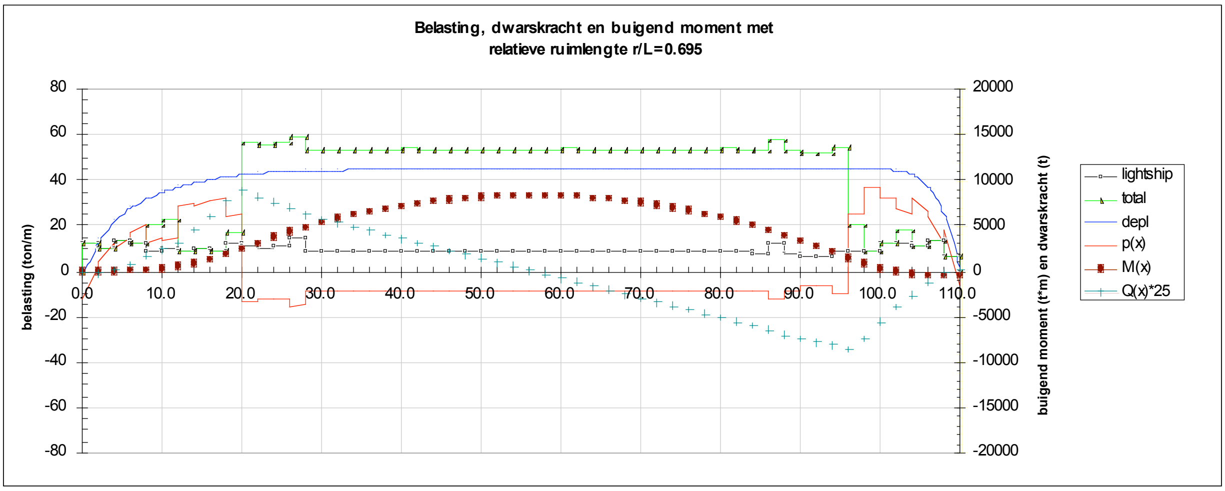
# 6 GRAFIEKEN EN RESULTATEN

## 6.1 GRAFIEKEN OP BASIS VAN VOORGAAND HOOFDSTUK

Belasting en buigend moment in beladen toestand met ruim r/L= 0.55




Belasting en buigend moment in beladen toestand met denkbeeldig ruim r/L=0.695



## 6.2 BEPALING SPANNINGEN VAN INGEDIEND GROOTSPANT, INDIEN EXTRAPOLATIE TOEGESTAAN ZOU ZIJN

| Keurtekening d.d. 22-07-02 /goedgekeurd d.d. 8-8-02 | direc-tion | length | thickness | lever z to basis | breadth | height | Area | Moment | $A\,z^2$ | I element |
|---|---|---|---|---|---|---|---|---|---|---|
| | - | cm | cm | m | cm | cm | $cm^2$ | $cm^2 \times m$ | $cm^2 \times m^2$ | $cm^4$ |
| bottom | h | 510.0 | 1.0 | -0.005 | 510.0 | 1.0 | 510 | -3 | 0 | 43 |
| bilge 1 | h | 25.0 | 1.3 | -0.006 | 25.0 | 1.3 | 33 | 0 | 0 | 5 |
| bilge 2 | v | 56.0 | 1.3 | 0.103 | 1.3 | 56.0 | 73 | 7 | 1 | 19025 |
| bilge 3 | v | 22.5 | 1.3 | 0.463 | 1.3 | 22.5 | 29 | 14 | 6 | 1234 |
| sideshell | v | 393.7 | 0.9 | 2.544 | 0.9 | 393.7 | 354 | 901 | 2293 | 4576753 |
| sheerstrake | v | 50.0 | 2.5 | 4.762 | 2.5 | 50.0 | 125 | 595 | 2835 | 26042 |
| deck | h | 171.5 | 1.2 | 5.032 | 171.5 | 1.2 | 206 | 1036 | 5211 | 25 |
| coaming OUTside | v | 98.1 | 0.8 | 5.521 | 0.8 | 98.1 | 78 | 433 | 2392 | 62938 |
| coaming top | h | 60.0 | 1.0 | 6.005 | 60.0 | 1.0 | 60 | 360 | 2164 | 5 |
| coaming hp top | v | 10.0 | 0.6 | 5.950 | 0.6 | 10.0 | 6 | 36 | 212 | 50 |
| coaming hp side | h | 10.0 | 0.6 | 5.521 | 10.0 | 0.6 | 6 | 33 | 183 | 0 |
| coaming INside | v | 145.0 | 1.2 | 5.275 | 1.2 | 145.0 | 174 | 918 | 4842 | 304863 |
| stringer plt | h | 32.0 | 0.8 | 2.254 | 32.0 | 0.8 | 26 | 58 | 130 | 1 |
| stringer fb | v | 10.0 | 2.5 | 2.254 | 2.5 | 10.0 | 25 | 56 | 127 | 208 |
| long bhd | v | 450.0 | 1.0 | 2.300 | 1.0 | 450.0 | 450 | 1035 | 2381 | 7593750 |
| tank top | h | 124.0 | 1.2 | 0.506 | 124.0 | 1.2 | 149 | 75 | 38 | 18 |
| tank top | h | 248.0 | 1.2 | 0.506 | 248.0 | 1.2 | 298 | 151 | 76 | 36 |
| side girder | v | 40.0 | 0.8 | 0.250 | 0.8 | 40.0 | 32 | 8 | 2 | 4267 |
| hp deck | v | 10.0 | 1.2 | 4.967 | 1.2 | 10.0 | 12 | 60 | 296 | 100 |
| | | 2465.8 | max: | 6.005 | | | 2645 | 5773 | 23189 | 12589362 |

| Keurtekening d.d. 22-07-02 | | |
|---|---|---|
| A total area cross section | $cm^2$ | 5290 |
| Mass/m | t/m | 4.23 |
| Moment of A to basis | $cm^3$ | 1 154 669 |
| Centre of gravity to basis | cm | 218 |
| Moment of inertia to basis A z² | $cm^4$ | 463 771 478 |
| Moment of inertia I elements | $cm^4$ | 25 178 724 |
| I total to basis | $cm^4$ | 488 950 202 |
| $I_{yy} = I_{basis} - A_{total} \times COG^2$ | $cm^4$ | 236 931 226 |
| $Z_{top\ coaming\ from\ basis}$ | cm | 601 |
| $Z_{half\ height\ coaming\ from\ basis}$ | cm | 551 |
| $Z_{deck\ from\ basis}$ | cm | 500 |
| $W_{bottom} = I_{yy}/z$ | $cm^3$ | 1 085 542 |
| $W_{deck} = I_{yy}/(deck-z)$ | $cm^3$ | 840 959 |
| $W_{half\ height\ coaming} = I_{yy}/(z$ halfco | $cm^3$ | 713 134 |
| $W_{coaming} = I_{yy}/(top-z)$ | $cm^3$ | 619 851 |

| | | HOGGING | | | SAGGING | | |
|---|---|---|---|---|---|---|---|
| M: Bending moment | kNm | 59 947 | **hogging** | | -95 952 | **sagging** | |
| | | actual | allowed | result | actual | allowed | result |
| $\sigma_{bottom} = M/W_{bottom}$ | $N/mm^2$ | -55 | -68 | goed | 88 | 160 | goed |
| $\sigma_{deck} = M/W_{deck}$ | $N/mm^2$ | 71 | 160 | goed | -114 | -160 | goed |
| $\sigma_{half\ coaming} = M/W_{halfoaming}$ | $N/mm^2$ | 84 | 160 | goed | -135 | -105 | fout |
| $\sigma_{coaming} = M/W_{coaming}$ | $N/mm^2$ | 97 | 137 | goed | -155 | -137 | fout |

| Toelaatbare drukspanning | t | h | | L= 108.20 | |
|---|---|---|---|---|---|
| coaming acc GL | plaatdikte | vrije lengte | sigma d | sigma abs | sigma d tot |
| bovenkant coaming | 10 | | na | 137 | 137 |
| binnenkant halve coaminghoogte | 12 | 942 | 105 | 160 | 105 |
| buitenkant halve coaminghoogte | 8 | 516 | 156 | 160 | 156 |

| Toelaatbare drukspanning dek en bo | t | a | u | | | |
|---|---|---|---|---|---|---|
| acc GL | plaatdikte | vrije lengte | afstand langs | sigma d | sigma abs | sigma d tot |
| dek | 12 | 500 | 572 | 359 | 160 | 160 |
| bodem | 10 | 500 | 2666 | 69 | 160 | 69 |

Uit deze opstelling blijkt, dat indien het al toegestaan zou zijn om het buigende moment te schatten in plaats van het uit te rekenen, dat ook dan al een overschrijding plaats vindt van de toelaatbare drukspanning in zowel het verticale als het horizontale deel van de coaming. Indien de fout niet zou zijn gemaakt met het buigende moment, dan nog zou het ingediende grootspant niet goedgekeurd mogen zijn. Het is dus niet alleen het onjuist gebruik van het buigend moment, maar ook het onjuist controleren. In de berekening van rekenbureau B d.d. 22-7-02 wordt slechts gesproken van een positief moment van 85051 kNm dat is opgebouwd met een factor 0.12, waarvan de oorsprong niet is te achterhalen, bovendien is een toeslag gehanteerd van 1.08, die kennelijk verwijst naar de toeslag noodzakelijk bij het in één gang laden en lossen.

## 6.3 BEPALING SPANNINGEN INGEDIEND GROOTSPANT DOOR IVW/DS

**Positief moment.** De controle berekening van IVW DS van het ingediende grootspant, is vervat in een spreadsheet. De berekening laat zien een positief buigend moment van 62345 kNm, bereikt met een factor tabel 1 van 0.06744. Niet te achterhalen hoe deze factor bepaald is, te verwachten zou zijn 0.045. Vergelijk met 59 947 kNm zoals in dit rapport afgeleid.

**Negatief moment.** Het negatief moment is bepaald met een 'factor tabel 2 van 0.12352" vergelijk 0.147 als afgeleid uit het diagram in dit rapport. Het negatief buigend moment wordt bepaald op 79 350 kNm. Vergelijk met 95 952 kNm, als in dit rapport afgeleid.

**Bepaling weerstandsmoment.** De berekening bevat een aantal flinke fouten:

- de hoogte van het gangboord staat ingevoerd op 5.0 cm boven de basis, terwijl de feitelijke afstand 503.0 cm is.
- de hoogte van de huid staat ingevoerd op 253.8 cm boven basis, terwijl de maat 245.0 cm is.
- Het eigen traagheidsmoment van de bergplaat wordt bepaald op 65 i.p.v. 26042 $cm^4$
- Dit alles leidt er toe dat, dat er een fout traagheidsmoment wordt bepaald van 230 863 599 $cm^4$, terwijl het traagheidsmoment bedraagt: 236 931 226 $cm^4$. Het zwaartepunt wordt berekend op 179.3 cm, terwijl het feitelijk zwaartepunt ligt op 218 cm boven de basis. Het weerstandsmoment van de bodem wordt berekend op 1 287 316 $cm^3$, terwijl de feitelijke waarde 1 085 542 bedraagt. Het weerstandsmoment van de coaming wordt bepaald op 548 809, terwijl het feitelijk 619 851 bedraagt.

**Bepaling toelaatbare spanningen**. De toelaatbare spanningen worden op niet traceerbare wijze bepaald als volgt:

| | **Vergelijking toelaatbare spanningen: dit rapport (zwart) en IVW (*rood*)** | |
|---|---|---|
| aard: | maximaal positief | maximaal negatief |
| welke conditie: | leeg schip conditie | tijdens laden/lossen |
| benaming: | hogging | sagging |
| verschijning: | kattenrug | paardenrug |
| **berekend dit rapport:** | **59 947** kNm | **-95 952** kNm |
| **berekend IVW** | ***62 345 kNm*** | ***-79 350 kNm*** |
| | | |
| bovenkant coaming | **trek: 137/*137*** N/mm² | **druk: -137/*-160*** N/mm² |
| binnenkant coaming | **trek: 160/*?*** N/mm² | **druk: -105/*?*** N/mm² |
| buitenkant coaming | **trek: 160/*?*** N/mm² | **druk: -156/*?*** N/mm² |
| dek: | **trek: 160/*160*** N/mm² | **druk: -160/*160*** N/mm² |
| bodem: | **druk: -68/*-83*** N/mm² | **trek: 160/*160*** N/mm² |

De volgende opmerkingen zijn te maken:

- toelaatbare drukspanning wordt voor bovenkant den te hoog ingezet met -160, moet zijn -137
- bodem wordt te hoge drukspanning toegelaten, mag zijn -68, wordt aangegeven -83
- binnenkant coaming wordt niet geadresseerd.

**Overige berekeningen.** Alleen het grootspant is gecontroleerd. Er is niet fundamenteel naar de constructie gekeken. Bijvoorbeeld:

- geen  opmerking over het ontbreken van het negatief moment in de ingediende berekening
- rechtstreekse berekening buigend moment
- geen opmerking over ontbreken dwarsschot
- geen opmerkingen over de dwarsscheepse sterkte met een relatief lage dubbele bodem voor een zware lading, geen berekening van het weerstandsmoment van de wrangen
- geen opmerking over grote dwarskrachten voor en achter het ruim en hoe deze op te vangen
- geen opmerking over het toepassen van dwarsverband i.p.v. langsverband voor lang en zwaar belast schip

**Conclusie.** De controle is slordig uitgevoerd. Grondslagen en invoergegevens zijn niet of slecht te achterhalen. Door verschillende fouten wordt uiteindelijk weerstandsmoment van coaming lager geschat dan aanwezig. Geen juiste interpretatie van de ontwerphulpmiddelen. Kritiekloos aanvaarden voorgestelde constructie.

Bepaling weerstandsmoment grootspant teken- en rekenbureau A. Ter informatie is ook het eerste grootspant weergegeven zoals opgesteld door het eerste reken- en tekenbureau voordat er kennelijk een bezuinigingsronde heeft plaatsgevonden.

In rood zijn de wijzigingen aangegeven. Ten opzichte van het gebouwde grootspant was het eerste voorstel 10% zwaarder qua langsscheeps materiaal. Ook dit grootspant zou niet voldaan zelfs niet als het moment juist zou zijn geweest. Echter een kleine verdikking van de buitenkant van de coaming, die slechts 6 mm is, zou het grootspant goed gemaakt hebben voor het negatieve moment van -95 952 kNm. Maar we weten dat dat moment bijna twee keer zo is geweest.

| OORSPRONKELIJKE TEKENING 04/02/02 HAPO01 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Tekening 04-02-02 | direc-tion | length | thickness | lever z to basis | breadth | height | Area | Moment | $A z^2$ | I element |
| | - | cm | cm | m | cm | cm | $cm^2$ | $cm^2 \times m$ | $cm^2 \times m^2$ | $cm^4$ |
| bottom | h | 510.0 | 1.0 | -0.005 | 510.0 | 1.0 | 510 | -3 | 0 | 43 |
| bilge 1 | h | 25.0 | 1.3 | -0.006 | 25.0 | 1.3 | 33 | 0 | 0 | 5 |
| bilge 2 | v | 56.0 | 1.3 | 0.103 | 1.3 | 56.0 | 73 | 7 | 1 | 19025 |
| bilge 3 | v | 22.5 | 1.3 | 0.463 | 1.3 | 22.5 | 29 | 14 | 6 | 1234 |
| sideshell | v | 393.7 | *1.0* | 2.544 | 1.0 | 393.7 | 394 | 1002 | 2548 | 5085281 |
| sheerstrake | v | 50.0 | 2.5 | 4.762 | 2.5 | 50.0 | 125 | 595 | 2835 | 26042 |
| deck | h | 171.5 | *2.0* | 5.032 | 171.5 | 2.0 | 343 | 1726 | 8685 | 114 |
| coaming OUTside | v | 98.1 | *0.6* | 5.521 | 0.6 | 98.1 | 59 | 325 | 1794 | 47204 |
| coaming top | h | 60.0 | 1.0 | 6.005 | 60.0 | 1.0 | 60 | 360 | 2164 | 5 |
| coaming hp top | v | 10.0 | 0.6 | 5.950 | 0.6 | 10.0 | 6 | 36 | 212 | 50 |
| coaming hp side | h | 10.0 | 0.6 | 5.521 | 10.0 | 0.6 | 6 | 33 | 183 | 0 |
| coaming INside | v | 145.0 | *2.5* | 5.275 | 2.5 | 145.0 | 363 | 1912 | 10087 | 635130 |
| stringer plt | h | 20.0 | 0.8 | 2.254 | 20.0 | 0.8 | 16 | 36 | 81 | 1 |
| stringer fb | v | 10.0 | *1.0* | 2.254 | 1.0 | 10.0 | 10 | 23 | 51 | 83 |
| long bhd | v | 450.0 | 1.0 | 2.300 | 1.0 | 450.0 | 450 | 1035 | 2381 | 7593750 |
| tank top | h | 124.0 | 1.2 | 0.506 | 124.0 | 1.2 | 149 | 75 | 38 | 18 |
| tank top | h | 248.0 | 1.2 | 0.506 | 248.0 | 1.2 | 298 | 151 | 76 | 36 |
| side girder | v | 40.0 | 0.8 | 0.250 | 0.8 | 40.0 | 32 | 8 | 2 | 4267 |
| hp deck | v | 10.0 | *0.0* | 4.967 | 0.0 | 10.0 | 0 | 0 | 0 | 0 |
| | | 2453.8 | | 6.005 | | | 2954 | 7335 | 31143 | 13412287 |

| OORSPRONKELIJKE TEKENING 04/02/02 HAPO01 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $A_{\text{total area cross section}}$ | $cm^2$ | 5908 | | | | | | |
| Mass/m | t/m | 4.73 | | 0.49 | t/m lichter | 10 | % | |
| Moment of A to basis | $cm^3$ | 1 466 971 | | | | | | |
| Centre of gravity to basis | cm | 248 | | | | | | |
| Moment of inertia to basis A | $cm^4$ | 622 869 384 | 0.96 | | | | | |
| Moment of inertia I element | $cm^4$ | 26 824 574 | 0.04 | | | | | |
| I total to basis | $cm^4$ | 649 693 958 | 1.00 | | | | | |
| $I_{yy} = I_{basis} - A_{total} \times COG^2$ | $cm^4$ | 285 442 477 | | 48511252 | cm4 kleiner | 17 | % | |
| $Z_{\text{top coaming from basis}}$ | cm | 601 | | | | | | |
| $Z_{\text{half height coaming from basis}}$ | cm | 551 | | | | | | |
| $Z_{\text{deck from basis}}$ | cm | 500 | | | | | | |
| $W_{bottom} = I_{yy}/z$ | $cm^3$ | 1 149 579 | | | | | | |
| $W_{deck} = I_{yy}/(deck-z)$ | $cm^3$ | 1 134 066 | | | | | | |
| $W_{\text{half height coaming}} = I_{yy}/(z$ ha | $cm^3$ | 944 554 | | 231419 | cm3 kleiner | 25 | % | |
| $W_{coaming} = I_{yy}/(top-z)$ | $cm^3$ | 810 460 | | | | | | |
| | | HOGGING | | | SAGGING | | | |
| M: Bending moment | kNm | 59 947 | **hogging** | | -95 952 | **sagging** | | |
| | | actual | allowed | | actual | allowed | | |
| $\sigma_{bottom} = M/W_{bottom}$ | $N/mm^2$ | -55 | -68 | goed | 83 | 160 | goed | |
| $\sigma_{deck} = M/W_{deck}$ | $N/mm^2$ | 71 | 160 | goed | -85 | -160 | goed | |
| $\sigma_{\text{half coaming}} = M/W_{halfoaming}$ | $N/mm^2$ | 84 | 160 | goed | -102 | -88 | fout | |
| $\sigma_{coaming} = M/W_{coaming}$ | $N/mm^2$ | 97 | 137 | goed | -118 | -137 | goed | |

| Toelaatbare drukspanning | t | h | | L= 108.20 | |
|---|---|---|---|---|---|
| coaming acc GL | plaatdikte | vrije lengte | sigma d | sigma abs | sigma d tot |
| bovenkant coaming | 10 | | na | 137 | 137 |
| binnenkant halve coaminghoogte | 25 | 942 | 458 | 160 | 160 |
| buitenkant halve coaminghoogte | 6 | 516 | 88 | 160 | 88 |

| Toelaatbare drukspanning dek en bo | t | a | u | | | |
|---|---|---|---|---|---|---|
| acc GL | plaatdikte | vrije lengte | afstand langs | sigma d | sigma abs | sigma d tot |
| dek | 20 | 500 | 572 | 996 | 160 | 160 |
| bodem | 10 | 500 | 2666 | 69 | 160 | 69 |

## 6.4 BEPALING SPANNINGEN TEN TIJDE ONGEVAL

De spanningen tijdens het breken in de sluis is bepaald in onderstaande berekening. Opgemerkt dient te worden, dat dit plaats vond op een diepgang die nog beduidend lag onder de diepgang waarvoor het schip ontworpen was, namelijk 4,85 m. Terwijl het te verwachten is dat dergelijke schepen doorladen tot het dek onderwater, in dit geval dus tot een diepgang van 5,05 m.

| Keurtekening d.d. 22-07-02 /goedgekeurd d.d. 8-8-02 | direc-tion | length | thickness | lever z to basis | breadth | height | Area | Moment | $A z^2$ | I element |
|---|---|---|---|---|---|---|---|---|---|---|
| | - | cm | cm | m | cm | cm | $cm^2$ | $cm^2 \times m$ | $cm^2 \times m^2$ | $cm^4$ |
| bottom | h | 510.0 | 1.0 | -0.005 | 510.0 | 1.0 | 510 | -3 | 0 | 43 |
| bilge 1 | h | 25.0 | 1.3 | -0.006 | 25.0 | 1.3 | 33 | 0 | 0 | 5 |
| bilge 2 | v | 56.0 | 1.3 | 0.103 | 1.3 | 56.0 | 73 | 7 | 1 | 19025 |
| bilge 3 | v | 22.5 | 1.3 | 0.463 | 1.3 | 22.5 | 29 | 14 | 6 | 1234 |
| sideshell | v | 393.7 | 0.9 | 2.544 | 0.9 | 393.7 | 354 | 901 | 2293 | 4576753 |
| sheerstrake | v | 50.0 | 2.5 | 4.762 | 2.5 | 50.0 | 125 | 595 | 2835 | 26042 |
| deck | h | 171.5 | 1.2 | 5.032 | 171.5 | 1.2 | 206 | 1036 | 5211 | 25 |
| coaming OUTside | v | 98.1 | 0.8 | 5.521 | 0.8 | 98.1 | 78 | 433 | 2392 | 62938 |
| coaming top | h | 60.0 | 1.0 | 6.005 | 60.0 | 1.0 | 60 | 360 | 2164 | 5 |
| coaming hp top | v | 10.0 | 0.6 | 5.950 | 0.6 | 10.0 | 6 | 36 | 212 | 50 |
| coaming hp side | h | 10.0 | 0.6 | 5.521 | 10.0 | 0.6 | 6 | 33 | 183 | 0 |
| coaming INside | v | 145.0 | 1.2 | 5.275 | 1.2 | 145.0 | 174 | 918 | 4842 | 304863 |
| stringer plt | h | 32.0 | 0.8 | 2.254 | 32.0 | 0.8 | 26 | 58 | 130 | 1 |
| stringer fb | v | 10.0 | 2.5 | 2.254 | 2.5 | 10.0 | 25 | 56 | 127 | 208 |
| long bhd | v | 450.0 | 1.0 | 2.300 | 1.0 | 450.0 | 450 | 1035 | 2381 | 7593750 |
| tank top | h | 124.0 | 1.2 | 0.506 | 124.0 | 1.2 | 149 | 75 | 38 | 18 |
| tank top | h | 248.0 | 1.2 | 0.506 | 248.0 | 1.2 | 298 | 151 | 76 | 36 |
| side girder | v | 40.0 | 0.8 | 0.250 | 0.8 | 40.0 | 32 | 8 | 2 | 4267 |
| hp deck | v | 10.0 | 1.2 | 4.967 | 1.2 | 10.0 | 12 | 60 | 296 | 100 |
| | | 2465.8 | max: | 6.005 | | | 2645 | 5773 | 23189 | 12589362 |

| Keurtekening d.d. 22-07-02 | | |
|---|---|---|
| A total area cross section | $cm^2$ | 5290 |
| Mass/m | t/m | 4.23 |
| Moment of A to basis | $cm^3$ | 1 154 669 |
| Centre of gravity to basis | cm | 218 |
| Moment of inertia to basis A $z^2$ | $cm^4$ | 463 771 478 |
| Moment of inertia I elements | $cm^4$ | 25 178 724 |
| I total to basis | $cm^4$ | 488 950 202 |
| $I_{yy} = I_{basis} - A_{total} \times COG^2$ | $cm^4$ | 236 931 226 |
| Z top coaming from basis | cm | 601 |
| Z half height coaming from basis | cm | 551 |
| Z deck from basis | cm | 500 |
| $W_{bottom} = I_{yy}/z$ | $cm^3$ | 1 085 542 |
| $W_{deck} = I_{yy}/(deck-z)$ | $cm^3$ | 840 959 |
| $W_{half\ height\ coaming} = I_{yy}/(z\ halfco$ | $cm^3$ | 713 134 |
| $W_{coaming} = I_{yy}/(top-z)$ | $cm^3$ | 619 851 |

| | | HOGGING | | | SAGGING | | |
|---|---|---|---|---|---|---|---|
| M: Bending moment | kNm | 59 947 | **hogging** | | -165 779 | **sagging** | |
| | | actual | allowed | result | actual | allowed | result |
| $\sigma_{bottom} = M/W_{bottom}$ | $N/mm^2$ | -55 | -68 | goed | 153 | 160 | goed |
| $\sigma_{deck} = M/W_{deck}$ | $N/mm^2$ | 71 | 160 | goed | -197 | -160 | fout |
| $\sigma_{half\ coaming} = M/W_{halfcoaming}$ | $N/mm^2$ | 84 | 160 | goed | -232 | -105 | fout |
| $\sigma_{coaming} = M/W_{coaming}$ | $N/mm^2$ | 97 | 137 | goed | -267 | -137 | fout |

| Toelaatbare drukspanning | t | h | | L= 108.20 | |
|---|---|---|---|---|---|
| coaming acc GL | plaatdikte | vrije lengte | sigma d | sigma abs | sigma d tot |
| bovenkant coaming | 10 | | na | 137 | 137 |
| binnenkant halve coaminghoogte | 12 | 942 | 105 | 160 | 105 |
| buitenkant halve coaminghoogte | 8 | 516 | 156 | 160 | 156 |

| Toelaatbare drukspanning dek en bo | t | a | u | | | |
|---|---|---|---|---|---|---|
| acc GL | plaatdikte | vrije lengte | afstand langs | sigma d | sigma abs | sigma d tot |
| dek | 12 | 500 | 572 | 359 | 160 | 160 |
| bodem | 10 | 500 | 2666 | 69 | 160 | 69 |

Af te lezen is dat de drukspanningen in de gehele coaming het dubbele hebben bedragen van de toelaatbare spanningen, dit terwijl de trekspanning in de bodem aan de grens van het toelaatbare zat. Nog een wonder dat het schip enige afstand heeft kunnen afleggen, maar dit is dankzij de enorme toegeeflijkheid van stalen constructies, die 20 % kunnen vervormen zonder te breken, en bij breken het dubbele van de ontwerpbelasting kunnen absorberen.

*Gewichtsverdeling en belasting diepgang = 3.90 m*

Deel 1: 0-54 m

| gewichtsverdeling | | | | grafische weergave | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | belasting schip en lading (t/m) | | | | waterverplaatsing (t/m) | |
| ghtship componer | Xa | Xv | | leeg schip | voorraden | lading | schip + lading | x | waterverplaatsing |
| 25.0 | 0 | 2 | 0.0 | 0.00 | 0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 21.0 | 2 | 4 | 0.0 | 12.50 | 0 | 0.0 | 12.5 | 0.0 | 0.0 |
| 27.1 | 4 | 6 | 2.0 | 12.50 | 0 | 0.0 | 12.5 | 2.0 | -14.9 |
| 24.0 | 6 | 8 | 2.0 | 10.50 | 0 | 0.0 | 10.5 | 2.0 | -14.9 |
| 16.6 | 8 | 10 | 4.0 | 10.50 | 0 | 0.0 | 10.5 | 4.0 | -25.1 |
| 20.6 | 10 | 12 | 4.0 | 13.55 | 0 | 0.0 | 13.6 | 4.0 | -25.1 |
| 18.3 | 12 | 14 | 6.0 | 13.55 | 0 | 0.0 | 13.6 | 6.0 | -31.9 |
| 20.0 | 14 | 16 | 6.0 | 12.00 | 0 | 0.0 | 12.0 | 6.0 | -31.9 |
| 18.5 | 16 | 18 | 8.0 | 12.00 | 0 | 0.0 | 12.0 | 8.0 | -36.5 |
| 24.7 | 18 | 20 | 8.0 | 8.30 | 12 | 0.0 | 20.3 | 8.0 | -36.5 |
| 22.6 | 20 | 22 | 10.0 | 8.30 | 12 | 0.0 | 20.3 | 10.0 | -39.5 |
| 20.7 | 22 | 24 | 10.0 | 10.30 | 12 | 0.0 | 22.3 | 10.0 | -39.5 |
| 22.3 | 24 | 26 | 12.0 | 10.30 | 12 | 0.0 | 22.3 | 12.0 | -41.5 |
| 28.3 | 26 | 28 | 12.0 | 9.15 | 0 | 0.0 | 9.2 | 12.0 | -41.5 |
| 16.7 | 28 | 30 | 14.0 | 9.15 | 0 | 0.0 | 9.2 | 14.0 | -42.7 |
| 16.4 | 30 | 32 | 14.0 | 10.00 | 0 | 0.0 | 10.0 | 14.0 | -42.7 |
| 16.4 | 32 | 34 | 16.0 | 10.00 | 0 | 0.0 | 10.0 | 16.0 | -43.5 |
| 16.4 | 34 | 36 | 16.0 | 9.25 | 0 | 0.0 | 9.3 | 16.0 | -43.5 |
| 16.4 | 36 | 38 | 18.0 | 9.25 | 0 | 0.0 | 9.3 | 18.0 | -44.0 |
| 16.4 | 38 | 40 | 18.0 | 12.35 | 5 | 0.0 | 17.4 | 18.0 | -44.0 |
| 16.9 | 40 | 42 | 20.0 | 12.35 | 5 | 0.0 | 17.4 | 20.0 | -44.3 |
| 16.4 | 42 | 44 | 20.0 | 11.30 | 0 | 0.0 | 11.3 | 20.0 | -44.3 |
| 16.4 | 44 | 46 | 22.0 | 11.30 | 0 | 0.0 | 11.3 | 22.0 | -44.4 |
| 16.4 | 46 | 48 | 22.0 | 10.35 | 0 | 0.0 | 10.4 | 22.0 | -44.4 |
| 16.4 | 48 | 50 | 24.0 | 10.35 | 0 | 0.0 | 10.4 | 24.0 | -44.5 |
| 16.4 | 50 | 52 | 24.0 | 11.15 | 0 | 0.0 | 11.2 | 24.0 | -44.5 |
| 16.4 | 52 | 54 | 26.0 | 11.15 | 0 | 0.0 | 11.2 | 26.0 | -44.6 |
| 16.4 | 54 | 56 | 26.0 | 14.15 | 0 | 0.0 | 14.2 | 26.0 | -44.6 |
| 16.4 | 56 | 58 | 28.0 | 14.15 | 0 | 0.0 | 14.2 | 28.0 | -44.6 |
| 16.4 | 58 | 60 | 28.0 | 8.35 | 0 | 59.8 | 68.1 | 28.0 | -44.6 |
| 16.9 | 60 | 62 | 30.0 | 8.35 | 0 | 59.8 | 68.1 | 30.0 | -44.6 |
| 16.4 | 62 | 64 | 30.0 | 8.20 | 0 | 59.8 | 68.0 | 30.0 | -44.6 |
| 16.4 | 64 | 66 | 32.0 | 8.20 | 0 | 59.8 | 68.0 | 32.0 | -44.6 |
| 16.4 | 66 | 68 | 32.0 | 8.20 | 0 | 59.8 | 68.0 | 32.0 | -44.6 |
| 16.4 | 68 | 70 | 34.0 | 8.20 | 0 | 59.8 | 68.0 | 34.0 | -44.6 |
| 16.4 | 70 | 72 | 34.0 | 8.20 | 0 | 59.8 | 68.0 | 34.0 | -44.6 |
| 16.4 | 72 | 74 | 36.0 | 8.20 | 0 | 59.8 | 68.0 | 36.0 | -44.6 |
| 16.4 | 74 | 76 | 36.0 | 8.20 | 0 | 59.8 | 68.0 | 36.0 | -44.6 |
| 16.4 | 76 | 78 | 38.0 | 8.20 | 0 | 59.8 | 68.0 | 38.0 | -44.6 |
| 16.4 | 78 | 80 | 38.0 | 8.20 | 0 | 59.8 | 68.0 | 38.0 | -44.6 |
| 16.9 | 80 | 82 | 40.0 | 8.20 | 0 | 59.8 | 68.0 | 40.0 | -44.6 |
| 16.4 | 82 | 84 | 40.0 | 8.45 | 0 | 59.8 | 68.2 | 40.0 | -44.6 |
| 15.5 | 84 | 86 | 42.0 | 8.45 | 0 | 59.8 | 68.2 | 42.0 | -44.6 |
| 24.3 | 86 | 88 | 42.0 | 8.20 | 0 | 59.8 | 68.0 | 42.0 | -44.6 |
| 15.9 | 88 | 90 | 44.0 | 8.20 | 0 | 59.8 | 68.0 | 44.0 | -44.6 |
| 12.9 | 90 | 92 | 44.0 | 8.20 | 0 | 59.8 | 68.0 | 44.0 | -44.6 |
| 13.1 | 92 | 94 | 46.0 | 8.20 | 0 | 59.8 | 68.0 | 46.0 | -44.6 |
| 18.6 | 94 | 96 | 46.0 | 8.20 | 0 | 59.8 | 68.0 | 46.0 | -44.6 |
| 16.5 | 96 | 98 | 48.0 | 8.20 | 0 | 59.8 | 68.0 | 48.0 | -44.6 |
| 16.5 | 98 | 100 | 48.0 | 8.20 | 0 | 59.8 | 68.0 | 48.0 | -44.6 |
| 25.1 | 100 | 102 | 50.0 | 8.20 | 0 | 59.8 | 68.0 | 50.0 | -44.6 |
| 25.4 | 102 | 104 | 50.0 | 8.20 | 0 | 59.8 | 68.0 | 50.0 | -44.6 |
| 22.2 | 104 | 106 | 52.0 | 8.20 | 0 | 59.8 | 68.0 | 52.0 | -44.6 |
| 25.9 | 106 | 108 | 52.0 | 8.20 | 0 | 59.8 | 68.0 | 52.0 | -44.6 |
| 13.4 | 108 | 110 | 54.0 | 8.20 | 0 | 59.8 | 68.0 | 54.0 | -44.6 |
| | | | 54.0 | 8.20 | 0 | 59.8 | 68.0 | 54.0 | -44.6 |

Deel 2: 54-110 m

| gewichtsverdeling | | | | grafische weergave | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | belasting schip en lading (t/m) | | | | waterverplaatsing (t/m) | |
| lightship component | Xa | Xv | | leeg schip | voorraden | lading | schip+lading | x | waterverplaatsing |
| | | | 54.0 | 8.20 | 0 | 59.8 | 68.0 | 54.0 | -44.6 |
| 1016 | | | 56.0 | 8.20 | 0 | 59.8 | 68.0 | 56.0 | -44.6 |
| | | | 56.0 | 8.20 | 0 | 59.8 | 68.0 | 56.0 | -44.6 |
| | | | 58.0 | 8.20 | 0 | 59.8 | 68.0 | 58.0 | -44.6 |
| 819 | | | 58.0 | 8.20 | 0 | 59.8 | 68.0 | 58.0 | -44.6 |
| 52 | | | 60.0 | 8.20 | 0 | 59.8 | 68.0 | 60.0 | -44.6 |
| 36 | | | 60.0 | 8.45 | 0 | 59.8 | 68.2 | 60.0 | -44.6 |
| 28 | | | 62.0 | 8.45 | 0 | 59.8 | 68.2 | 62.0 | -44.6 |
| 80 | | | 62.0 | 8.20 | 0 | 59.8 | 68.0 | 62.0 | -44.6 |
| 1015 | | | 64.0 | 8.20 | 0 | 59.8 | 68.0 | 64.0 | -44.6 |
| | | | 64.0 | 8.20 | 0 | 59.8 | 68.0 | 64.0 | -44.6 |
| | | | 66.0 | 8.20 | 0 | 59.8 | 68.0 | 66.0 | -44.6 |
| | | | 66.0 | 8.20 | 0 | 59.8 | 68.0 | 66.0 | -44.6 |
| | | | 68.0 | 8.20 | 0 | 59.8 | 68.0 | 68.0 | -44.6 |
| | | | 68.0 | 8.20 | 0 | 59.8 | 68.0 | 68.0 | -44.6 |
| | | | 70.0 | 8.20 | 0 | 59.8 | 68.0 | 70.0 | -44.6 |
| | | | 70.0 | 8.20 | 0 | 59.8 | 68.0 | 70.0 | -44.6 |
| | | | 72.0 | 8.20 | 0 | 59.8 | 68.0 | 72.0 | -44.6 |
| | | | 72.0 | 8.20 | 0 | 59.8 | 68.0 | 72.0 | -44.6 |
| | | | 74.0 | 8.20 | 0 | 59.8 | 68.0 | 74.0 | -44.6 |
| | | | 74.0 | 8.20 | 0 | 59.8 | 68.0 | 74.0 | -44.6 |
| | | | 76.0 | 8.20 | 0 | 59.8 | 68.0 | 76.0 | -44.6 |
| | | | 76.0 | 8.20 | 0 | 59.8 | 68.0 | 76.0 | -44.6 |
| | | | 78.0 | 8.20 | 0 | 59.8 | 68.0 | 78.0 | -44.6 |
| | | | 78.0 | 8.20 | 0 | 59.8 | 68.0 | 78.0 | -44.6 |
| | | | 80.0 | 8.20 | 0 | 59.8 | 68.0 | 80.0 | -44.6 |
| | | | 80.0 | 8.45 | 0 | 59.8 | 68.2 | 80.0 | -44.6 |
| | | | 82.0 | 8.45 | 0 | 59.8 | 68.2 | 82.0 | -44.6 |
| | | | 82.0 | 8.20 | 0 | 59.8 | 68.0 | 82.0 | -44.6 |
| | | | 84.0 | 8.20 | 0 | 59.8 | 68.0 | 84.0 | -44.6 |
| | | | 84.0 | 7.75 | 0 | 59.8 | 67.5 | 84.0 | -44.6 |
| | | | 86.0 | 7.75 | 0 | 59.8 | 67.5 | 86.0 | -44.6 |
| | | | 86.0 | 12.15 | 0 | 0.0 | 12.2 | 86.0 | -44.6 |
| | | | 88.0 | 12.15 | 0 | 0.0 | 12.2 | 88.0 | -44.6 |
| | | | 88.0 | 7.95 | 0 | 0.0 | 8.0 | 88.0 | -44.6 |
| | | | 90.0 | 7.95 | 0 | 0.0 | 8.0 | 90.0 | -44.6 |
| | | | 90.0 | 6.45 | 0 | 0.0 | 6.5 | 90.0 | -44.6 |
| | | | 92.0 | 6.45 | 0 | 0.0 | 6.5 | 92.0 | -44.6 |
| | | | 92.0 | 6.55 | 0 | 0.0 | 6.6 | 92.0 | -44.6 |
| | | | 94.0 | 6.55 | 0 | 0.0 | 6.6 | 94.0 | -44.6 |
| | | | 94.0 | 9.30 | 0 | 0.0 | 9.3 | 94.0 | -44.6 |
| | | | 96.0 | 9.30 | 0 | 0.0 | 9.3 | 96.0 | -44.5 |
| | | | 96.0 | 8.25 | 6 | 0.0 | 14.3 | 96.0 | -44.5 |
| | | | 98.0 | 8.25 | 6 | 0.0 | 14.3 | 98.0 | -44.3 |
| | | | 98.0 | 8.25 | 6 | 0.0 | 14.3 | 98.0 | -44.3 |
| | | | 100.0 | 8.25 | 6 | 0.0 | 14.3 | 100.0 | -43.9 |
| | | | 100.0 | 12.55 | 0 | 0.0 | 12.6 | 100.0 | -43.9 |
| | | | 102.0 | 12.55 | 0 | 0.0 | 12.6 | 102.0 | -42.9 |
| | | | 102.0 | 12.70 | 5 | 0.0 | 17.7 | 102.0 | -42.9 |
| | | | 104.0 | 12.70 | 5 | 0.0 | 17.7 | 104.0 | -40.7 |
| | | | 104.0 | 11.10 | 0 | 0.0 | 11.1 | 104.0 | -40.7 |
| | | | 106.0 | 11.10 | 0 | 0.0 | 11.1 | 106.0 | -35.7 |
| | | | 106.0 | 12.95 | 0 | 0.0 | 13.0 | 106.0 | -35.7 |
| | | | 108.0 | 12.95 | 0 | 0.0 | 13.0 | 108.0 | -24.6 |
| | | | 108.0 | 6.70 | 0 | 0.0 | 6.7 | 108.0 | -24.6 |
| | | | 110.0 | 6.70 | 0 | 0.0 | 6.7 | 110.0 | 0.0 |
| | | | 110.0 | 0.00 | 0 | 0.0 | 0.0 | 110.0 | 0.0 |

## 6.5 Bepaling belasting, dwarskracht en buigend moment

Gewichtsverdeling en belasting diepgang = 3.90 m

Gewichtsverdeling ledig schip:

| lightship component | gewichtsverdeling ledig schip<br>Xa (m) | Xv (m) |
|---|---|---|
| 25.0 | 0 | 2 |
| 21.0 | 2 | 4 |
| 27.1 | 4 | 6 |
| 24.0 | 6 | 8 |
| 16.6 | 8 | 10 |
| 20.6 | 10 | 12 |
| 18.3 | 12 | 14 |
| 20.0 | 14 | 16 |
| 18.5 | 16 | 18 |
| 24.7 | 18 | 20 |
| 22.6 | 20 | 22 |
| 20.7 | 22 | 24 |
| 22.3 | 24 | 26 |
| 28.3 | 26 | 28 |
| 16.7 | 28 | 30 |
| 16.4 | 30 | 32 |
| 16.4 | 32 | 34 |
| 16.4 | 34 | 36 |
| 16.4 | 36 | 38 |
| 16.4 | 38 | 40 |
| 16.9 | 40 | 42 |
| 16.4 | 42 | 44 |
| 16.4 | 44 | 46 |
| 16.4 | 46 | 48 |
| 16.4 | 48 | 50 |
| 16.4 | 50 | 52 |
| 16.4 | 52 | 54 |
| 16.4 | 54 | 56 |
| 16.4 | 56 | 58 |
| 16.4 | 58 | 60 |
| 16.9 | 60 | 62 |
| 16.4 | 62 | 64 |
| 16.4 | 64 | 66 |
| 16.4 | 66 | 68 |
| 16.4 | 68 | 70 |
| 16.4 | 70 | 72 |
| 16.4 | 72 | 74 |
| 16.4 | 74 | 76 |
| 16.4 | 76 | 78 |
| 16.4 | 78 | 80 |
| 16.9 | 80 | 82 |
| 16.4 | 82 | 84 |
| 15.5 | 84 | 86 |
| 24.3 | 86 | 88 |
| 15.9 | 88 | 90 |
| 12.9 | 90 | 92 |
| 13.1 | 92 | 94 |
| 18.6 | 94 | 96 |
| 16.5 | 96 | 98 |
| 16.5 | 98 | 100 |
| 25.1 | 100 | 102 |
| 25.4 | 102 | 104 |
| 22.2 | 104 | 106 |
| 25.9 | 106 | 108 |
| 13.4 | 108 | 110 |

Belasting door schip, lading, voorraden en waterverplaatsing bij T=3.90 m

| | zwaartekracht (t/m) | | | | opwaartse kracht (t/m) | |
|---|---|---|---|---|---|---|
| lengte positie (m) | leeg schip | voorraden | lading | schip + lading + voorraden | x (m) | water verplaat sing |
| 0.0 | 0.00 | 0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 12.50 | 0 | 0.0 | 12.5 | 0.0 | 0.0 |
| 2.0 | 12.50 | 0 | 0.0 | 12.5 | 2.0 | -14.9 |
| 2.0 | 10.50 | 0 | 0.0 | 10.5 | 2.0 | -14.9 |
| 4.0 | 10.50 | 0 | 0.0 | 10.5 | 4.0 | -25.1 |
| 4.0 | 13.55 | 0 | 0.0 | 13.6 | 4.0 | -25.1 |
| 6.0 | 13.55 | 0 | 0.0 | 13.6 | 6.0 | -31.9 |
| 6.0 | 12.00 | 0 | 0.0 | 12.0 | 6.0 | -31.9 |
| 8.0 | 12.00 | 0 | 0.0 | 12.0 | 8.0 | -36.5 |
| 8.0 | 8.30 | 12 | 0.0 | 20.3 | 8.0 | -36.5 |
| 10.0 | 8.30 | 12 | 0.0 | 20.3 | 10.0 | -39.5 |
| 10.0 | 10.30 | 12 | 0.0 | 22.3 | 10.0 | -39.5 |
| 12.0 | 10.30 | 12 | 0.0 | 22.3 | 12.0 | -41.5 |
| 12.0 | 9.15 | 0 | 0.0 | 9.2 | 12.0 | -41.5 |
| 14.0 | 9.15 | 0 | 0.0 | 9.2 | 14.0 | -42.7 |
| 14.0 | 10.00 | 0 | 0.0 | 10.0 | 14.0 | -42.7 |
| 16.0 | 10.00 | 0 | 0.0 | 10.0 | 16.0 | -43.5 |
| 16.0 | 9.25 | 0 | 0.0 | 9.3 | 16.0 | -43.5 |
| 18.0 | 9.25 | 0 | 0.0 | 9.3 | 18.0 | -44.0 |
| 18.0 | 12.35 | 5 | 0.0 | 17.4 | 18.0 | -44.0 |
| 20.0 | 12.35 | 5 | 0.0 | 17.4 | 20.0 | -44.3 |
| 20.0 | 11.30 | 0 | 0.0 | 11.3 | 20.0 | -44.3 |
| 22.0 | 11.30 | 0 | 0.0 | 11.3 | 22.0 | -44.4 |
| 22.0 | 10.35 | 0 | 0.0 | 10.4 | 22.0 | -44.4 |
| 24.0 | 10.35 | 0 | 0.0 | 10.4 | 24.0 | -44.5 |
| 24.0 | 11.15 | 0 | 0.0 | 11.2 | 24.0 | -44.5 |
| 26.0 | 11.15 | 0 | 0.0 | 11.2 | 26.0 | -44.6 |
| 26.0 | 14.15 | 0 | 0.0 | 14.2 | 26.0 | -44.6 |
| 28.0 | 14.15 | 0 | 0.0 | 14.2 | 28.0 | -44.6 |
| 28.0 | 8.35 | 0 | 59.8 | 68.1 | 28.0 | -44.6 |
| 30.0 | 8.35 | 0 | 59.8 | 68.1 | 30.0 | -44.6 |
| 30.0 | 8.20 | 0 | 59.8 | 68.0 | 30.0 | -44.6 |
| 32.0 | 8.20 | 0 | 59.8 | 68.0 | 32.0 | -44.6 |
| 32.0 | 8.20 | 0 | 59.8 | 68.0 | 32.0 | -44.6 |
| 34.0 | 8.20 | 0 | 59.8 | 68.0 | 34.0 | -44.6 |
| 34.0 | 8.20 | 0 | 59.8 | 68.0 | 34.0 | -44.6 |
| 36.0 | 8.20 | 0 | 59.8 | 68.0 | 36.0 | -44.6 |
| 36.0 | 8.20 | 0 | 59.8 | 68.0 | 36.0 | -44.6 |
| 38.0 | 8.20 | 0 | 59.8 | 68.0 | 38.0 | -44.6 |
| 38.0 | 8.20 | 0 | 59.8 | 68.0 | 38.0 | -44.6 |
| 40.0 | 8.20 | 0 | 59.8 | 68.0 | 40.0 | -44.6 |
| 40.0 | 8.45 | 0 | 59.8 | 68.2 | 40.0 | -44.6 |
| 42.0 | 8.45 | 0 | 59.8 | 68.2 | 42.0 | -44.6 |
| 42.0 | 8.20 | 0 | 59.8 | 68.0 | 42.0 | -44.6 |
| 44.0 | 8.20 | 0 | 59.8 | 68.0 | 44.0 | -44.6 |
| 44.0 | 8.20 | 0 | 59.8 | 68.0 | 44.0 | -44.6 |
| 46.0 | 8.20 | 0 | 59.8 | 68.0 | 46.0 | -44.6 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 46.0 | 8.20 | 0 | 59.8 | 68.0 | 46.0 | -44.6 |
| 48.0 | 8.20 | 0 | 59.8 | 68.0 | 48.0 | -44.6 |
| 48.0 | 8.20 | 0 | 59.8 | 68.0 | 48.0 | -44.6 |
| 50.0 | 8.20 | 0 | 59.8 | 68.0 | 50.0 | -44.6 |
| 50.0 | 8.20 | 0 | 59.8 | 68.0 | 50.0 | -44.6 |
| 52.0 | 8.20 | 0 | 59.8 | 68.0 | 52.0 | -44.6 |
| 52.0 | 8.20 | 0 | 59.8 | 68.0 | 52.0 | -44.6 |
| 54.0 | 8.20 | 0 | 59.8 | 68.0 | 54.0 | -44.6 |
| 54.0 | 8.20 | 0 | 59.8 | 68.0 | 54.0 | -44.6 |
| 56.0 | 8.20 | 0 | 59.8 | 68.0 | 56.0 | -44.6 |
| 56.0 | 8.20 | 0 | 59.8 | 68.0 | 56.0 | -44.6 |
| 58.0 | 8.20 | 0 | 59.8 | 68.0 | 58.0 | -44.6 |
| 58.0 | 8.20 | 0 | 59.8 | 68.0 | 58.0 | -44.6 |
| 60.0 | 8.20 | 0 | 59.8 | 68.0 | 60.0 | -44.6 |
| 60.0 | 8.45 | 0 | 59.8 | 68.2 | 60.0 | -44.6 |
| 62.0 | 8.45 | 0 | 59.8 | 68.2 | 62.0 | -44.6 |
| 62.0 | 8.20 | 0 | 59.8 | 68.0 | 62.0 | -44.6 |
| 64.0 | 8.20 | 0 | 59.8 | 68.0 | 64.0 | -44.6 |
| 64.0 | 8.20 | 0 | 59.8 | 68.0 | 64.0 | -44.6 |
| 66.0 | 8.20 | 0 | 59.8 | 68.0 | 66.0 | -44.6 |
| 66.0 | 8.20 | 0 | 59.8 | 68.0 | 66.0 | -44.6 |
| 68.0 | 8.20 | 0 | 59.8 | 68.0 | 68.0 | -44.6 |
| 68.0 | 8.20 | 0 | 59.8 | 68.0 | 68.0 | -44.6 |
| 70.0 | 8.20 | 0 | 59.8 | 68.0 | 70.0 | -44.6 |
| 70.0 | 8.20 | 0 | 59.8 | 68.0 | 70.0 | -44.6 |
| 72.0 | 8.20 | 0 | 59.8 | 68.0 | 72.0 | -44.6 |
| 72.0 | 8.20 | 0 | 59.8 | 68.0 | 72.0 | -44.6 |
| 74.0 | 8.20 | 0 | 59.8 | 68.0 | 74.0 | -44.6 |
| 74.0 | 8.20 | 0 | 59.8 | 68.0 | 74.0 | -44.6 |
| 76.0 | 8.20 | 0 | 59.8 | 68.0 | 76.0 | -44.6 |
| 76.0 | 8.20 | 0 | 59.8 | 68.0 | 76.0 | -44.6 |
| 78.0 | 8.20 | 0 | 59.8 | 68.0 | 78.0 | -44.6 |
| 78.0 | 8.20 | 0 | 59.8 | 68.0 | 78.0 | -44.6 |
| 80.0 | 8.20 | 0 | 59.8 | 68.0 | 80.0 | -44.6 |
| 80.0 | 8.45 | 0 | 59.8 | 68.2 | 80.0 | -44.6 |
| 82.0 | 8.45 | 0 | 59.8 | 68.2 | 82.0 | -44.6 |
| 82.0 | 8.20 | 0 | 59.8 | 68.0 | 82.0 | -44.6 |
| 84.0 | 8.20 | 0 | 59.8 | 68.0 | 84.0 | -44.6 |
| 84.0 | 7.75 | 0 | 59.8 | 67.5 | 84.0 | -44.6 |
| 86.0 | 7.75 | 0 | 59.8 | 67.5 | 86.0 | -44.6 |
| 86.0 | 12.15 | 0 | 0.0 | 12.2 | 86.0 | -44.6 |
| 88.0 | 12.15 | 0 | 0.0 | 12.2 | 88.0 | -44.6 |
| 88.0 | 7.95 | 0 | 0.0 | 8.0 | 88.0 | -44.6 |
| 90.0 | 7.95 | 0 | 0.0 | 8.0 | 90.0 | -44.6 |
| 90.0 | 6.45 | 0 | 0.0 | 6.5 | 90.0 | -44.6 |
| 92.0 | 6.45 | 0 | 0.0 | 6.5 | 92.0 | -44.6 |
| 92.0 | 6.55 | 0 | 0.0 | 6.6 | 92.0 | -44.6 |
| 94.0 | 6.55 | 0 | 0.0 | 6.6 | 94.0 | -44.6 |
| 94.0 | 9.30 | 0 | 0.0 | 9.3 | 94.0 | -44.6 |
| 96.0 | 9.30 | 0 | 0.0 | 9.3 | 96.0 | -44.5 |
| 96.0 | 8.25 | 6 | 0.0 | 14.3 | 96.0 | -44.5 |
| 98.0 | 8.25 | 6 | 0.0 | 14.3 | 98.0 | -44.3 |
| 98.0 | 8.25 | 6 | 0.0 | 14.3 | 98.0 | -44.3 |
| 100.0 | 8.25 | 6 | 0.0 | 14.3 | 100.0 | -43.9 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 100.0 | 12.55 | 0 | 0.0 | 12.6 | 100.0 | -43.9 |
| 102.0 | 12.55 | 0 | 0.0 | 12.6 | 102.0 | -42.9 |
| 102.0 | 12.70 | 5 | 0.0 | 17.7 | 102.0 | -42.9 |
| 104.0 | 12.70 | 5 | 0.0 | 17.7 | 104.0 | -40.7 |
| 104.0 | 11.10 | 0 | 0.0 | 11.1 | 104.0 | -40.7 |
| 106.0 | 11.10 | 0 | 0.0 | 11.1 | 106.0 | -35.7 |
| 106.0 | 12.95 | 0 | 0.0 | 13.0 | 106.0 | -35.7 |
| 108.0 | 12.95 | 0 | 0.0 | 13.0 | 108.0 | -24.6 |
| 108.0 | 6.70 | 0 | 0.0 | 6.7 | 108.0 | -24.6 |
| 110.0 | 6.70 | 0 | 0.0 | 6.7 | 110.0 | 0.0 |
| 110.0 | 0.00 | 0 | 0.0 | 0.0 | 110.0 | 0.0 |

5.8 BEPALING BELASTING, DWARSKRACHT EN BUIGEND MOMENT:

| Belasting (t/m) | | deelopp | Balans | | Dwarskracht | | deelopp | Moment | |
|---|---|---|---|---|---|---|---|---|---|
| x (m) | Belasting p(x) | p(x)dx | | | x (m) | Q(x) | Q(x)dx | x (m) | Buigend moment M(x) |
| 0 | -13 | 0.0 | 0.0 | 0.0 | 0 | 0 | 0 | 0 | 0 |
| 0 | -13 | | | | | | | 1 | -5 |
| 2 | 2 | -10.1 | 0.0 | -10.1 | 2 | -10 | -10 | 2 | -10 |
| 2 | 4 | | | | | | | 3 | -11 |
| 4 | 15 | 19.0 | 0.0 | 19.0 | 4 | 9 | -1 | 4 | -11 |
| 4 | 12 | | | | | | | 5 | 12 |
| 6 | 18 | 29.9 | 0.0 | 29.9 | 6 | 39 | 48 | 6 | 36 |
| 6 | 20 | | | | | | | 7 | 97 |
| 8 | 25 | 44.5 | 0.0 | 44.5 | 8 | 83 | 122 | 8 | 158 |
| 8 | 16 | | | | | | | 9 | 259 |
| 10 | 19 | 35.5 | 0.0 | 35.5 | 10 | 119 | 202 | 10 | 360 |
| 10 | 17 | | | | | | | 11 | 497 |
| 12 | 19 | 36.4 | 0.0 | 36.4 | 12 | 155 | 274 | 12 | 634 |
| 12 | 32 | | | | | | | 13 | 822 |
| 14 | 34 | 65.9 | 0.0 | 65.9 | 14 | 221 | 376 | 14 | 1010 |
| 14 | 33 | | | | | | | 15 | 1264 |
| 16 | 33 | 66.2 | 0.0 | 66.2 | 16 | 287 | 508 | 16 | 1518 |
| 16 | 34 | | | | | | | 17 | 1840 |
| 18 | 35 | 69.0 | 0.0 | 69.0 | 18 | 356 | 643 | 18 | 2162 |
| 18 | 27 | | | | | | | 19 | 2545 |
| 20 | 27 | 53.5 | 0.0 | 53.5 | 20 | 410 | 766 | 20 | 2928 |
| 20 | 33 | | | | | | | 21 | 3370 |
| 22 | 33 | 66.1 | 0.0 | 66.1 | 22 | 476 | 885 | 22 | 3813 |
| 22 | 34 | | | | | | | 23 | 4323 |
| 24 | 34 | 68.2 | 0.0 | 68.2 | 24 | 544 | 1020 | 24 | 4833 |
| 24 | 33 | | | | | | | 25 | 5410 |
| 26 | 33 | 66.8 | 0.0 | 66.8 | 26 | 611 | 1155 | 26 | 5988 |
| 26 | 30 | | | | | | | 27 | 6629 |
| 28 | 30 | 60.9 | 0.0 | 60.9 | 28 | 672 | 1282 | 28 | 7270 |
| 28 | -24 | | | | | | | 29 | 7918 |
| 30 | -24 | -47.1 | 0.0 | -47.1 | 30 | 625 | 1296 | 30 | 8566 |
| 30 | -23 | | | | | | | 31 | 9168 |
| 32 | -23 | -46.7 | 0.0 | -46.7 | 32 | 578 | 1202 | 32 | 9769 |
| 32 | -23 | | | | | | | 33 | 10323 |
| 34 | -23 | -46.7 | 0.0 | -46.7 | 34 | 531 | 1109 | 34 | 10878 |
| 34 | -23 | | | | | | | 35 | 11386 |
| 36 | -23 | -46.7 | 0.0 | -46.7 | 36 | 484 | 1016 | 36 | 11893 |
| 36 | -23 | | | | | | | 37 | 12354 |
| 38 | -23 | -46.7 | 0.0 | -46.7 | 38 | 438 | 922 | 38 | 12815 |
| 38 | -23 | | | | | | | 39 | 13230 |
| 40 | -23 | -46.7 | 0.0 | -46.7 | 40 | 391 | 829 | 40 | 13644 |
| 40 | -24 | | | | | | | 41 | 14011 |
| 42 | -24 | -47.2 | 0.0 | -47.2 | 42 | 344 | 735 | 42 | 14379 |
| 42 | -23 | | | | | | | 43 | 14699 |
| 44 | -23 | -46.7 | 0.0 | -46.7 | 44 | 297 | 641 | 44 | 15019 |
| 44 | -23 | | | | | | | 45 | 15293 |
| 46 | -23 | -46.7 | 0.0 | -46.7 | 46 | 250 | 547 | 46 | 15567 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 46 | -23 | | | | | | | 47 | 15794 |
| 48 | -23 | -46.7 | 0.0 | -46.7 | 48 | 204 | 454 | 48 | 16020 |
| 48 | -23 | | | | | | | 49 | 16201 |
| 50 | -23 | -46.7 | 0.0 | -46.7 | 50 | 157 | 360 | 50 | 16381 |
| 50 | -23 | | | | | | | 51 | 16514 |
| 52 | -23 | -46.7 | 0.0 | -46.7 | 52 | 110 | 267 | 52 | 16648 |
| 52 | -23 | | | | | | | 53 | 16734 |
| 54 | -23 | -46.7 | 0.0 | -46.7 | 54 | 63 | 173 | 54 | 16821 |
| 54 | -23 | | | | | | | 55 | 16861 |
| 56 | -23 | -46.7 | 0.0 | -46.7 | 56 | 17 | 80 | 56 | 16901 |
| 56 | -23 | | | | | | | 57 | 16894 |
| 58 | -23 | -46.7 | 0.0 | -46.7 | 58 | -30 | -13 | 58 | 16888 |
| 58 | -23 | | | | | | | 59 | 16834 |
| 60 | -23 | -46.7 | 0.0 | -46.7 | 60 | -77 | -107 | 60 | 16781 |
| 60 | -24 | | | | | | | 61 | 16680 |
| 62 | -24 | -47.2 | 0.0 | -47.2 | 62 | -124 | -201 | 62 | 16580 |
| 62 | -23 | | | | | | | 63 | 16432 |
| 64 | -23 | -46.7 | 0.0 | -46.7 | 64 | -171 | -295 | 64 | 16285 |
| 64 | -23 | | | | | | | 65 | 16091 |
| 66 | -23 | -46.7 | 0.0 | -46.7 | 66 | -218 | -388 | 66 | 15897 |
| 66 | -23 | | | | | | | 67 | 15656 |
| 68 | -23 | -46.7 | 0.0 | -46.7 | 68 | -264 | -482 | 68 | 15415 |
| 68 | -23 | | | | | | | 69 | 15127 |
| 70 | -23 | -46.7 | 0.0 | -46.7 | 70 | -311 | -575 | 70 | 14840 |
| 70 | -23 | | | | | | | 71 | 14505 |
| 72 | -23 | -46.7 | 0.0 | -46.7 | 72 | -358 | -669 | 72 | 14171 |
| 72 | -23 | | | | | | | 73 | 13790 |
| 74 | -23 | -46.7 | 0.0 | -46.7 | 74 | -404 | -762 | 74 | 13409 |
| 74 | -23 | | | | | | | 75 | 12981 |
| 76 | -23 | -46.7 | 0.0 | -46.7 | 76 | -451 | -856 | 76 | 12553 |
| 76 | -23 | | | | | | | 77 | 12079 |
| 78 | -23 | -46.7 | 0.0 | -46.7 | 78 | -498 | -949 | 78 | 11604 |
| 78 | -23 | | | | | | | 79 | 11083 |
| 80 | -23 | -46.7 | 0.0 | -46.7 | 80 | -545 | -1042 | 80 | 10562 |
| 80 | -24 | | | | | | | 81 | 9994 |
| 82 | -24 | -47.2 | 0.0 | -47.2 | 82 | -592 | -1136 | 82 | 9425 |
| 82 | -23 | | | | | | | 83 | 8810 |
| 84 | -23 | -46.7 | 0.0 | -46.7 | 84 | -639 | -1230 | 84 | 8195 |
| 84 | -23 | | | | | | | 85 | 7533 |
| 86 | -23 | -45.8 | 0.0 | -45.8 | 86 | -684 | -1323 | 86 | 6872 |
| 86 | 32 | | | | | | | 87 | 6220 |
| 88 | 32 | 65.0 | 0.0 | 65.0 | 88 | -619 | -1304 | 88 | 5568 |
| 88 | 37 | | | | | | | 89 | 4985 |
| 90 | 37 | 73.3 | 0.0 | 73.3 | 90 | -546 | -1166 | 90 | 4403 |
| 90 | 38 | | | | | | | 91 | 3895 |
| 92 | 38 | 76.3 | 0.0 | 76.3 | 92 | -470 | -1016 | 92 | 3387 |
| 92 | 38 | | | | | | | 93 | 2955 |
| 94 | 38 | 76.1 | 0.0 | 76.1 | 94 | -394 | -863 | 94 | 2523 |
| 94 | 35 | | | | | | | 95 | 2165 |
| 96 | 35 | 70.5 | 0.0 | 70.5 | 96 | -323 | -717 | 96 | 1807 |
| 96 | 30 | | | | | | | 97 | 1513 |
| 98 | 30 | 60.3 | 0.0 | 60.3 | 98 | -263 | -586 | 98 | 1220 |
| 98 | 30 | | | | | | | 99 | 987 |
| 100 | 30 | 59.7 | 0.0 | 59.7 | 100 | -203 | -466 | 100 | 754 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 100 | 31 | | | | | | | 101 | 582 |
| 102 | 30 | 61.7 | 0.0 | 61.7 | 102 | -142 | -345 | 102 | 409 |
| 102 | 25 | | | | | | | 103 | 292 |
| 104 | 23 | 48.2 | 0.0 | 48.2 | 104 | -93 | -235 | 104 | 174 |
| 104 | 30 | | | | | | | 105 | 108 |
| 106 | 25 | 54.2 | 0.0 | 54.2 | 106 | -39 | -133 | 106 | 42 |
| 106 | 23 | | | | | | | 107 | 20 |
| 108 | 12 | 34.5 | 0.0 | 34.5 | 108 | -5 | -44 | 108 | -2 |
| 108 | 18 | | | | | | | 109 | -1 |
| 110 | -7 | 11.2 | 0.0 | 11.2 | 110 | 7 | 2 | 110 | 0.0 |
| 110 | 0 | | | | max: | **672** | | max: | **16901** |
| | | | | | min: | -684 | | min: | -11 |

## APPENDIX 3: EXTRACT FROM INSPECTION REGULATIONS FOR VESSELS ON THE RHINE (ROSR) 1995

### Article 3.01 General rule

Vessels must be built according to proper shipbuilding practices.

### Article 3.02 Strength and stability

1. The strength of the ship's hull must be such that it is adequate for the stresses which the hull is exposed to under normal conditions.

   a. For new vessels and for renovations by which the strength of the vessel can be affected, calculations must be provided to demonstrate that the ship's hull is sufficiently strong. This is not necessary if a classification certificate or a statement from a certified Classification Society is submitted.
   b. For investigations as referred to in article 2.09, the minimal thicknesses of the bottom, bilge and side plating of the ship's shell must be checked in accordance with the following method:
      The minimum thickness, $t_{min}$, must be the larger of the values established using the following formulas:

      1. For vessels exceeding 40 m in length:
         $t_{min} = f \cdot b \cdot c \cdot (2.3+0.04L)$ $[mm]$;
         for ships equal to or less than 40 m in length:
         $t_{min} = f \cdot b \cdot c \cdot (1.5+0.06L)$ $[mm]$,
         in any case, at least 3.0 mm.
      2. For vessels regardless of the length: $t_{min} = 0.005 \cdot a \sqrt{T}$ $[mm]$.

      The letters used in these formulas have the following meaning:

      a = frame distance in [mm];

      f = factor for frame distance:

      $f = 1$ for $a \leq 500$ mm

      $f = 1 + 0.0013 (a - 500)$ for $a > 500$ mm

      b = factor for bottom and side plating or bilge plating

      $b = 1.0$ for bottom and side plating

      $b = 1.25$ for bilge plating.

      For the calculation of the minimum thickness of the bilge plating, the factor for the frame distance may be assumed to be $f = 1$. The minimum thickness of the bilge plating, however, may never be less than that of the bottom and side plating.

      c = factor for building method:

      $c = 0.95$ for vessels with a double bottom and side tanks, for which the cargo hold longitudinal bulkhead in the side is placed vertically under the fore-and-aft bulkhead.

      $c = 1.0$ for ships with another building method.

The values established according to the above method for the minimum thicknesses of the plating of the ship’s shell are limit values for normal and even wear and tear, under the condition that shipbuilding steel is used and that the internal construction parts, such as frames, bottom timbers and main frame, longitudinal strength and bracket frame components are in good condition and that the hull does not have any damage that indicates that it has been overloaded in the fore-and-aft direction.
If the actual values are lower than the calculated values, the plates in question must be replaced or repaired. Local spots which are small in size and thinner are allowed, up to a maximum deviation of 10% of the minimum thickness.

c. For ships built in a longitudinal direction and those equipped with a double bottom and side tanks, the minimum plate thickness calculated using the formulas stated in part b may be a certain amount less as determined and documented by a certified Classification Society, after it has been demonstrated by means of calculations that the ship’s hull is sufficiently strong.
It is necessary to renew the plating if the thickness of the bottom or side plating is less than the value calculated in this manner.

2. The stability of the vessels must be in accordance with the purpose for which they are intended.