S. II - 3

A STORM SURGE BARRIER ON THE NEW WATERWAY, THE NETHERLANDS
without obstacle to shipping to and from the Rotterdam harbor

by

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INTRODUCTION

The Delta Act calls for the reinforcement of the Dutch water-retaining structures to the extent that all the Dutch coastal areas are protected against high water levels and the chances of a flood disaster as occurred in 1953 are reduced to a politically defined minimum. This Act originally also stipulated that the New Waterway is to remain open in the interest of shipping. This means that the dikes along this waterway and along the waterways that are in open connection with it had to be raised in order to reach the required level of protection for the land behind them (see Fig. 1). During the extensive dike reinforcement program, problems have increasingly arisen due to buildings and infrastructure situated on and in these dikes. The major problem areas are in the built-up parts of Rotterdam, Dordrecht, Sliedrecht and Hardinxveld-Giessendam, and this fact led to a search for alternatives. For some time the idea had existed that it might also be possible to achieve the required level of protection through the construction of a movable storm surge barrier on the New Waterway.

With this type of protection the need to reinforce the dikes behind it would be either eliminated or considerably reduced, because high storm surges would not be able to penetrate into the lower reaches of the river Rhine.

Therefore in 1987 the Minister of Transport and Public Works commissioned a study into the desirability of such a barrier and its technical and financial feasibility.

In accordance with the statutory EC regulations, five selected construction consortiums submitted within three months an offer for the all-including design and construction of a barrier on the basis of a detailed set of requirements. The designs were examined with regard to technical feasibility, quality and financial and management aspects by a broadly-based review board. Several divisions of the Public Works Department participated in the assessment. In 1988, the Dutch Government decided to proceed with the detailed design of a storm surge barrier on the New Waterway.

The main characteristic of the storm surge barrier alternative on the New Waterway is that the influence of the sea would not be allowed in the area behind the barrier above a certain level. Two important requirements to be met by the design of the storm surge barrier are reliability and minimum obstruction to navigation. Moreover, it is desirable to find a solution with the least overall costs.

LOCATION OF THE BARRIER

From the standpoint of protection against storm surges, the barrier should be constructed as far seawards as possible.

However, there are a number of reasons for not locating it near Hook of Holland. One of the conditions is that the barrier should in principle form no obstacle to shipping to and from the Rotterdam harbor area. The barrier will be situated to the east of the entrance to the Maasvlakte and

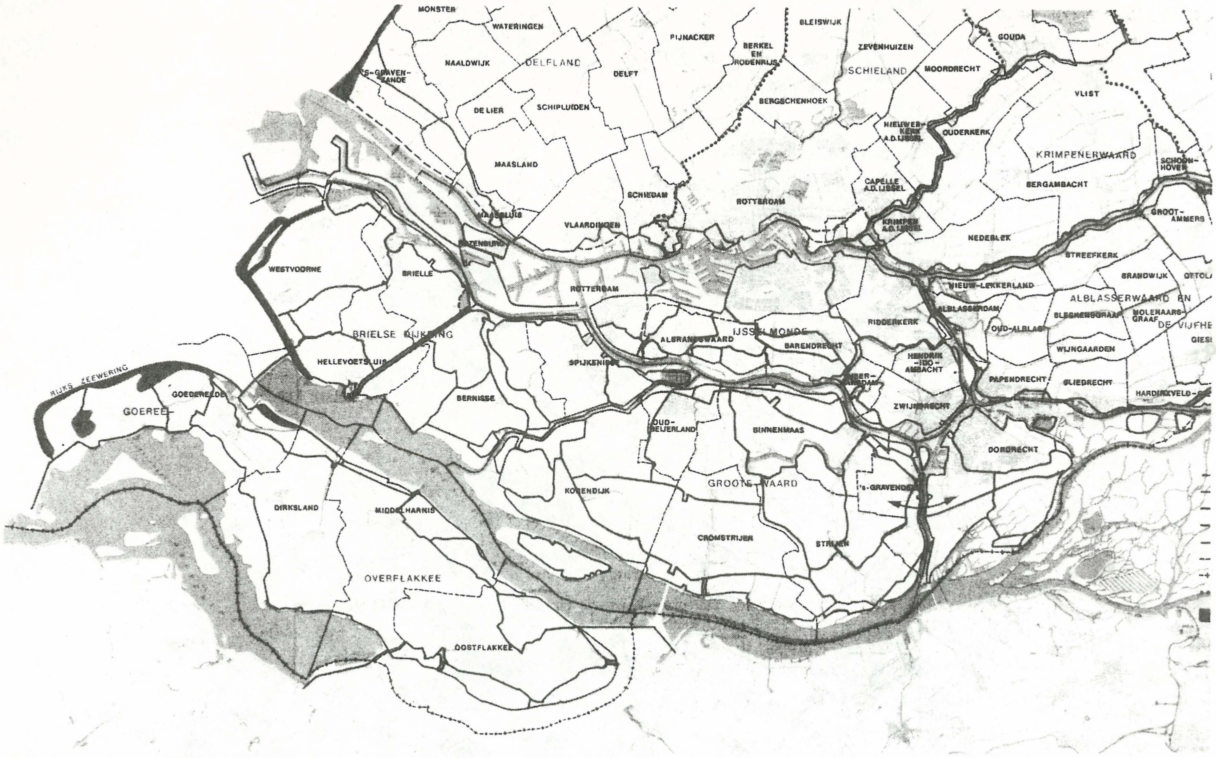

Figure 1.

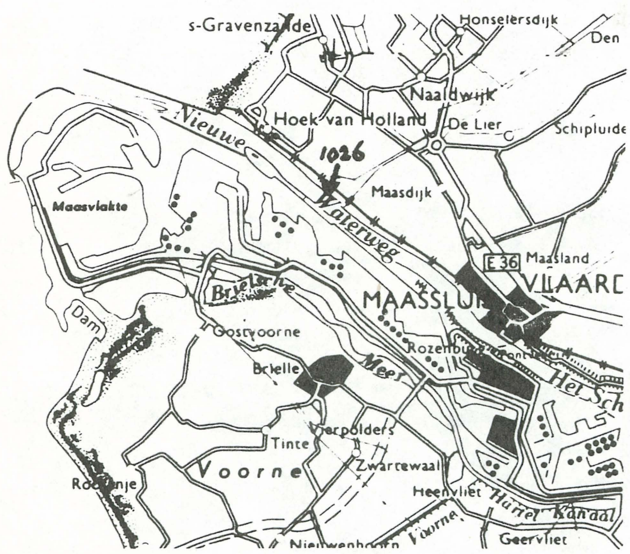

Figure 2.

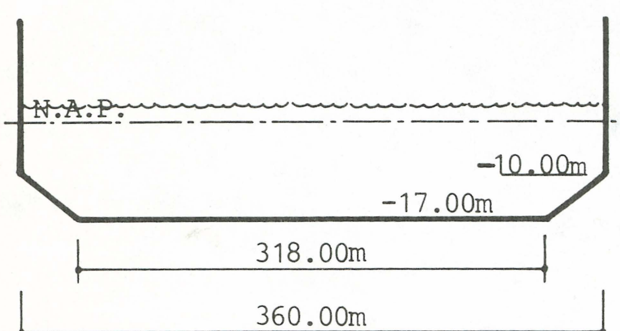

Figure 3.

Europoort; that way the deepest and most important part of the harbor area will still be accessible when the barrier is closed.

The Maasvlakte and Europoort are the port of destination and departure respectively of a large share of the import and export sea cargo.

The Hartelkanaal, which has been continuously connected to the Oude Maas since the removal of the Hartel locks, would be the westernmost extension of the river area if the storm surge barrier is closed. The separation between the Hartelkanaal (river) and the Calandkanaal (sea) would consist of the area formed by the Maasvlakte, Europoort and Botlek. Technically speaking, this area would be outside the dikes but, as a result of the level chosen, it would hardly be endangered by water levels beyond the dikes. A final consideration is that the bed of the New Waterway is steadily deepening in a westerly direction.

It should be clear that for technical and financial reasons a barrier in the mouth of the Maas is not desirable. Therefore, and also taking into account local infrastructural circumstances, km 1026 was chosen as the location where a barrier could be built.

OPERATION AND MANAGEMENT OF A BARRIER

The effect of a storm surge barrier on the normative high water levels depends on the policy that is chosen.

The aim will be to operate the barrier so as to produce the greatest possible effect on the normative high water levels behind the barrier. In this way the benefits, measured in less need to raise dikes, will be greatest. At the same time the frequency of closure should be minimized for shipping. It should be kept in mind that if a predetermined level for closing is maintained, in the course of time the frequency of closing could increase as a result of the rising of the sea level. In the very long run a reconsideration of the chosen frequency of closing should therefore not be ruled out.

The way the barrier is operated will be determined by the head difference over the barrier that the structure itself must be able to withstand, and along with it, its building costs.

The operation of the barrier can be characterized as follows (see Fig. 4):
- a closing of the barrier when the expected high tide level at Hook of Holland is MSL + 3 m or higher; in practice, this means a closing frequency of once in 10 years without sea level rise and twice in 10 years with sea level rise;
- when the outer water level between the storm surge high tides is lower than the inner water level discharging takes place through openings in the barrier;
- the barrier is opened completely when the outer water level is definitely lower than the inner water level;
- the opening and closing procedures take 1 to 2 hours each;
- the average duration that the barrier is closed is 30 hours.

SOME PRECONDITIONS

Besides the aim and the location of the barrier, the following preconditions were established relative to its operation:

1. SURVEY OF THE SPACE AVAILABLE TO SHIPPING

The requirements to be met by the barrier relating to shipping are (see Fig. 3):
- connected width of passage perpendicular to the river; above MSL -10 m: at least 360 m; below MSL -10 m: narrowing in the same way on each side to not less than 318 m; at MSL -17 m: at least 318 m;
- sill depth: MSL -17 m;
- height of passage: unlimited;
- max. retaining level: MSL +6 m.

2. OBSTRUCTION OF THE NEW WATERWAY

The average expected frequency of the closing of the barrier after it is completed and operational is at the most once to twice in 10 years.

Obstructing for the purpose of checking the functioning of the barrier may take place once a year for a short period at a time that shipping is at minimum. During the construction blocking of and obstruction to shipping should be kept to a minimum.

3. MAXIMUM PERMISSIBLE TRANSLATION WAVE

In the Europoort and Rotterdam harbors the translation waves which may result from closing and opening the barrier should be lower than 10 cm. On the river the translation wave may not exceed 40 cm on either side of the barrier, and the angle at the front should not be less than 1 %.

4. PROBABILITY OF MALFUNCTIONING

The acceptable probability of malfunctioning of the barrier has been set at 1/1,000,000 a year. The barrier has malfunctioned if the water level in the downstream area is higher than the projected level in a situation, brought on by the sea, in which the barrier is supposed to function.

The acceptable chances of malfunctioning of the barrier to open after a closure period have been set at 1/10,000 a year, due to navigation reasons.

5. WATER FLOW

In the interest of shipping the flow velocities at the open storm surge barrier should not increase to more than 5% above the current velocities.

The transport of ice and sludge should be possible without interruption.

6. OPERATION, MANAGEMENT AND MAINTENANCE

Within a radius of 3 km visual information should be given to ships regarding the closing of the barrier.

The supply of information for purposes of maintenance and management, including a database with respect to the behavior of parts of the installation should be automated.

7. LIFE EXPECTANCY

The barrier should be built to last for 100 years. A distinction should be made between parts that are replaceable and those that are not. Every irreplaceable part should fulfil the life expectancy requirements. For replaceable parts a shorter life expectancy may be taken into consideration provided that all replacement costs are included in the estimated cost of maintenance at the end of the life expectancy.

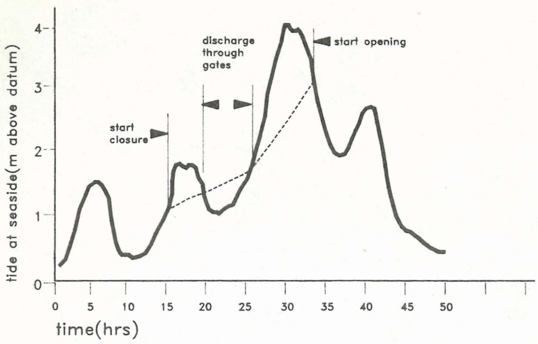

Figure 4 - Typical operation scenario.

ALTERNATIVE DESIGNS

Hereafter three basic designs are described, viz.
A. The BMK Sector Gate Barrier
B. The NIWAS Segment Door Barrier
C. The Sliding Door Barrier

All three designs met the requirements and performance standards as formulated.
The preliminary result of the design competition is that for financial reasons the BMK sector gate barrier and the NIWAS segment door barrier will be developed in detail, after which a final choice will be made at the end of 1989.

The activities involved in this design study and proposal for the construction of a storm surge barrier on the New Waterway have taken place under the authority of the Minister of Transport and Public Works.

In BMK the following companies are active :
- Hollandse Beton Groep N.V.
- Royal Volker Stevin N.V.
- IGB Holding N.V.
- Hollandia Kloos Holding N.V.

The actual works are carried out by their operating companies :
- Hollandse Beton en Waterbouw B.V.
- Van Hattum en Blankevoort B.V.
- Dirk Verstoep B.V.
- Hollandia B.V.
- Hollandse Constructie Groep B.V.
- Shipyard Stapel B.V.

and the in-house consultants :
- Aveco Infrastructure Consultants B.V.
- Delta Marine Consultants B.V.

The NIWAS combination consists of the following contractors :
- Ballast Nedam Beton en Waterbouw B.V.
- Boskalis Westminster Dredging B.V.
- Grootint B.V.
- Van Oord Groep N.V.
- Van Rietschoten & Houwens, Electronische Maatschappij B.V.

and is supported by the following engineering firms :
- Ballast Nedam Engineering B.V.
- DHV Raadgevend Ingenieursbureau B.V.
- Gusto Engineering B.V.
- Raadgevend Ingenieursbureau Lievense B.V.
- Consulting Engineers H. Veth B.V.
- F.C. de Weger International B.V.

A. SECTOR GATE BARRIER

1. INTRODUCTION

Replying to the request of the Dutch Ministry of Public Works the contractor's joint venture BMK (Bouwkombinatie Maeslant Kering) has studied the possibilities for a storm surge barrier on the New Waterway. The study was carried out by the contractor's own engineering staff.

A large number of concepts were worked out on a conceptual level, of which finally two were selected, viz. a (pneumatic) flap type barrier and a sector gate barrier. The first one belongs to the group of alternatives that transfers the hydraulic loads directly to the bottom and the second one transfers the hydraulic loads to a strong point ashore (Fig. 5).

The concept of the flap type barrier was finally discarded by the Ministry of Public Works, in favor of the alternate concept, the sector gate barrier.

2. BASIC CONCEPT

The concept comprises two steel sector gates which pivot around a hinge point ashore. The radius is 246 m. In a parked position the doors are located inshore of a bulkhead in a parking dock. The doors are rotating in position in floating condition. Once in position they are water ballasted and immersed to close off the channel. The circular shape of the doors ensures that positioning in floating condition can be done even under extreme conditions of tide and current.

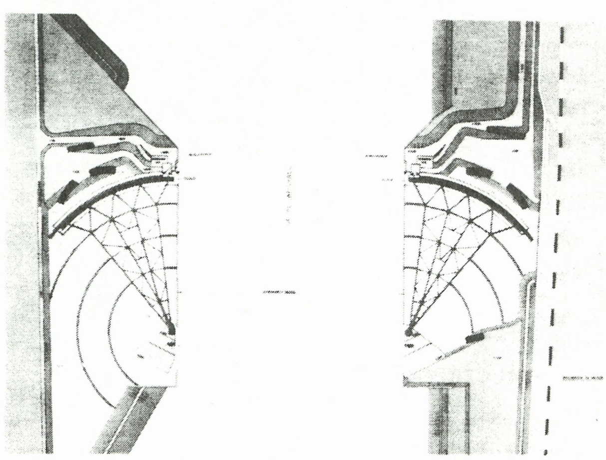

Figure 5.

After immersion, the water ballast ensures that the doors are resting stable on the sill in spite of wave and current forces. However, the support forces on the sill will still be minor, as all horizontal hydraulic loads due to the head differences are being transferred to the hinge point ashore. As a result the sill structure can be of a simple design and vertical tolerances can be relatively large.

The top of this sill structure consists of concrete blocks of 2.5 m thickness, placed in a granular filter by a heavy lift vessel. Adjacent to this concrete structure is a conventional erosion protection of rock stone.

The sector doors are being rotated into position by locomobiles riding on top of the gates. The locomobiles are connected to a concrete support building near the waterfront. The traction of the locomobiles is transferred into a horizontal motion of the door, the locomobiles themselves remain stationary. The connection to the support building can slide vertically, to follow the immersion of the gate and motion due to waves and current while floating.

The central ball hinge point is of a special design to allow rotation in all directions. Since the hinge is a vital element in the functioning of the barrier, care is being taken that all elements of the hinge can be taken out for repair without obstructing the normal functioning of the barrier. It's designed to withstand an ultimate load of about 360,000 kN.

3. OPERATION OF THE BARRIER

Since the water levels in the delta area depend on tidal motion, river discharges, wind effects and inertia of the water motion, the operational plan is a complex one.

The BMK design team has developed its own mathematical model of the delta area to prepare the operational plan and also to optimize the design within the given basic boundary conditions. Calculations with this model showed that a complete closure was not required to obtain sufficient tide reduction inland. Under normal river discharge conditions a certain flood discharge can be allowed. The effect of such discharge is that the hydraulic head difference over the barrier can be reduced.

To allow this flood discharge, sliding gates are designed in the sector gates. These gates are also used to discharge excess water from the rivers during an intermediate low tide (Fig. 4). During closing and opening, the gates function to reduce the translation waves.

4. MAIN CHARACTERISTICS OF THE DESIGN

The total construction is of a large scale, but still simple and transparent in the transference of hydraulic loads. Deformations and settlements can therefore be accepted to a large extent.

Due to the relaxed tolerance requirements and relatively small forces, the construction of the concrete sill can be simple and easy to carry out with minimum obstruction to the navigation. All other elements of the barrier being constructed outside the navigation channel, the BMK concept allows unobstructed navigation during all stages of construction.

In parked position, the sector gates will be located in a dock ashore. The dock can be pumped dry so that all maintenance works and inspections can be done in dry condition. The structure between the actual gate and the hinge point is also rotating above dry land and therefore permanently accessible for maintenance. In case of a high tide alarm the dock is inundated and the gate is ready to be floated out. While still in the dock the complete mechanism of traction, ballast system and discharge gates can be tested without necessity to float the gate out into the river (a free maneuvering space of 15 m is available within the dock).

In the study much attention has been given to the location of the sensitive structural elements in the protection of the heavy bulk head. This way damage due to navigation accidents is reduced to an acceptable low level. A risk analysis integrated into the design process has been carried out, focussed on structural integrity, control mechanisms and human failure. This risk analysis defined not only the strength and stability requirements, but also redundancies and operation and control processes. In this way a well balanced design is obtained with a level of reliability appropriate for a structure protecting a major part of the most densely populated area of the Netherlands including the biggest port in the world.

B. SEGMENT DOOR BARRIER

1. INTRODUCTION

The NIWAS design was submitted under the title « Segment Door Barrier », the name of which was derived from the shape of the door. It was the aim of NIWAS to find a concept that was simple in terms of the transfer of forces and simple in terms of movement despite the huge dimensions, and which was based on existing proven techniques or on the implementation of sound extrapolations based on those techniques. Therefore NIWAS used an integral design approach which would lead to a balanced construction in which all parts contribute equally to strength and safety.

2. BASIC CONCEPT

The concept was based on the philosophy to give a maximum freedom of control in the use of the barrier to the Waterway board as operator, specifically through (see Fig. 6):

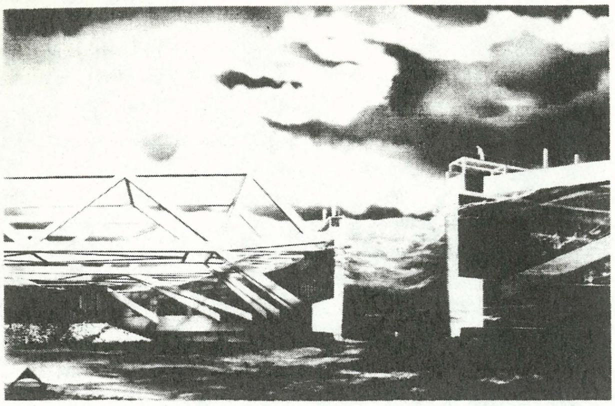

Figure 6.

- a short preparation period after the decision to close the barrier, resulting in a limited number of « unnecessary closures » ;
- little time for actually closing or opening the barrier ;
- optimum controllability of the barrier while closing irrespective of the velocities and the difference in water levels.

Another important principle was the reliability which could be judged by an extensive risk analysis program, which is illustrated by :

- the balance in the design, with partial solutions within the area of experience ;
- limiting the number of consecutive steps for closure ;
- the degree of susceptibility to damage ;
- the probability of the barrier malfunctioning as a result of a single component failure.

As stated in the conditions, the entire design is based on the durability of all components and a 100 year life expectancy.

During the development of the design process, economical considerations were constantly made in order to meet the functional standard while keeping costs at a minimum.

The concept chosen by NIWAS for the storm surge barrier is characterized by a single unambiguous movement which closes the doors. It basically consists of two water barrier walls shaped like cylindrical segments.

Each segment door is supported and held in position by a rotatable arm, which is in turn connected to its foundation with a hinged construction.

During closing and opening, the segment doors are driven along a sill, guided by rollers underneath.

The capacity of the door moving gear of the segment doors is based on closure in a relatively short period of time. Thereafter the gates in the doors can be closed very quickly.

Because of the cylindrical segment shape of the doors and the position of the hinge, which coincides with the vertical axis of the cylinder, all horizontal pressure due to the difference in the water level and water flow pressure will always pass through the hinges. As a result, the power required to open or close the segment doors is totally independent of the flow velocity and the difference in the water level, enabling to open and close the doors under any circumstances. This results in maximum controllability, which contributes significantly to the freedom of management of the barrier.

3. MAJOR COMPONENTS OF THE DESIGN

The wall and the rotatable arm are designed as a steel structure in which part of the wall has a floating capacity. The distribution of forces is clear, which is important in calculating both the static and dynamic reactions of the rotatable arm, which consists of a space frame structure composed of box sections.

Radius rotatable arm = 255 m

Theoretical length of the door = 217 m.

The segment door is pushed closed by a mobile power unit located on the quay walls. The closing operation is a single activity and can be executed quickly.

Four sets of guide rollers have been mounted under the segment doors to enable them to move along the sill.

To prevent upward movements due to hydraulic forces, a certain contact pressure between the guide rollers and the sill is ensured by using a preliminary load of water ballast.

The entire hinge structure is situated above the water level, and is designed with a division of functions in order to absorb the main loads in three directions :

- the pressure resulting from a positive difference in the water level is transferred to the foundation through a dish-shaped supporting structure ;
- the tensile force resulting from a negative difference in the water level is led to the foundation by a separate steel plate ;
- the vertical supporting force is independently transferred to the foundation through a conventional bridge support.

The sill is built directly on the subsoil. This is possible because the vertical forces on the sill are limited due to the floating capacity of the structure. But to prevent floating and loss of contact with the sill the vertical force of the doors can be controlled by using a well trimmed water ballasting system.

Moulded in the upper side of the prefabricated elements is a steel track profile for the guide roller wheels. The necessary smoothness of the sill is proportionate to the narrow space under the segment doors.

The sill elements are placed on a stone layer, which is placed on top of a sandproof filter. The space between the element and the stone layer is filled with grout, which is injected into the space for support and seals the space.

Sand and silt which builds up on the top of the sill is ploughed through by the horizontally driven segment door. To enhance this « ploughing », the front resistance is one of the factors determining the drive capacity.

Both segment doors are equipped with gates which are operated hydraulically.

These gates are required for the outlet and intake of surplus water. Depending on expected behavior of the storm surge and the discharge of the river the difference in the water level over the barrier can be optimized.

The moving gear that opens and closes the segment doors is situated in an electrically driven « locomotive » which moves along a geared track. The door and the locomotive are connected by a coupling rod. To absorb the horizontal reaction, the locomotive is equipped with horizontal guide wheels, which move along the back of the geared track. The calculated capacity of the moving gear is among others based on the combination of rolling friction, plough resistance of the door, which acts as a bulldozer, and wind pressure.

C. THE SLIDING DOOR BARRIERS

1. INTRODUCTION

During the 99,7 % of the non-active time the two 200 m long doors are placed in two docks, one on each side of the New Waterway. When the water level at sea exceeds a critical level, the steel doors are moved across the concrete sill at a speed of about 0.05 m/s. Gates in the doors are still open and minimize the forces on the moving doors. Only when the doors are fully closed, will these gates close as well. The 2000 m^2 flushing capacity provided by the gates, gives considerable flexibility in the operations.

The Sliding Door solution was proposed by the CHNW Consortium, comprising Heerema B.V., Hochtief A.G., Broekhoven B.V. and Ver. Bedrijven Vermeer N.V. with Frederic R. Harris B.V. as their technical advisor.

2. BASIC CONCEPT AND MAJOR COMPONENTS

The two doors each have a total length of 200 m, a width of 62 m and a height of 24.5 m. As shown on fig. 7 the cross-section is triangular, the seaward side forming the actual protection wall against storm surge.

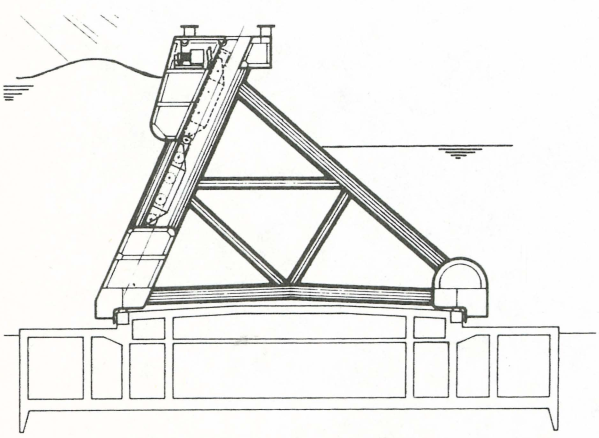

Figure 7.

The large diameter tubular frame, supporting this front face, provides full stability under maximum positive head of 6.95 m and maximum negative head of 2.5 m. Each door has 11 sliding gates in the front face, which will be open during closure and when the sea level falls below the river level at the end of a storm. The doors are moved across the sill, which extends into the two docks on both sides, either by sliding or by rolling. In the sliding alternative special provisions are made at the contact surface between doors and sill to minimize friction.

The docks and the two sill elements across the river between the docks are prefabricated reinforced concrete caissons, which will be built in graving docks, transported to the site in floating condition and sunk into position. Main dimensions of the docks are 220 x 55 x 33 m while the sill elements measure 180 x 44.5 x 10.7 m. All four elements are to be founded directly on the subsoil, which has a high bearing capacity.

Both for sliding and rolling doors the tracks in the dock can be adjusted, so as to match the corresponding tracks on the sill at all times, even if differential settlements occur. A double driving system for the doors has been designed to give sufficient redundancy in case the primary system would fail and to have double power available in case an obstruction on the sill would hamper normal closure. Moreover special provisions at the outward end of both doors are designed to remove any sand deposits and obstructions from the sill.

3. SPECIAL FEATURES

The design of the door, the sill and the bottom protection was guided by two-dimensional model test.

A steel and a concrete solution for the door were compared in the model. The tests showed the steel door to be superior in terms of flow stability and discharge coefficient during flow through the open gates.

In an early stage of design a risk analysis for the whole system was set up. This analysis helped to identify components with a high failure probability and to adjust them in such a way that the resulting design is well balanced in its primary failure modes. The risk analysis showed that the posed failure criterium of 10^{-6}/year was met.

The operational control for the barrier was developed in accordance with the functional and operational requirements set by the Government. In addition to that an Emergency Closing System was introduced, which closes the doors and the gates full automatically, in case the standard closure procedures would fail. A similar system had been successfully implemented at the Eastern Scheldt Storm Surge Barrier in the Netherlands.

RESUME

Une porte marée-tempête mobile dans le « Nieuwe Waterweg » aux Pays-Bas, sans obstacle à la navigation en provenance et à destination de Rotterdam.

Les normes concernant la protection des Pays-Bas contre les raz-de-marée ont été fixées dans la loi sur les travaux du Delta. Dans cette loi il a été décrété que les bras de mer les plus importants au Sud-Ouest des Pays-Bas doivent être fermés.

Pour des raisons de navigation seulement, les digues le long du « Nieuwe Waterweg » devaient être surélevées. Pendant l'exécution de ce programme à grande échelle, nous avons été confrontés avec des problèmes de plus en plus nombreux de surélévation des digues dans les régions urbaines comme Rotterdam et Dordrecht.

En 1987 le Ministre des Transports et des Travaux Publics a commandé une étude de faisabilité d'une porte marée-tempête.

Cette porte dans le « Nieuwe Waterweg », entre Maassluis et Hoek van Holland devait satisfaire aux conditions suivantes :

- une hauteur de passage illimitée,
- une largeur de 360 m et un seuil de profondeur de NAP - 17 m. La fréquence des fermetures sera d'une fois tous les 5 à 10 ans et les fermetures dureront à peu près 30 heures.

Parmi les nombreuses propositions présentées lors de la soumission-concours pour le contrat de « conception clef sur porte et construction », les deux idées suivantes ont été retenues :

- une porte marée-tempête comportant deux grandes vannes segment flottantes ;
- une porte marée-tempête comportant deux grandes vannes segment coulissantes.

Le choix définitif sera arrêté fin 1989.