33 The Use of Floating Gates for Storm Surge Barriers

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INTRODUCTION

In the event of a "high tide" storm, harbour facilities as well as efficient ship loading and unloading can be maintained by closing a barrier. Nevertheless, the main reason for building such structures is the reduction of flooding risks in the estuary. With regards to tidal rivers, tide effects govery often tens of kilometers upstream from the coast. Thus, the flooding could reach a very large region and affect thousands of people. The storm surge barrier is probably the easiest way to preserve environment without having to raise natural beaches, banks and dunes by artificial dykes, sea walls and embankments.

The design of such devices is now recognized as an efficient protection technology and is used throughout the world, in Europe and more particularly in the North Sea. Examples are the Thames Barrier in London, the Hull lifting gate (G-B), the moveable weirs on the Elbe (Germany) and the large Oosterschelde barrier in the Netherlands. Today, there are still some new projects aiming at protecting cities such as Rotterdam, Antwerp and Venice. Such protection devices are often used in Japan, where typhoons or tsunamis combined with hide tides have flooded several cities during the last century (Osaka, Tokyo, Nagoya). Osaka Bay with its numerous ports and river mouths, has many hide tide gates such as in Tokyo area.

For many years, our laboratory has promoted a new system of storm surge barriers. It is a floating barrier with a main floating box-girder and four small lateral floats creating a double catamaran effect. Taking into account the environment protection and specially the preservation of the estuaries' natural aspect, floating barriers give the designer new possibilities. For instance, in Antwerp a complete structure composed of two 100m long floating barriers, one on each side of the river, has been proposed. The central part is composed of several traditional movable barrages, allowing the water flow. After rotating at minimum draft, the floating barriers can be ballasted in closed position in order to protect the city and the harbour.

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FLOATING AND ROTATING STORM SURGE BARRIER

Thanks to our experience of the design of floating gates for large maritime locks (40 to 70m width and 15 to 20m depth) we developed of a new concept of floating storm surge barrier [1,2,3,4]. Floating lock gates were studied for the lock of Zeebrugge in the early 70s. In 1975, investigations started on the design of self-propelled floating gates for the Storm Surge Barrier of Antwerp. This barrier was included in the Sigma Plan which has been worked out after the 1953 and 1976 hide tides from which floods occurred. The Sigma Plan (1977) was divided into 3 phases and the third phase was the construction of a storm surge barrier.

The aim of the Sigma Plan was to reduce the flooding risk to a probability of 1/10000. Completion was planned for 10 years later. The main protection device was a storm surge barrier in the Oosterweel. The Antwerp barrier had to keep two channels for the navigation at least 60m wide and 9.7m deep. In 1980, the selected design (Fig. 1.a) was composed of 3 lift gates with a 80m span and 6 radial gates with a 35m span. As the requirements meant an unlimited air clearance, the projected gates had to be lifted 80m above the river water level with the help of four towers of 125m. The high cost, the huge head rooms including lifting powers, and the negative effect on the environment, specially related to the site aestheticism, have probably caused the project to be abandoned.

From the first step of this project, another design has been suggested which provides lower cost and higher aestheticism. This design (Fig. 1.b) is composed of two 100m span floating gates, one on each side, allowing navigation in the two directions. The closing process starts with the rotation of the gates which are floating with a minimum draft. Thereafter they are ballasted to completely close the two 100m wide navigation channels. The central part is composed of usual moveable weirs which control discharge and water levels after the closure of the two main floating gates.

The advantages of a such floating gate are as follow:

- *excellent integration* in the landscape,
- *no expensive* sea bed improvements are required and the gate is not sensitive to floor defaults, erosion or settlements as the gate will never stay on the foundation,
- *no continuous submerged mechanical elements* like rail, carriage, large hinge and socket joint, etc.,
- *very little sensitivity to current effects* during the closing and opening stages, thanks to its small draft in a relatively deep area [2],
- *very little sensitivity to wave action*, thanks to its large width [5],
- *sustainable structure as it can easily be controlled, maintained and repaired*, since the gate is floating and has no mechanical system under water,
- *easily and quickly manoeuvred* as experimentally demonstrated on a large scale model [5,6,7],
- *reliable structure* since the design of the structure is not sophisticated, the construction process is standardized and the gate structure looks like an usual floating dock,
- *can easily be completely prefabricated* since the gate can float and it consists of standard parts of structure,
- submitted to *normal stresses*, despite its huge dimensions. Thanks to its box-girder structure it gets a paramount torque rigidity which helps to keep it almost insensitive to floor settlements,
- ...

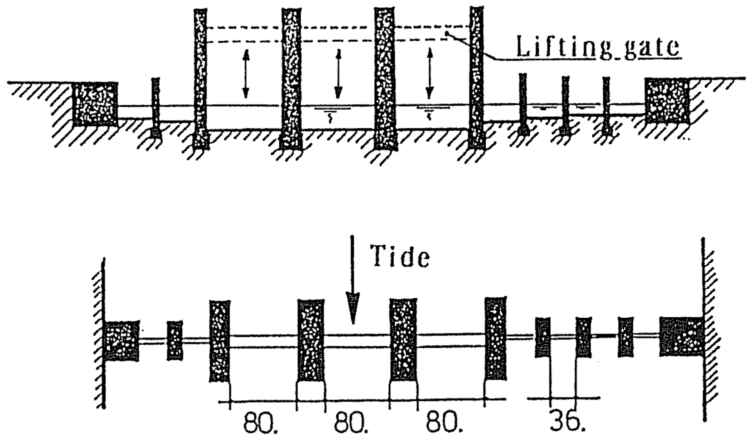


Figure 1a Antwerp lifting gates project

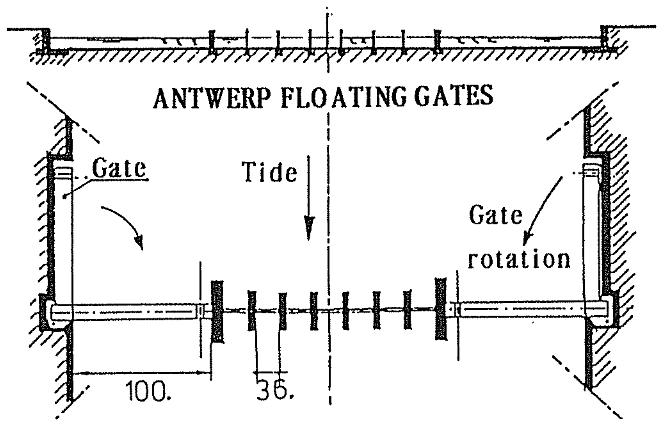


Figure 1b Antwerp floating gates project.

A 390m Span Floating Barrier

With Rotterdam's storm surge barrier project resulting in the closing of the New Waterway, the Dutch authorities have started a protection project for their last unprotected estuary. The foreseen construction is, after completion of the Oosterschelde Dam, the last link of the dutch shore shielding against the exceptional tides (Delta Plan established in 1957). The conditions that were imposed are the most demanding ones ever met in the design of a moving gate. The Nieuwe Waterweg is indeed the busiest maritime channel in the world, since at least 60,000 ships pass through it every year. The actual channel is about 600 m wide, and 17 m deep (low tide) under the datum level. The constraints require to keep at least a 360 m opening and that width should remain available for navigation without any hinder.

Several construction consortiums submitted their designs to these authorities [3]. With regards to the marine environment, it is interesting to show one innovative design which is cost effective and reliable (Fig. 2.a to Fig 2.d). The proposed solution remarkably protects the site aestheticism and avoids any costly bed improvement and expensive mechanical systems. The main ideas that led to the solution set up by the SVKR Group (Combinatie

Storm VloedKering Nieuwe Waterweg) are :

- The requirement to keep an *unlimited air clearance* excludes any possibility to design any portal. A solution like the one suggested for Antwerp on Fig. 1.a. must be discarded.
- The condition of navigation are such that it is highly commendable not *to reduce the 360m navigation channel* by temporary fixed structures (cofferdams), even during short periods.
- The very low operation frequency, even for maintenance, leads to a *solution that requires no support on the bed* to avoid any problem due to silting.
- For sake of perennial working, hydraulic constructions must have *a limited number of mechanical devices under water*, so any solution of a tilting type, or with unattainable hinge must be discarded.
- Lateral wave action and our own expertise in matter of large maritime sea lock gates with lateral movement, led us *to discard any system progressively closing the navigable channel by transverse movement.*
- Due to the current and wave constraints, it is well known that a structure rigidly linked to banks or bottom develops stresses more than a movable structure with a great number of degrees of freedom and more flexibility under the action of external loads.

To summarize, we can say that the main elements, features and devices included in the floating gate are the following (Figures 2 and 3):

- A *main watertight box-girder* allows floating with a minimum draught when not in use and during the set up period.
- Walls, stiffeners, frames allow to bear, when closed, the most important level differences.
- Floats laid down to create a *double catamaran effect* (transverse and longitudinal) when floating, lead to a very great general stability.
- A "*Gate Articulation System*" composed of "Guide-columns" and a "Spring-cable". This uniformly extended spring-cable allows to keep continuously the gate in close contact with the columns acting like a guide.
- *Side wall openings* are controlled by regulating valves located at the lower part of the barrier near the floating line. Their function is double :
  - when the gate is floating they reduce the impact of exceptional waves,
  - when the barrier is in the closed position they allow a control of the discharge and of the upstream and downstream level.
- A *lateral and upper streamlining* fitted to reduce the wind effect and thus the friction forces when moving.
- A *double row of king-sized tyres* fastened to the gate and located at its ends. 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.
- A *double row of Teflon skids* fastened to the gate allows a vertical movement, even when the pressure is of paramount importance.
- A *series of valves* (compressed air) to control the ballasting of the box-girders and floats.
- A group of two *propellers* controls the rotating movement of the gate.
- A group of *Kevlar cables* in case of emergency (if propellers fail).
- A *service chamber* to fit out the controlling devices of the propellers and the ballasting

facilities.

- At the top the gate, *a double deck*is fitted acting as a float and aimed to reduce stresses and deformations due to bending in the vertical plane when exceptional loads occur.
- Designed that way the barrier looks better like a floating dry dock than a ship.
- An optional layout consists of two bilge keels to reduce the roll motion (see Fig. 4).

Since 1988, several experiences were achieved to show the reliability of this new system of barrier. Manoeuvrability and feasibility tests were performed including gate rotation, tanks ballasting, wave and current actions, and control of natural heave and roll motions (Fig. 4). Experimental tests have demonstrated the reliability of the "Gate Articulation System" composed of "Guide-columns" and a "Spring-cable". This uniformly extended spring-cable (force = constant) allows to continuously keep the gate in close contact with at least one guide-column without inducing any limitations on the gate motions (roll, pitch and heave). After the rotation phase the cable extension is released.

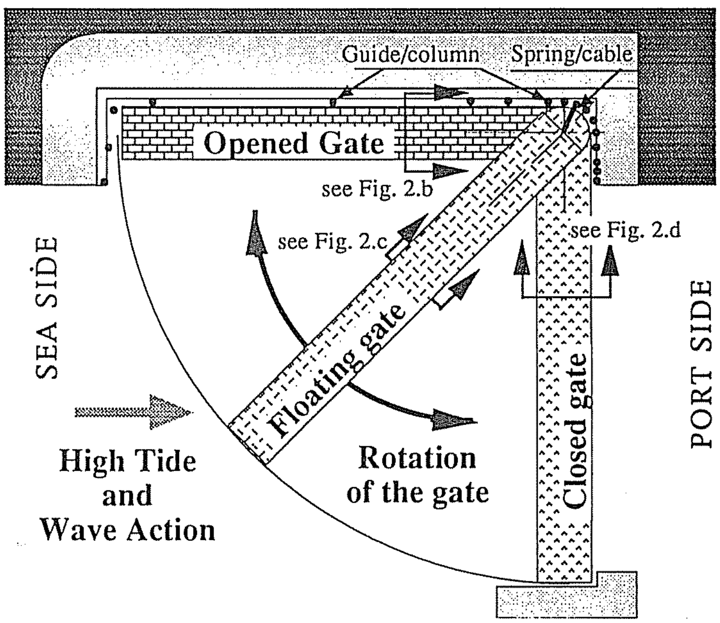


Figure 2.a Principle of the proposed floating storm surge barrier.

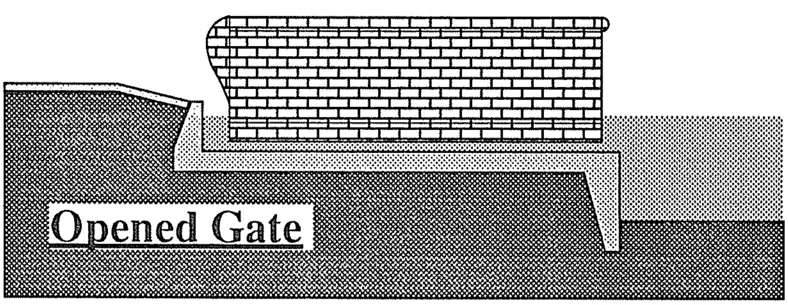


Figure 2.b Open Position :
The gate is along the river bank and rests on its end supports.

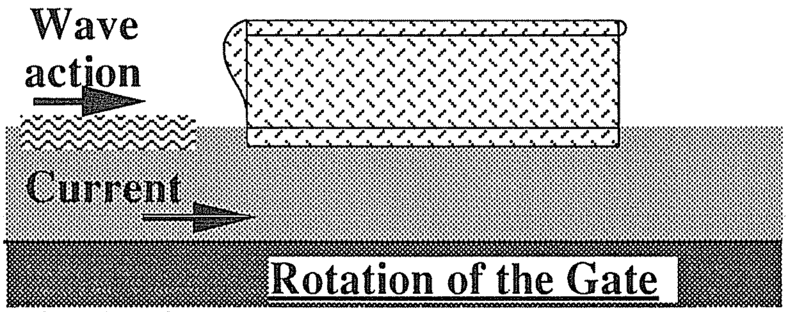


Figure 2.c Rotation of the Gate :
The gate is along the river bank and rests on its end supports.

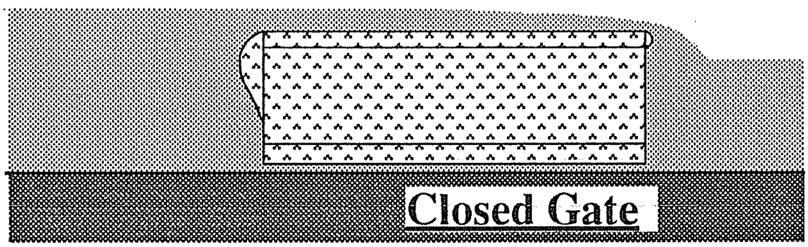


Figure 2.d Closed Position : The gate is sunk by filling the ballasts.

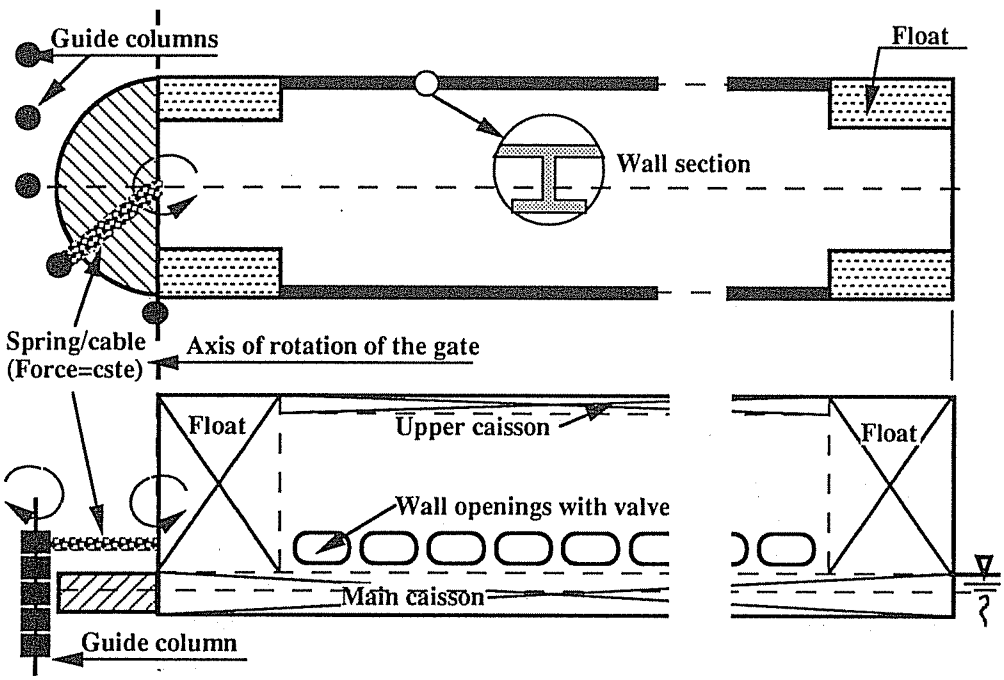


Figure 3.a Details of the floating barrier (cross section, plan view and front view).

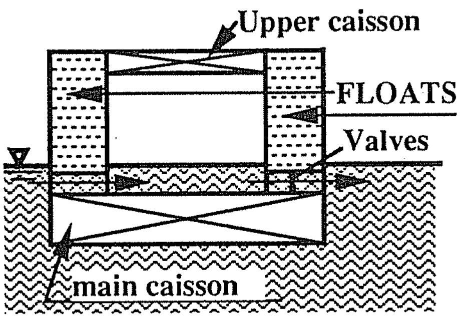


Figure 3.b Ballasts of the barrier

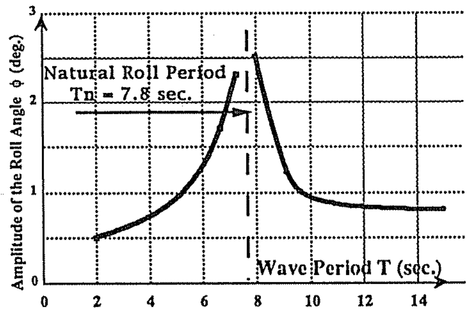


Figure 4 The measured natural roll motion.

In its *open position*, the barrier is parallel to the banks and permanently allows a 360 m clearance between the piers. In this position the ballasted gates rests at the level - 4 m on its end supports and is naturally protected against any hurt with ships sailing in the Nieuwe Waterweg. *In case of emergency*, floating is set up with a 3 m draught and a 19 m height in the open air. The overall 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). At 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 "articulation". The rotation has been computed so that it lasts 20 minutes and ends with a controlled contact of the floating structure on the absorbing tyres. Fig. 5 shows the computed roll motion during the rotation process [5].

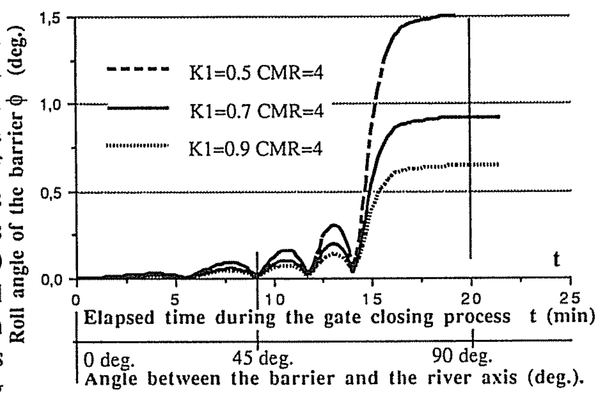


Figure 5 Roll angle during the rotation of the gate.

Then the second stage begins : *the controlled immersion* [7]. Immersion is carried out in a time that can be controlled and for which a 40 min. period has been proposed. It is done by a partial filling of ballasts. To achieve this, a control is maintained on the pressure of the compressed air in the ballasts and the side floats. An upper ballast and an air-chamber brake the vertical motion to ensure a soft contact. During these operations, all the openings crossing the gate remain opened. At the beginning of the immersion process and during the second stage, the gate rolls on the tires. When the pressure which comes from the difference of hydrostatic load acting on the gate, becomes too high, the tyres are compressed (deflection=20 cm) and the structure rests on the Teflon skids. These ones are mounted on reinforced Neopren in order to keep an uniform contact even during the rotation of the both ends of the gate which are induced by the horizontal bending moment. The skids are designed so that they can be easily replaced. The sliding surfaces on the supporting abutments are in stainless steel. Finally, the gate is lowered until the level - 16 m, keeping 1 m clearance above the floor. Then it is supported on the abutments facing the port side.

The third and last stage can begin : that is *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 vertical supports up to level - 4 m after a slight displacement towards 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 the gate returns to its original position under control of propellers and cables. In case an ebb current should remain, the gate would tend to close by itself, though the draught be reduced to 3 m. A hydraulic braking will act as soon as the gate enters its chamber.

The Structure of the Floating Barrier.

The scantling was based on the Bureau Veritas Ship Rules [9]. Even at the preliminary stage and for the design itself, the strength analysis of the structure was carried out with the L.B.R.-4 stiffened sheathing software. This method is one of harmonic analysis and is founded on the Fourier series expansions. It is based on analytical solution of the governing differential equations for orthotropic cylindrical shells [4]. The main L.B.R.-4 software qualities are ease in the discretization process and simplicity.

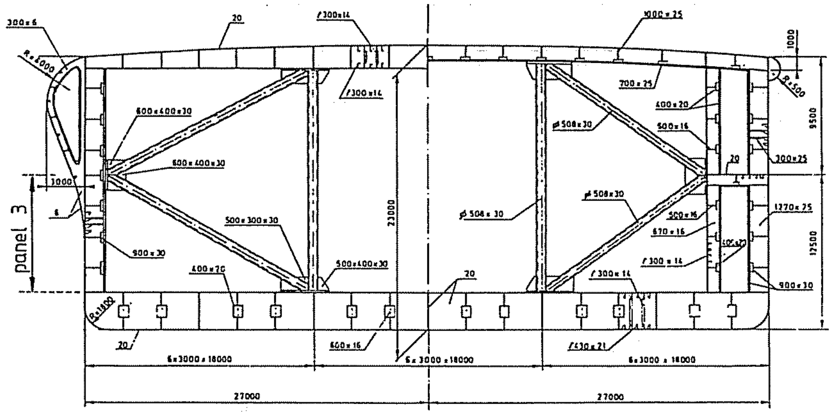
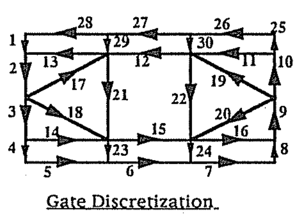


Figure 6 Cross section of floating barrier



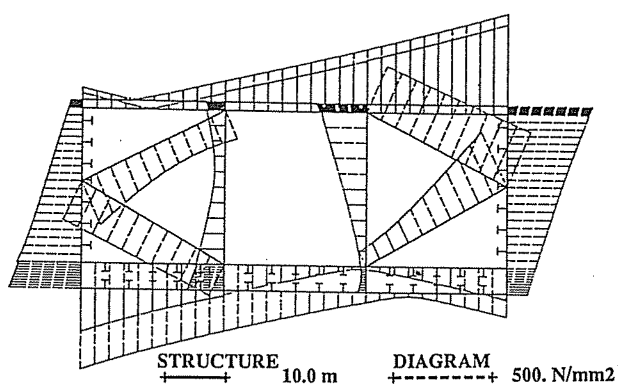


Figure 7 Discretization

Figure 8 von-Mises comparison of stresses at midspan

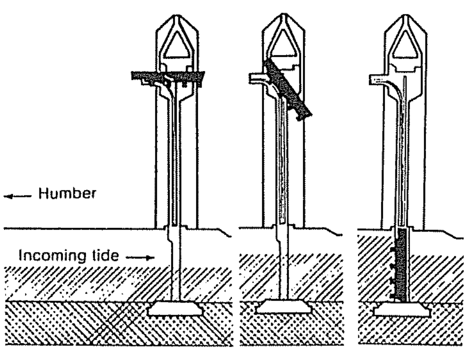
Figure 6 shows two representative cross sections of the barrier including tanks, decks, transverse frames, longitudinals and pillars. The discretization (mesh model) for the strength analysis is shown in Fig. 7. It needs 30 panels, 24 are stiffened (long. and trans. stiffeners and cross-bars) and the remaining 6 panels (n°17 to n°22) represent the pillars. Main characteristics of panel n°3 (Figs. 6 and 7) are : an overall 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. All these elements require 11 data lines in order to use L.B.R.-4 software. As an example of results, Fig. 8 shows the diagram of the von-Mises comparison of stresses at mid-span. The complete computing of such a complex structure can be carried out within 12 hours (discretization, data correction, computing - 30 min. on a Macintosh Computer, printing and result analysis).

Loads acting on the side walls of the barrier are mainly hydrostatic water pressures but on the upper deck and under the barrier, the hydrodynamic pressure must be considered as the current velocity is not negligible. This is particularly important at the last stage of the immersion when the pressure under the barrier drops due to the important discharge flowing through the remaining 1 m high interstice (chink under the barrier). At this stage, the reduced pressure under the barrier could induce a deflection of several tens of centimeters and high stresses in the deck platings. Hopefully, when the effect of this reduction of pressure under the barrier is compensated by the buoyancy effect of the upper tank (see figs 3 and 6).

Compared to the other proposals, it is observed that the use of ship rules leads to lighter structure that most of the land based civil engineering codes. At the final stage of our proposal, the weight of the floating barrier was 55,000 metric tons.

IMPACTS OF THE BARRIERS ON THE ENVIRONMENT

The main elements relating to marine environment are waves, winds, sea-water currents which change the motion of the bed material, the pollution rate, the sea-level rise, the earthquakes which induce tsunamis, ... and last but not least the flora and fauna of marine life. However, according to the authors, aesthetic values must be considered by the designers as one of their foremost worries [8].



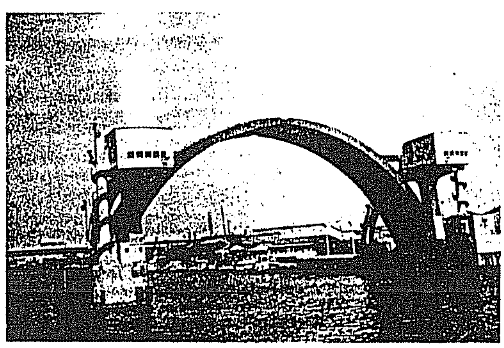


Figure 9a Hull lifting gate. **Figure 9b** Osaka arch gate.

At the dawn of the 21th century, as far as ports and harbors are concerned, the estuary aesthetic values must be protected as they could be completely modified by the building of large structures such as storm surge barriers. As a result of this protection purpose, of the