Innovative Large Span Structures
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Concept, Design, Construction

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VOLUME 1

THE BIGGEST ONE-SPAN FLOATING GATE DESIGNED TO-DATE.

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SUMMARY

In the present paper, the IASS's members are informed about the biggest one-span movable floating gate projected to-date. The design and the computation of this tidal surge barrier concerns the barrier to be built in the entrance channel of Rotterdam Harbor.

The imposed conditions are the most constrained ones ever met in the design of a moving gate. The actual channel is about 600 m wide, and 17 m deep under the datum level (NAP). The constraints include the requirement of maintaining an opening of at least 360 m wide which should allow navigation without hindrance (Fig.1). Air clearance must remain unlimited.

Responding to an international tender, a Belgian-Dutch group (SVKR) proposed a new design. This design looks like a pivoting robot-pontoon and is submergible and easy to control either during immersion or during emersion. In brief, the main features are: 390 m span, 22 m height, 54 m width and 55000 tons weight. A main watertight box-girder allows floating with a draught limited to 3 m. Floats laid down to create a double catamaran effect lead to a very great general stability. A rotating center links the structure to the bank. At the top of the gate, there is a double deck acting as a float.

According to the design, when the gate is in the open position, it is parallel to the banks of the river. For emergency, it can be floated with a 3 m draught and a 19 m free board. When needed, the gate is rotated around its hinge point. Then the second stage begins: the controlled submersion. Sinking is carried out by a partial filling of ballasts put in the lower sections and side floats. After a storm has passed, the gate is set afloat again, using 4-bar compressed air, and moored at its original position.

The importance of the stiffening of this structure has required an appropriate software called L.B.R.-3. The mesh model used for the stress analysis is shown in Fig.8. Figs 10 to 14 show stresses, shear stresses, bending moments and displacements.

The complete stress analysis of such a complex structure can be carried out within 24 hr on a personal computer MAC II of 8MB capacity (mesh model, data correction, computing - 4hr CPU, printing and analysis of the results).

INTRODUCTION

The design of this 390m span gate concerns the construction of a floating storm-surge barrier, which could be built in the entrance channel of Rotterdam Harbor in the Netherlands (Dehousse et al, 1990). The design under consideration (Figs. 1 to 4) has been proposed by the SVKR Group (Combinatie Storm Vloedkering Nieuwe Waterweg) to respond to an international tender (Huis in't Veld et al, 1990). Such a floating barrier is also envisaged in the future to protect the Antwerp estuary in Belgium.

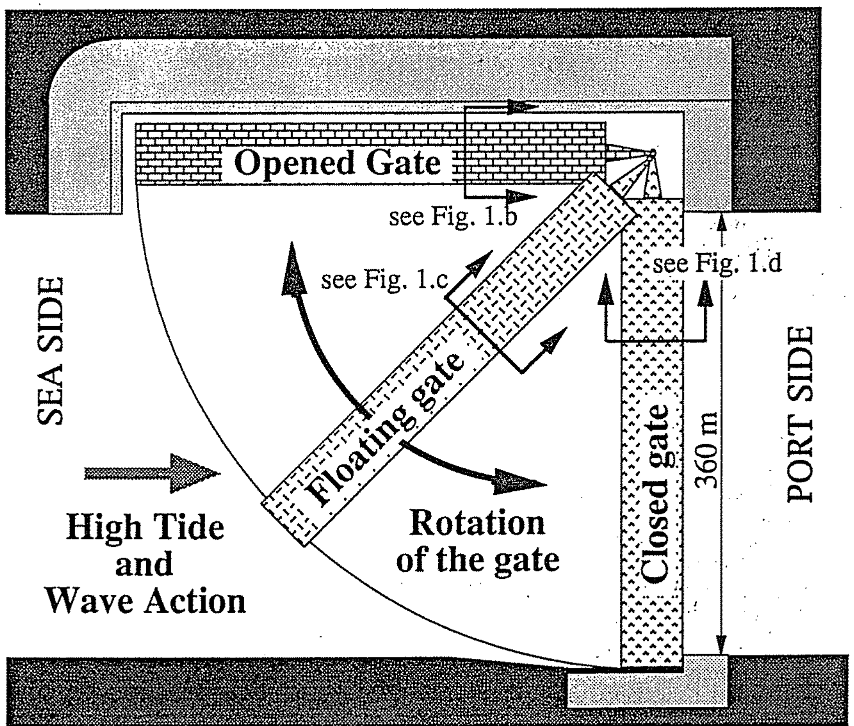

Fig.1 : The floating storm surge barrier designed for the port of Rotterdam.

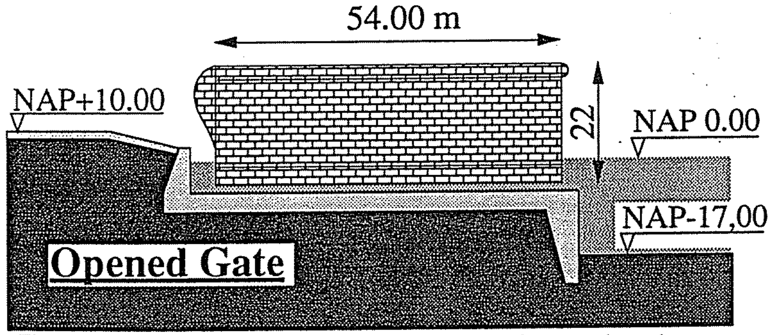

Fig.2 : Opened Position : The gate is along the bank and rests on its end supports.

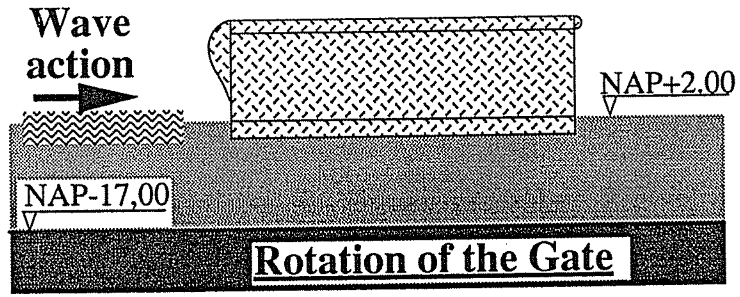

Fig.3 : Rotation of the Gate : The gate floats with a 3 m draft and rotates under the control of propellers and cables.

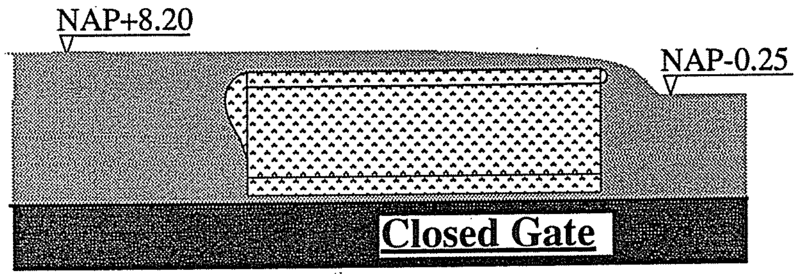

Fig.4 : Closed Position : The gate is sunk until the -6m level by filling of ballasts.

In Rotterdam, the constraints require to keep at least a **360 m opening** (Fig.1). That width should remain available for navigation without any hinder.

- The **highest water levels** to consider are shown in Fig.4.
- **The currents in the channel** can reach values up to 2 - 2.50 m/s in both directions and are caused by the tide or the added discharge of waters coming from the Rhine and Meuse rivers.
- **Winds** speeding up to 35 m/s in the axis line of the channel are to be considered.
- **Wave Action** can be summarized as follows; two major actions are considered:
    - 1.80 m amplitude and 4 s period
    - 0.60 m amplitude and 8 s period.
- **Air Clearance** must remain unlimited. Closure working must be possible when the level reaches NAP + 2, to prevent the storm tide entering the harbor.

Those conditions are, as showed, extremely severe and the most constrained ones ever met to-date by hydraulic engineers.

DESCRIPTION OF THE FLOATING STORM SURGE BARRIER

The barrier under consideration looks like a pivoting robot-pontoon (Figs. 1 and 5). It is submergible (Fig. 4) and easy to control during either immersion or emersion with the four floats at the four corners of the gate (Fig.5).

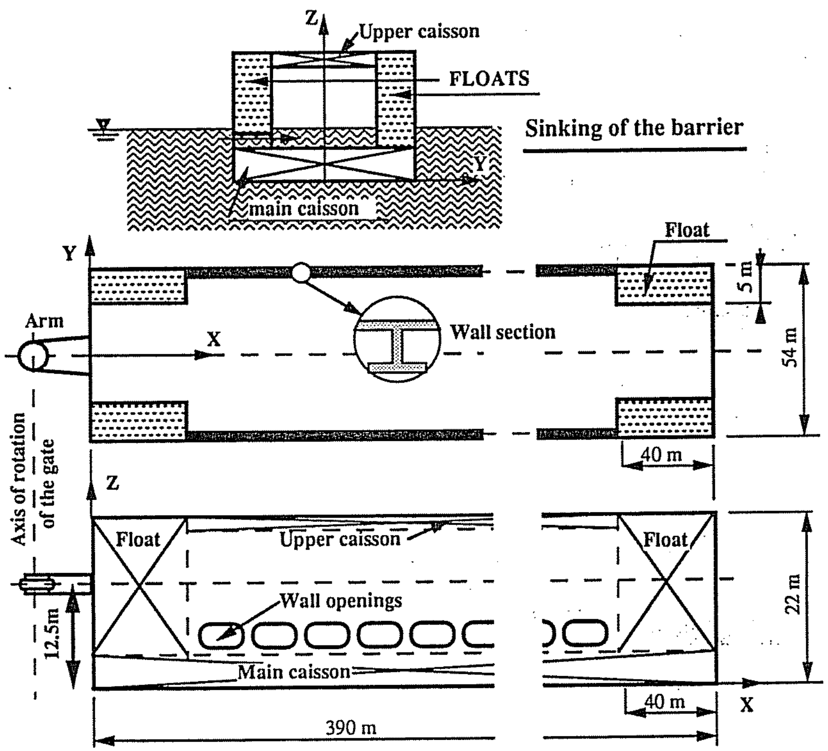

Fig.5 : Details of the floating barrier (cross section, plan view and front view).

We can sum up its main features, as follows (Figs. 5, 6, 7a and 7b)

- **A main watertight box-girder** allows floating with a draught limited to 3 m when the gate is not in use and during the set up period (Fig.7a&b - point 2).
- **Walls, stiffeners, frames** allow to bear, when closed, the most important water level differences (Fig.6).
- Four **floats** laid down to create a double catamaran effect (transverse and longitudinal) when floating, lead to a very great general stability (Fig.7a&b - points 8 and 9).
- **A rotating center** links the structure to the bank, while it allows 6 freedom degrees (3 rotations and 3 displacements). This rotation center is on one end at the metacenter level of the floating structure (Fig.5).
- There are large **openings** in the both lateral sides (Fig.7a&b - point 5). On the upstream side, regulating valves located near the floating line control these openings.
  The function of it is double:
  - when the barrier is sunk, they allow a regulation of the discharge and a control of the upstream water level,
  - they allow to reduce the effect of pressures caused by exceptional waves.
- **A streamlining** fitted to reduce the effect of wind, and thus reducing friction forces when moving (Fig.7a&b - point 11).
- At the ends, a **double row of king-sized tyres fastened** to the gate. Their role is double: on one hand they act as shock absorber during the closure operation, on the other hand they allow rolling on the vertical end supports (Fig.7a&b - point 15).
- **A double row of *Teflon*© skids** fastened to the gate allow a vertical movement, even when the pressure is of paramount importance (Fig.7a&b - point 16).

- **A series of valves** controlling box-girders and floats (Fig.7a&b - point 5).
- **A group of two propellers** controls the rotating movement of the gate. They act in two directions and can be retracted (Fig.7a&b - point 14).
- **A group of *Kevlar*© cables** has the same goal as the propellers but they bring an added safety to maneuver.
- **A service chamber** to house the controlling devices of the propellers and these used for filling and emptying the ballasts and the lateral floats (Fig.7a&b - point 10).
- At the top the gate is fitted with a **double deck** acting as a float. Its aim is to reduce stresses and deformations due to bending in the vertical plane when exceptional loads occur (Fig.7a&b - points 12 and 13).
- An optional layout was foreseen but not drawed. It is **two bilge keels** as may be seen on ships.

The floating gate does not look like a ship because there is no end wall (neither stern nor bow). Comparison looks better with a **floating dry dock.**

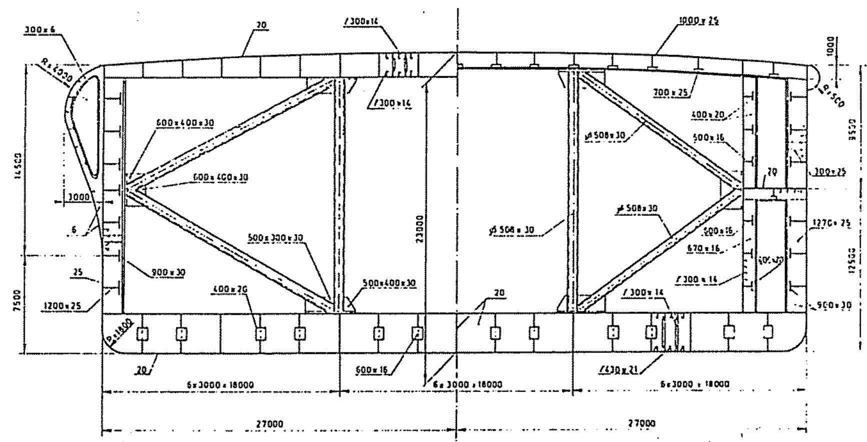

Fig.6 : Cross-sections at mid span and at the ends.

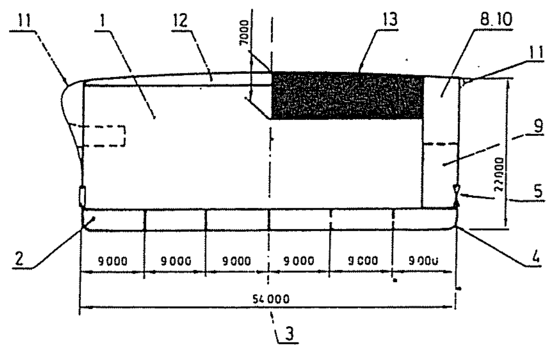

Fig.7.a : Cross-section A-A at mid span (left side) and End view from N -see Fig.7.b (right side).

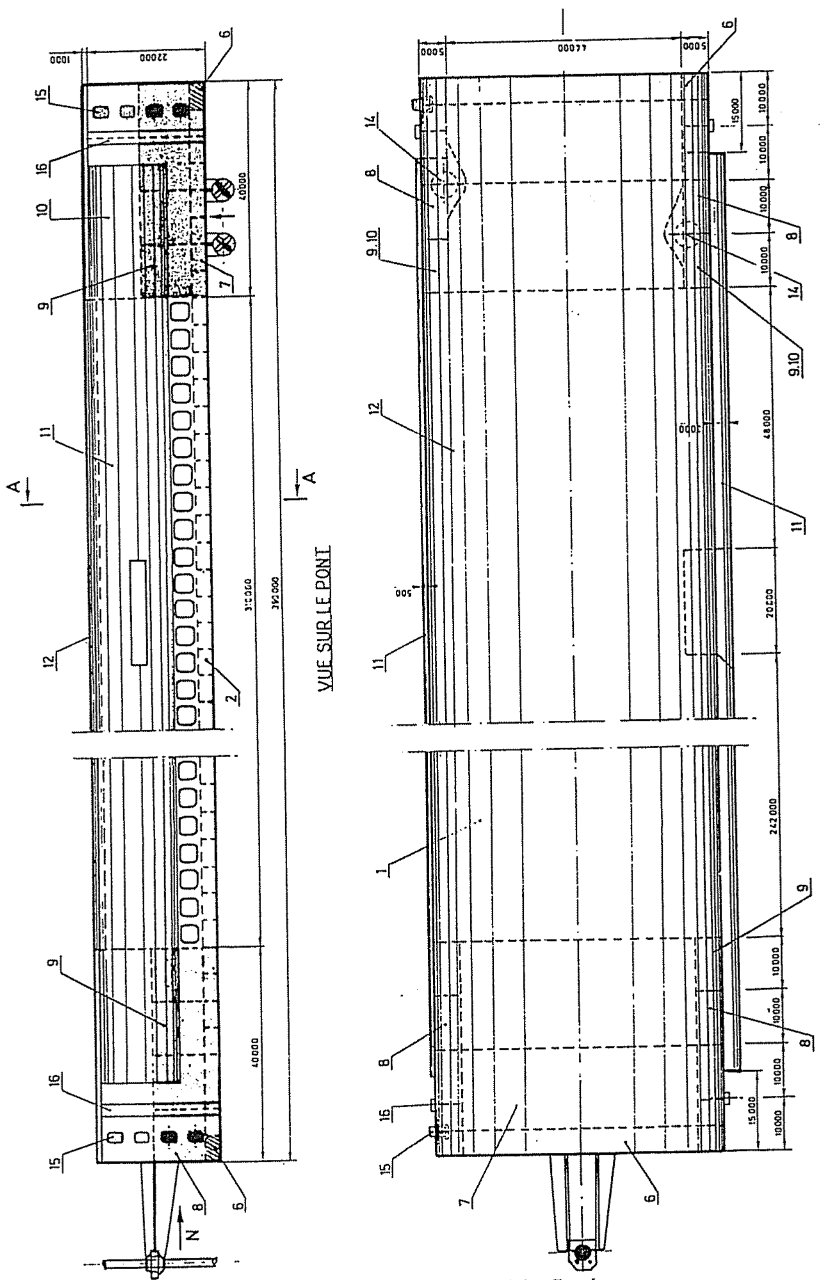

Fig. 7.b : Plan view and front view of the floating gate.

CLOSING OPERATIONS OF THE BARRIER

Designed that way, the gate may find itself in **open position**, parallel to the banks of the Nieuwe Waterweg permanently allowing a 360 m clearance between the piers. It is then sunk at the level - 4 m resting on its end supports and is accordingly ballasted (about 2400 water tons). In this position it is naturally protected against any hurt with ships sailing in the Nieuwe Waterweg (Fig.2).

For **emergency**, it is set up floating with a 3 m draught and a 19 m height in the open air (Fig.3). The total height is thus 22 m, the width is 54 m, and the length is 390 m (360 m + 2 x 15 m for the supports). In this stage all the transverse valves are opened; the cross section of the sluiceways is 700 m^2. When needed, through the propellers and under control of cables, the gate rotates around its hinge point. The rotation has been computed so that it lasts for 20 minutes and ends with a controlled contact of the floating structure on the absorbing tyres.
Owing to wave action, roll motion will occur during the rotation (Rigo, 1992). This movement will be maximum when the gate axis and the wave direction are perpendicular. The maximum roll angle (ϕ_{max}) is the most important characteristic in the design of the rotating center and the rigid arm connecting the gate to this center.

Then the second stage begins: **the controlled submersion**. Sinking is carried out in a time that can be controlled and for which a period of 40 minutes has been proposed. It is done by a partial filling of ballasts put in the lower sections and of side floats. To do this, a control is maintained on the upstream and downstream level and on the regulating valves of the ballasts and side floats to keep the desired sinking time. An upper ballast and an air-chamber (Fig.7a&b - points 12 and 13) brake the sinking movement to ensure a soft contact. During these operations, all the openings crossing the gate remain opened. At the beginning of the sinking process and eventually during the second stage, the gate rolls on the tires. When the pressure, coming from the difference of hydrostatic load acting on the gate becomes too high, the tyres are compressed at their maximum loading capacity (20 cm) and the structure rests on the *Teflon*© skids. These ones are mounted on reinforced *Neopren*© to allow an angular horizontal displacement of each support when the gate will be loaded in the horizontal plane. The skids are designed so that they can be easily replaced. The sliding surfaces on the supporting abutments are in stainless steel.

The gate sinks thus until the level - 16 m, keeping 1 m clearance above the floor. Then it is supported on the abutments facing Rotterdam, up to the level +20 m (Fig.4).

The third and last stage can then begin. That is the **closing of the valves**. Here too, closure is controlled according to the levels. They are butterfly valves with horizontal axis and streamlined movable part. The closure of the flow through the gate is thus achieved.

In case the level on sea side is lower than on Rotterdam side, the gate rests on its vertical downstream side supports up to level - 4 m after a slight displacement toward the sea side. At that moment, a small lateral leakage will occur.

Finally, **after the storm, the gate is set afloat again**, through 4-bar compressed air within about 30 minutes. Then the level difference quickly disappears and under control of propellers and cables, the gate returns to its original position. In case an ebb current should remain, the gate would tend to close by itself, though the draught has been reduced to 3 m. A hydraulic braking will act when the gate enters its chamber, but if necessary long-travel hydraulic jacks can be installed.

STRESS ANALYSIS

In 1989, for the 30 years of IASS the Stiffened Sheathings Method was presented in Madrid (Dehousse and Rigo, 1989). This method derived from the D.K.J. method of cylindrical shells allows to compute easily and accurately structures composed by many stiffened cylindrical shells. Based on this method, the so-called L.B.R.-3 software was established (Rigo, 1989). In Madrid, theoretical equations were recalled as designs which have already been carried out: lock gates, canal-bridges, storm surge barriers, mobile weirs, etc. It was still said that main advantages of this method are ease, quickness, simplicity, reliability and ease. Recently, new improvements have been added and designs related to a new application field (naval architecture and floating structures) have been carried out.

Fig.8 shows the mesh model used for the stress analysis (Rigo, 1989). It needs 30 elements, 24 are stiffened panels (stiffeners, stringers and frames) and the remaining 6 elements (n°17 to n°22) represent the pillars. The importance of the stiffening of this structure proves the advantages of L.B.R.-3 software very well. For example, consider panel n°3 (Figs. 6 and 8). Its main characteristics are: a total dimension of 9.5 m x 390 m = 2000 m^2, 3 cross-bars of 390 m long, 79 transversal stiffeners of 7.9 m long and a total of 5850 m of longitudinal stiffeners. These elements require only 14 data lines to use L.B.R.-3 software (see data list below). Thus, it can be easily understood how attractive L.B.R.-3 is to the designer.

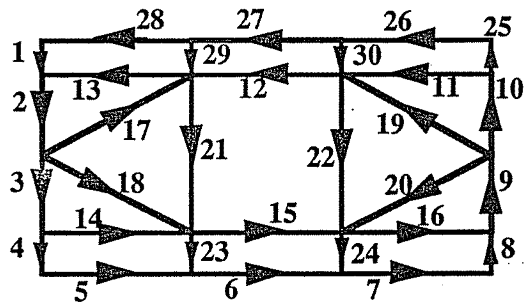

Fig. 8: Mesh model used for the stress analysis.

__Data Required to Model the Barrier using the L.B.R.-3 Software.__

Storm Surge Barrier	title
0 -2 0 0	parameters to select the required results ;
1	JLPH= number of terms of the Fourier series expansion ;
30	NETO= number of panels used in the mesh model ;
2.1E+11 0.3	E= modulus of elasticity and ETA=Poisson coef. ;
375.	L= span of the prismatic structure - ox axis ;
1	dead load or gravity load : 1 yes, 0 no ;
PLATE 1	Element n° 1 : PLATE or SHELL ;
3.5	H= length of the element - transversely - oy axis ;
90.	ANG= angle between the horizontal line and the element,
5. 0.5 0.025	E1 and E2= frame and stiffener spacings, D=thickness ;
1.27 0.025 0.9 0.03	flange and web dimensions of the frames equally spaced ;
0.38 0.021 0.081 0.05	flange and web dimensions of the stiffeners equally spaced ;
1	MT =number of unequally spaced longitudinal stringers -ox axis ;
1.20 0.025 0.9 0.03 1.75	flange and web dimensions of the stringer n°1, position from y=0 ;
1 1 1 0 0 1	element side where stif. , loads, etc. are located ; load parameters ;
0.0 0.0	XI, XF = Load at the both ends, y=0 and y=H -uniform along ox ;
0	loads varying along the ox axis :1 yes, 0 no ;
2 0 0 0 0 0 0 0 0 0	other elements connected to the element n°1 at its end y=H ;
PLATE 2	Element n° 2 : PLATE or SHELL ;
etc.	
PLATE 3	Element n° 3 is a stiffened plate,
9.5	H=9.5m,
90.	ANG= 90° , it is a vertical panel pointing down
5. 0.5 0.025	Frame spacing =5m, stiffener spacings =0.5m, D=0.025m
1.27 0.025 0.9 0.03	Flange : 1.27x0.025m , Web : 0.9x0.03m : frame equally spaced
0.38 0.021 0.081 0.05	Flange : 1.27x0.025m , Web : 0.9x0.03m : stif. equally spaced ;
3	There are 3 longitudinal stringers ;
1.20 0.025 0.9 0.03 2.5	Flange : 1.20x0.025m , Web : 0.9x0.03m located at y=2.5m ;
1.20 0.025 0.9 0.03 5.00	Flange : 1.20x0.025m , Web : 0.9x0.03m located at y=2.5m ;
1.20 0.025 0.9 0.03 7.5	Flange : 1.20x0.025m , Web : 0.9x0.03m located at y=2.5m ;
1 1 1 1 0 1	Stiffeners, load, etc. are located on the negative side z<0 ;
7.00 7.00	Load varying from 7t/m^2 in y=0 to 7t/m^2 in y=H=9.5m ;
0	There is no load varying along the ox axis ;
4 14 0 0 0 0 0 0 0 0	Elements n° 4 and n°14 follow the element n°3 (see Fig.8);
etc.	

Owing to its huge dimensions and its equipment the proposed barrier is submitted to normal stresses. In particular, thanks to its box-girder structure, the structure got a paramount torque rigidity.

Figs. 9 to 15 show respectively: the hydrostatic pressure diagram, the longitudinal displacement at the ends, the longitudinal bending moments at mid-span, the transversal bending moments at mid-span, the transversal stresses in the platings at mid-span, the shear stresses in the platings at the ends and the diagram of the von-Mises combined stresses at mid-span.

The complete stress analysis of such a complex structure can be carried out within 24 hours on a personal computer MAC II of 8MB capacity (mesh model, data correction, computing - 4h CPU, printing and analysis of the results).

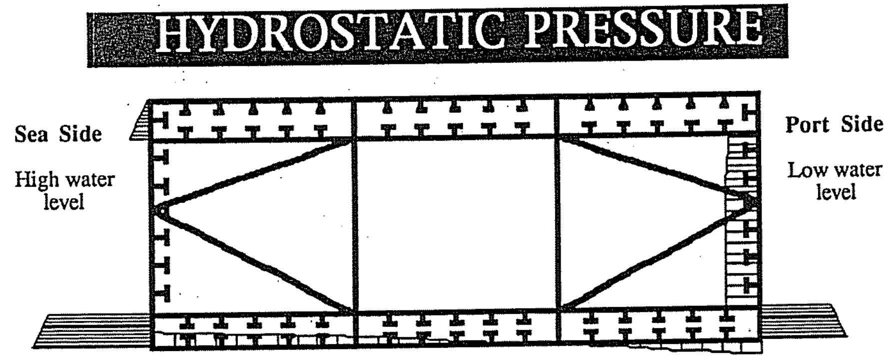

Fig.9.: The hydrostatic pressure.

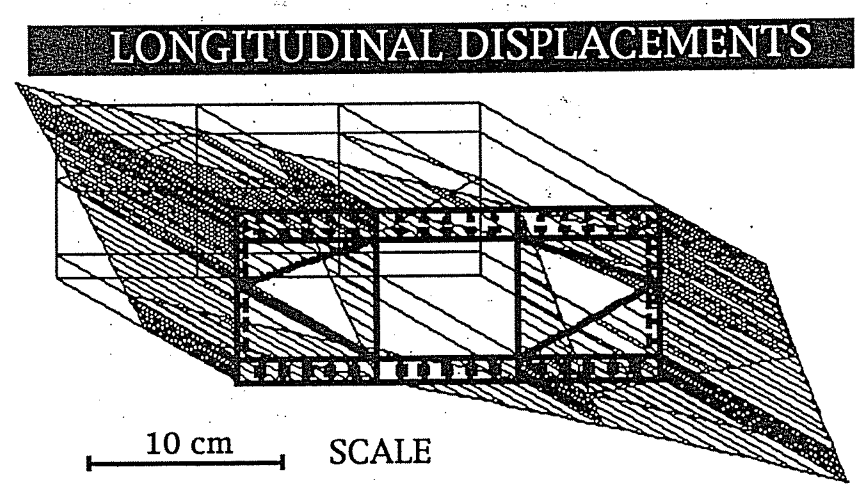

Fig.10 : The longitudinal displacement at the ends.

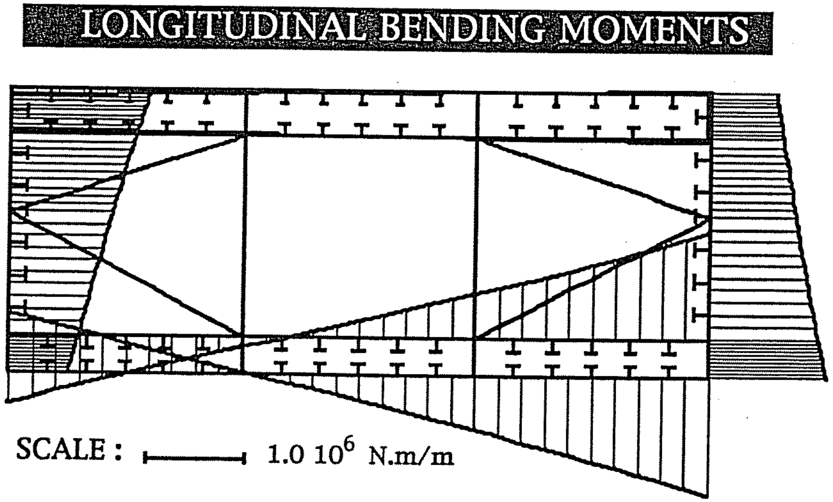

Fig.11: The longitudinal bending moments M_x at mid-span.

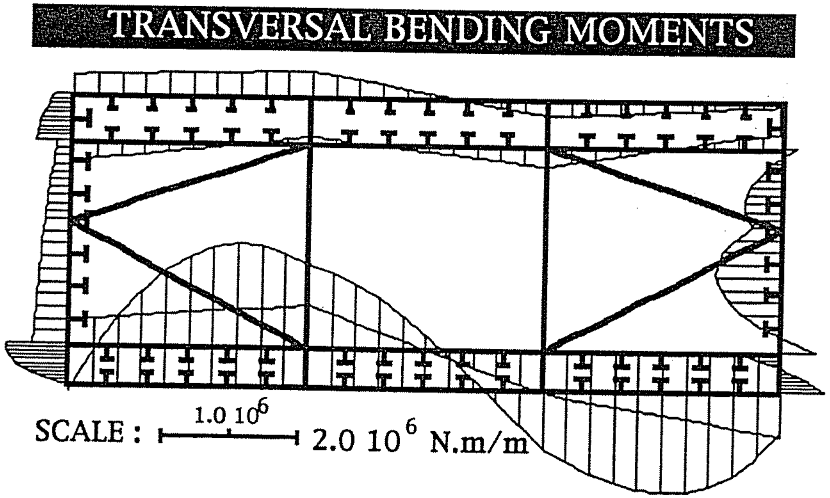

Fig.12 : The transversal bending moments M_φ at mid-span.

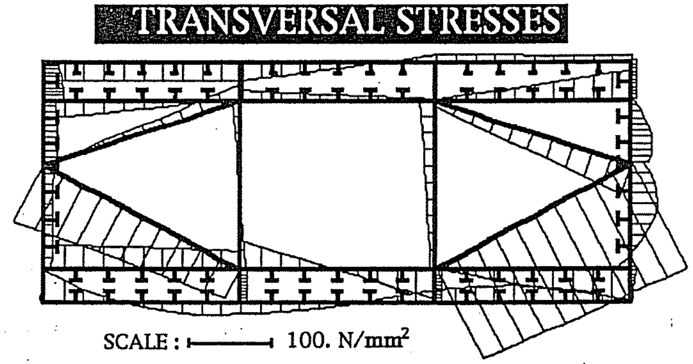

Fig.13 : The transversal stresses σ_φ in the platings at mid-span,.

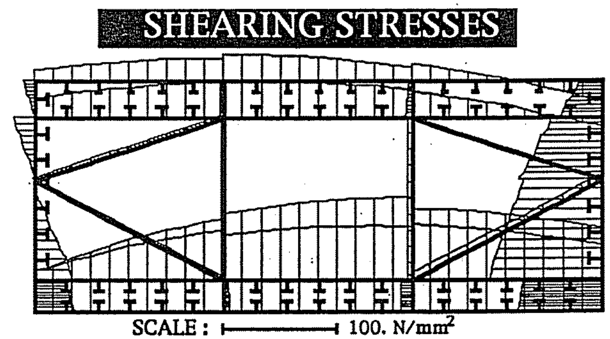

Fig.14 : The shearing stresses $\tau_{x\varphi}$ in the platings at the ends.

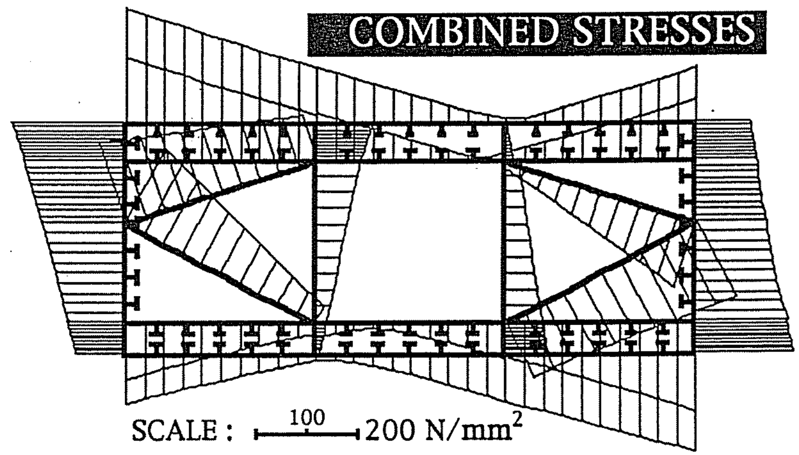

Fig.15 Diagram of the von-Mises combined of stresses at mid-span.

CONCLUSIONS

To sum up, the proposed barrier is:

- **very little sensitive to current effects** during the closing and opening stages, thanks to its small draught (3 m) in a deep area (17 m),
- **very little sensitive to wave action,** thanks to its large width (54 m).
- able to **allow a great discharge through itself** thanks to a 700 m^2 controlled opening (valves)
- **not sensitive to floor defaults** since it does not contact the bottom.
- **apt to enable an under-vacuum floor achievement** allowing to escape to fixed cofferdams during its construction;
- **easy to build,** since it only has standard parts of structure.
- **easy to repair,** since a large part of the structure (19/22) remains above the water level in normal time and the bottom can be repaired through tilting of the gate in its chamber.
- **apt to be easily and quickly saved,** if necessary, since the structure is a floating one and is near the towing harbor of Hoek van Holland.
- **submitted to normal stresses** thanks to its huge dimensions and its equipment (loads controlled by a serious ballasting system at each end, upper ballasting tank to face exceptional tides, and an air-chamber installed at the top of the gate). Particularly, thanks to its box-girder structure it get a paramount torque rigidity which helps the structure to keep **almost insensitive to floor settlements.**
- **fitted classically like a ship** and its rotation movement is the same as the one of a ship rotating around its anchor.

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