

**Day 1**

**Part 5**

**The Design and Construction of the Nieuwe Waterweg**

**Storm Surge Barrier in The Netherlands**

**Technical and Contractual Implications**

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## 1. INTRODUCTION

For the South-Western part of the Netherlands the safety against flooding is prescribed by the Delta Act. This Act was made after the severe flood disaster of 1953 in which nearly 2000 people drowned. The Delta Act prescribed the shortening of the coast line by closing off many of the existing tidal inlets and the strengthening of the remaining dikes. It also proclaimed that the Nieuwe Waterweg and the Western Scheldt had to remain open as they are the main fairway to the harbours of Rotterdam and Antwerp. The dikes along these waterways and along the waterways connected to it had to be strengthened. In 1985 a re-examination of the design water levels led to even higher values than those considered in the Delta Act, meaning that another 200 kilometres strengthening of river dikes including costly protection works in densely populated or infrastructurally complicated areas was of utmost importance. See figure 1 for the project area.

The work involved with the strengthening of dikes would not be finished before the year 2020. Therefore, in 1987, the Dutch Government initiated a study to reconsider a movable storm surge barrier in the Nieuwe Waterweg. To be feasible the barrier had to meet several requirements, the most important ones being:

- \* closing frequency of the barrier less than once every 10 years now and once every 5 years after 50 years of operation (due to 25 cm sea level rise)
- \* prescribed reduction of design water levels (a local water level with a fixed frequency of exceedance) at two representative locations, the cities of Rotterdam and Dordrecht

The prescribed maximum closing frequency puts a strong emphasis on the open character of the Rotterdam harbour. Other goals also reflected that the Dutch Government highly appreciated the economic importance of the Rotterdam harbour.

After an extensive study the feasibility and the effectiveness of a movable barrier was shown and 5 contractor consortia were asked to make predesigns for the barrier. Towards the end of 1989 a definite choice was made for the sector gate barrier designed by B.M.K. Barrier Design and Construction Group and a design and construct contract was granted. The BMK barrier turned out to be an economic alternative for the original programme in which the dikes had to be improved. In accordance with this decision, the Delta Act had to be changed. Clearly, even after the barrier is completed and is operating, dikes will be necessary and still some will have to be strengthened although to a much lesser extent. This was taken into account when making the decision in favour of the barrier.

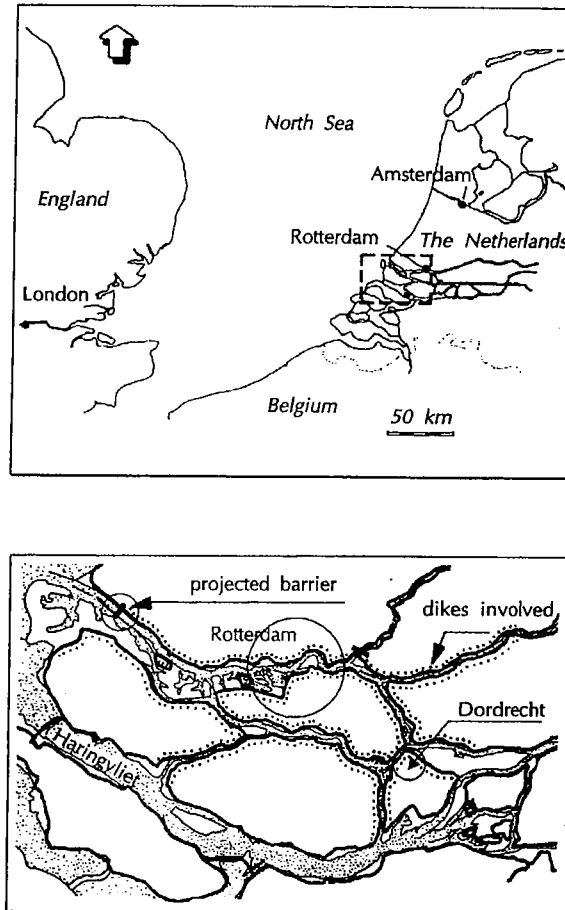


Fig. 1 Project area

This contribution concentrates on the next phases. It describes the tender philosophy and the procedure of selecting the final barrier design, the design and construct contract with all its specific problems and advantages, the details of the current barrier-design which is slightly different from the original one as well as a description of the design process itself, the hydrodynamic problems that strongly influenced the final geometry of the barrier and last but not least the management of the design process. Finally some conclusions will be drawn. However, first the project area and its hydraulic features are described to obtain a better understanding of the preconditions imposed on the barrier-design.

## 2. PROJECT DESCRIPTION AND HYDRAULIC SYSTEM

The project area covers the lower river reaches in the South-Western part of the Netherlands, as shown in figure 1. The bottom map represents the Rhine and Meuse Delta network, in which water levels will be influenced by operating a storm surge barrier in the Nieuwe Waterweg. Combined with the dikes along the river branches the barrier will provide safety against flooding.

In figure 2 the hydraulic system is shown in a schematic form. Basically there are two river branches with several connections. The southern branch runs into the large Haringvliet estuary which is separated from the sea by a barrage with large discharge sluices. These sluices are closed during high tide to prevent sea water from entering the delta region. During low tide they are closed only when the river discharge is low. In this way the water is forced to discharge through the Northern branches, to stop salt intrusion from the sea.

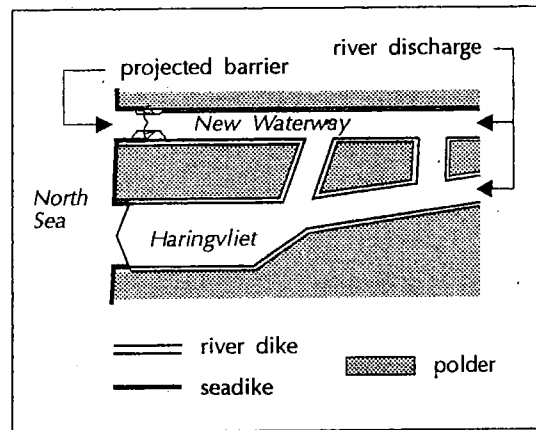


Fig. 2 Hydraulic system

The Northern branch runs freely into the sea through the city of Rotterdam and the Nieuwe Waterweg. Tidal movement and storm surges enter the system through this northern branch. Close to the river mouth the water level is determined by the tidal movement and the storm surge. Travelling upstream the incoming wave is damped and the phase is shifted. The water levels in this intermediate region are determined by both sea-water levels and river discharge.

In the hydraulic system the effect of the barrier on water levels is twofold. One effect is the reduction of water levels because the storm surges can no longer enter the system. On the other hand there is an increase of water levels due to accumulation of river water behind the barrier.

To calculate the total balance of effects the hydraulic system has been modelled by a mathematical open-channel network model. The schematization of the system is conform figure 2 and consists of about 200 branches and nodes. This model has been in use for a long time to predict water levels on a daily basis and to determine design water levels for the situation without a barrier. To study the effects of a barrier the model has been extended with a weir structure. Boundary conditions for the model are the river discharge and the combined effect of tide and storm surge.

Due to shipping, strict requirements have been imposed upon the barrier-design. The most important ones being the maximum closing frequency of the barrier and the restriction of operation induced translation-waves within specified limits. Also the space required for the passage of ships is prescribed. The minimum width above Mean Sea Level (MSL) -10 m is 360 m and the minimum sill depth is MSL -17 m.

Since the performance of the barrier is measured in statistical quantities (e.g. design water level reduction and closing frequency) probabilistic calculations are necessary. The hydraulic model is used to translate boundary conditions into local water levels. The probability density functions of the boundary conditions are used to derive the probability of exceedance of the local water levels by a probabilistic full integration method. In the probabilistic calculations also the reliability of the barrier is taken into account. The reliability of the barrier concerns the probability that the barrier is not closed due to:

- inaccurate water level prediction
- human or technical errors
- collapse (insufficient strength)

The performance of the barrier is also influenced by the characteristics of the barrier and its operation, e.g. moment and duration of both closing and opening.

Since design water levels are a Governmental responsibility it seems logical to set technical requirements to the characteristics of the barrier that influence the design water levels. On the other hand the contractor should have as much freedom of design as possible.

The technical requirements have been established by a sensitivity analysis for the barrier performance. In this analysis the influence of the reliability, the characteristics and the operation (strategy) of the barrier is established. Aiming for adequate performance, an optimum strategy and realistic reliability targets (especially with human errors involved) can be described.

The optimum strategy is:

- closure at a sea water level of MSL +2.00 m for river discharges less than 6000 m<sup>3</sup>/s and at slack water for higher discharges,
- opening at equal water levels on both sides of the barrier,
- discharging water through the barrier between two high waters at sea (i.e. when water levels on the riverside of the barrier are higher than on the seaside) with a minimum wet surface of 1000 m<sup>2</sup> net that has to be realised within 20 minutes.

The reliability targets are:

- probability of not closing due to human or technical errors less than  $10^{-3}$  on demand,
- probability of collapse less than  $10^{-6}$  in any year,
- probability of not opening due to human or technical errors less than  $10^{-4}$  on demand.

For the barrier-characteristics limits have been targeted. Within these limits the barrier performs well. The targeted barrier-characteristics are:

- full closure in less than 2.5 hours and 80% closed within 1.5 hours,
- full opening in less than 2.5 hours and 20% open within 1 hour,
- average retaining level MSL +5 m,
- leakage area through the closed barrier less than 100 m<sup>2</sup> net,
- up to 4000 m<sup>3</sup>/s river discharge it is allowed to reduce the hydraulic head over the barrier by letting in water through a limited opening in the barrier.

If the contractor satisfies the technical requirements, the design water levels are sufficiently reduced. Since it is not described how to fulfil the requirements, this procedure gives the contractor maximum freedom of design.

### 3. BASIC TENDER PHILOSOPHY AND SELECTION PROCEDURE

The construction of the Eastern Scheldt storm surge barrier (1978-1986) induced considerable negative publicity because of its budget overruns (approx. 30% in total). Therefore, the intention was to realise the storm surge barrier in the Nieuwe Waterweg following the basic principles of market mechanism philosophy. The market (designer-contractors) should be given the opportunity to show their skills as opposed to the usual designer-role of the Rijkswaterstaat of the Dutch Ministry of Public Works. Moreover this philosophy was enhanced by political aims to diminish activities of governmental bodies in favour of a stronger market approach, the result being that a "design and construct contract" was put out for tender according to European rule. This tender philosophy was new to the Rijkswaterstaat. It should result in a project where the owner would surely get:

- a storm surge barrier for a predetermined price,
- value for money through competitive designing and bidding by Europe's most outstanding designers/contractors,
- a technical state of the art work that complies with the specifications,
- design and construction in one hand.

Therefore, different European contractor consortia were invited to:

- draw up a preliminary design of a storm surge barrier, based on a limited number of rather abstract technical (operational and design boundary conditions) requirements,
- present a lump-sum price for the design and construction of the barrier including maintenance for a period of 5 years.

To do this the contractors were given a period of three months. The technical requirements were intentionally formulated on a high level of abstraction to encourage innovative, bright and economical solutions.

Initially 6 contractor consortia applied for the tender. After a first selection (considering the contractor's design experience), 5 consortia were invited to prepare the conceptual design and to offer a fixed price within 3 months.

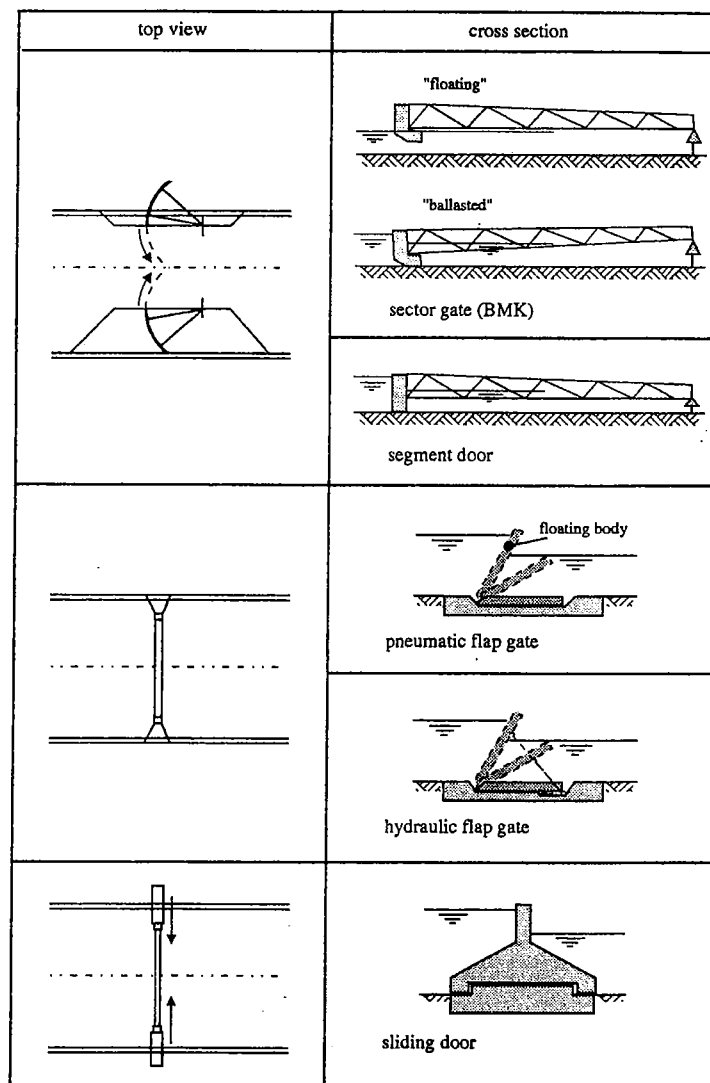


Fig. 3 Basic concept 5 predesigns

During these 3 months Rijkswaterstaat prepared the technical requirements for the next phase of the selection. This resulted in the basic requirements for reliability, operational management and characteristics of the barrier as described in the previous section.

To select the most appropriate technical and financial solution Rijkswaterstaat felt the need to acquire sufficient knowledge of the specific "snags" in the design process. Therefore, they elaborated a number of conceptual designs of the barrier to such a level, that all major problem areas and other areas of interest were understood. This work was carried out by a team of specialists during the same three months in which the contractors prepared their design and bid offer. This resulted in a clear understanding of what was possible and what was not. Reliability and maintainability were the key criteria to select the designs on, apart from cost and design quality.

After the three month period, the 5 barrier-designs were evaluated. In figure 3 the barriers are shown schematically. Based on the criteria mentioned above, the sector gate and the segment door were chosen for further competition. An important difference between the two designs is that the sector gate is floated into the river and then sunk to the bottom and the segment door is ridden into the river. In this final phase of the competition the two consortia did hydraulic model testing on their designs at the Delft Hydraulics Laboratory to eliminate all remaining uncertainties. Rijkswaterstaat monitored these testings. Then the consortia refined their bids. After a technical evaluation Rijkswaterstaat finally selected the BMK sector gate on the basis of cost. The BMK consortium was granted the contract amounting to approximately 700 million guilders in total.

The main technical reason for selecting the BMK design is the simplicity of the technical concept. Moreover, the structure is easy to maintain, mainly in dry conditions with only limited parts remaining under water.

The selection procedure took the better part of one year. The use of a step by step selection procedure guaranteed a continuing market mechanism throughout the procedure and induced the best quality.

#### **4. CONTRACT CONSIDERATIONS**

The contract involves both the total design as well as the construction of the storm surge barrier. Moreover, the contractor is responsible for the maintenance of the barrier during the first five years of operation. This combination of responsibilities (risks) should give the contractor an incentive to search for an overall economically sound solution for all design problems.

However, the Nieuwe Waterweg storm surge barrier is a structure to defend one of the most densely populated parts of the Netherlands against floods. Defending the country against floods is one of the responsibilities of the government which of course cannot be transferred to a private organisation. If the structure would fail under design conditions this would mean a major national disaster.

Furthermore it is hardly possible from an economical point of view to have the design insured against risks of this magnitude. Therefore the Dutch government takes over the risks of faulty design work on delivery.

Another problem to bear in mind is the fact that the design loads (with very low frequencies of occurrence) on the barrier are not likely to occur. It is thus impossible to run tests on delivery to determine whether the barrier meets its basic requirements.

The three considerations mentioned above are directive to the role the owner should play in the process. It has therefore been decided that a team of experts from Rijkswaterstaat monitors the design and construction. To enforce this role, the contract contains a so called "procedure of acceptance". Each part of the design or construction that influences on the barrier's performance has to be accepted by the team of Rijkswaterstaat. If no acceptance is given, the contractor is not allowed to release that particular part for further engineering or construction.

To ensure a clear phase-to-phase working procedure, the contract states that a number of documents have to be produced in a certain order. In this way fast tracking is eliminated for most of the work. Again, acceptance of these documents by the owner is necessary in order to continue parts of the project. Successively, basic design documents, engineering documents, specification documents, quality control documents and construction plans have to be produced. All of this work is done following the requirements imposed by the ISO-9000 standards. These quality assurance standards are rather new to the practice of civil engineering in the Netherlands. Subsequently all parties involved (both owner and contractor(s)) had to put a lot of energy into the design and the implementation of quality assurance (QA) and quality control (QC) procedures and also create and maintain a quality minded workforce.

This procedure has now been followed for about three years. The experiences have been mostly positive. At the start of the project, differences had to be overcome mainly concerning the new roles of both contractor and Rijkswaterstaat. The contractor was used to building and now had to include designing, Rijkswaterstaat was used to designing and now had to refrain from doing this. The following exaggeration will further clarify this: the staff engineers of Rijkswaterstaat felt that they were the only really experienced designers; the contractor engineers felt that they had to go through the ordeal of some design work before the real job, being the construction, could start. Fairly soon after some initial "misunderstandings" both parties found out that the only way to fulfil the assignment was by working together as the complementary components of a team and to respect one another.

## 5. DESCRIPTION OF THE FINAL DESIGN AND BARRIER OPERATION

The lay-out of the sector gate barrier is shown in figure 4. On each side of the channel an abutment is constructed between the groynes. As such, the space available to shipping and water flow remains virtually unaltered.

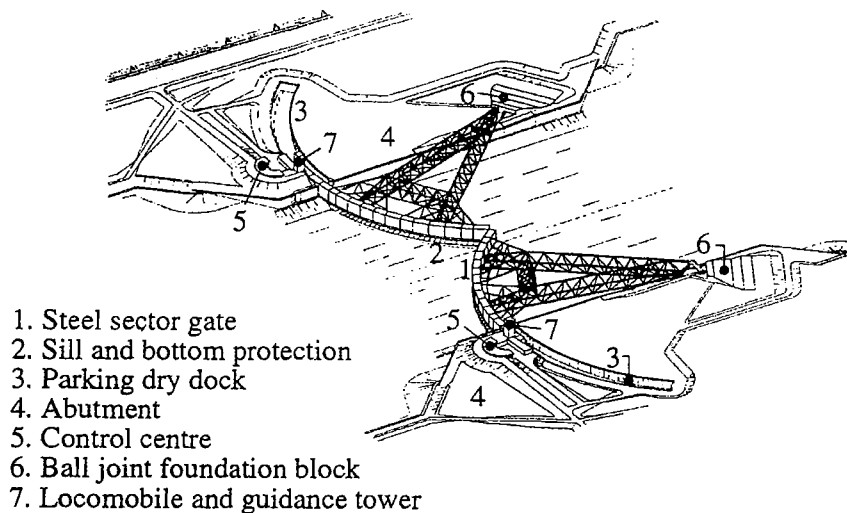


Fig. 4 Lay-out BMK sector gate

Inshore of the abutment a steel sector gate is parked in a dry dock. A sector gate consists of a circular shaped retaining wall, connected to a hinge point by means of two steel truss works. Due to the circular shape, the rotation of the sector gate is barely influenced by currents or hydraulic head. The traction of the sector gate can therefore be simple and small, especially because the gates are floating during motion. As such, the motion of the gates is similar to the motion of a ship.

The traction consists of a traction work, the locomobile, generating the horizontal force. The traction of the locomobile is transferred to a rail construction on top of the gate. Thus the locomobile rides on top of the retaining wall. While the locomobile remains stationary the gate moves horizontally. As shown in figure 5, the connection between the locomobile and the support near the dock must allow a vertical motion, while a horizontal displacement is prevented. Once in position, the floating doors are ballasted with water and then sunk to the bottom.

In immersed position the sector gate rests on a sill consisting of large concrete blocks. On both sides of the sill a conventional granular scour protection is situated. The structural integrity and dimensions of the barrier are largely influenced by the hydraulic head over the barrier.

The concept of the barrier is, however, mainly determined by the strict requirements concerning obstruction to shipping during construction and maintenance of the barrier. The barrier has to be built to last for 100 years. In its operational lifetime, closure of the barrier is expected to occur once or twice in ten years. Management of the structure focuses on inspection and maintenance.

