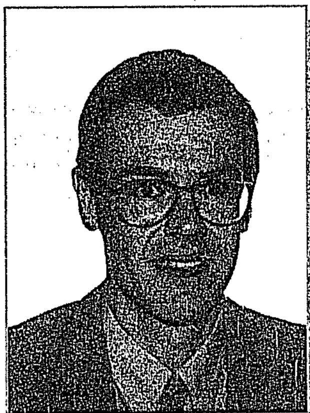

Ph. RIGO

S. RODRIGUEZ

J.L.J. MARCHAL

STORM SURGE BARRIERS AND MARINE ENVIRONMENT

by

Ph. RIGO, S. RODRIGUEZ and J.L.J. MARCHAL
University of Liège
Val-Benoît, 6 quai Banning, B-4000 Liège
(Belgium)
Tel.: +32-43-662111 - Fax: +32-43-669133

1. INTRODUCTION

In 1990, marine structures and sea-level rises of 0.5 to 1.0 or 1.5 m in 2100 are still novel considerations for storm surge barrier design relating to the environment. It is with the knowledge of the past as well as with new projects that these design problems have been studied. The increase of the frequency of exceptional storm surges is a new challenge for marine structures and particularly for storm surge barriers. Engineers and designers have to overcome obstacles now to maintain safety in the future. Moreover, together with this challenge they must consider the growing role of public opinion and its influence on the design.

In the following paper, we would like to present non exhaustive recommendations to help engineers in their further designs. These recommendations are based on our own experiences, but above all on the experiences dealing with practical applications.

2. STORM SURGE BARRIER PURPOSES

Harbour facilities and efficient ship loading and unloading can be maintained by closing a barrier when a storm occurs at high tide. Nevertheless, the main reason for building such structures is to reduce flooding risks in the estuary. Very often, in regard to tidal rivers, tide effects reach 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 method to preserve the environment without having to replace natural beaches, banks and dunes by artifical dykes, sea walls and embankments.

The design of such structures is now recognized as an efficient protection technology and is used throughout the world, in Europe and more particularly in the North Sea. Examples of those 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 to protect cities such as Rotterdam, Antwerp and Venice. Japan is also a country where such protection devices are often used. In Japan, usual tides are relatively small (about 1 m). However, typhoons or tsunamis combined with high tides have flooded several cities during the last century (Osaka, Tokyo, Nagoya). Osaka Bay with its numerous ports and river mouths has many high tide gates as well as the Tokyo area.

2.1 The role of public opinion

The decision to protect an estuary (including its upstream harbor and cities) must be taken into account by the national/federal and regional political leaders as well as by harbor authorities. Public opinion has to play a fundamental role in the decision process. When flooding occurs, public opinion is suddenly and poignantly focused on this problem. Thus, at such time political leaders become aware of the problem and then they quickly plan protection devices to satisfy the population [12]. Usually such projects concern large areas and need intensive studies before starting. Above all they can become very costly. So, political leaders require several years of planning and two or three decades are necessary before work completion (the Delta Plan in the Netherlands was accepted in 1958 and projects were finished in 1986). Owing to influential public opinion, and leaders' awareness which usually occurs just after flooding, planned protection projects have often been started hastily and as soon as possible. After several months or years the interest of public opinion has decreased, the information about projects, whether completed or not becomes smaller and smaller. At that moment, the leaders have an option to continue, to reduce or to stop the planned works.

The Delta Plan is a good example of political leaders being continuously pressed by an interested public opinion. In this case the government has carried the projects to a successful conclusion. Upon completion in 1987, the Dutch Ministry of Transport and Public Works continued to consult with contractors and engineers to develop designs related to the construction of a tidal surge barrier in the entrance of the channel to Rotterdam Harbour [1]. The planned construction was (after completion of the Oosterschelde dam) the last link of the Dutch shoreline protection against exceptional tides. Currently, in relation to the sea-level rise, studies are made to examine how the existing protection structures could be modified or changed [3].

In Belgium, after the 1953 and 1976 high tides, at the time the floods occurred, the Sigma Plan (1977), divided into 3 phases, was established and had to be completed in 1987. The first phase was to raise 450 km of banks of the Scheldt estuary and the second concerned flooding basins to reduce the high tide effect. The third phase was the construction of a storm surge barrier.

In 1995, only 250 km of banks had been raised and from the experience of recent high tides (1991 to 1995), it is obvious that the flooding risk is not yet limited to a probability of 1/1000 or even 1/100. Of course, one can understand that due to the high cost of the required works, some unexpected economical problems and the federalization of the country, authorities had to modify or extend the scheduled time. But from a scientific point of view, it is not "acceptable" to stop the project until at the next flooding public opinion arises. The public and their representatives should stay attentive to the works in progress until completion.

Nowadays more and more engineers and political leaders take into account public opinion when they have to plan their projects. But this is not enough, after planning they also have to update each step of the process in function of the change of public opinion.

For instance, 35 years ago, just after the Isewan typhoon flooded Nagoya, a moveable weir on the Nagara river mouth in Nagoya had already been planned. At the time the goal was to protect land and water resources against flooding. Environmental protection was neglected. In 1990, the water resource problem was solved and this estuary remained the biggest and one of the rare natural river mouths in Japan. This project, after being started, was quickly stopped owing to public reaction (for saving the existing river environment). Two mistakes were made. After 30 years, a planned project had to be reconsidered and updated with regard to the aims of construction and the renewed public interest in the environment. To avoid such problems, it is highly recommended to work as close as possible with the public in order to follow up on public opinion and its pressure for evolution.

The Dutch storm surge barrier on the Oosterschelde shows another example of changing public opinion. A conventional fixed dam was under construction with completion scheduled for 1978. However, the rise of the environmentalist's concerns in the 1970s prompted a drastic re-thinking. Responding to public concern on the fate of the region's rich natural habitat, the Government ordered a change of plans, which called for a moveable barrier rather than the fixed dam already under construction.

2.2 The North Sea

In the past few decades, the flood menace in the coastal areas of the North Sea has been increasing progressively. The North Sea water level is subject to large variations which have their origin in 3 phenomena.

The first is related to the local climate behaviour. When an atmospheric depression reaches the North Sea, the induced north winds create a sea-level rise which produces water accumulation along the coasts. The reduced water depth of the North Sea as well as the shape of the estuary prompt an amplification of this phenomenon.

The second phenomenon concerns world climatic behaviour : the "Greenhouse Effect". It is estimated on the basis of observed changes, that a global warming trend of 1.5 C° to 4.5 C° for the next century would lead to a sea-level rise of 0.5 to 1.0 or 1.5 m and maybe more [2 and 5].

The third concerns geological behaviour. It is now established that as a reaction to the rising movement in the Alps area, North Sea countries are now under the influence of a slow but huge movement of subsidence. So, it is estimated a subsidence of tens of cm will occur in Hull before 2100.

Of capital importance for the North Sea countries is the sea-level rise which will also seriously concern Bangladesh, Taiwan, Venice, most of the Atlantic coast, the Mexican gulf, the Mississippi delta, the Nile delta as well as the deltas of the main Chinese rivers. A two-meter rise would inundate 10 to 20% of Bangladesh. The Maldives Islands (670 km southwest of Sri Lanka) are generally less than two metres above sea-level.

3. INTERACTION BETWEEN ENVIRONMENT AND COASTAL PROTECTION STRUCTURES

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

Included among coastal protection structures are fixed structures like dikes, jetties, piers, groynes, wharfs, etc. But in this study, we will mostly be interested in moveable gates and weirs called storm surge barriers or tidal surge barriers.

In analysing the interaction between marine structures and marine environment, the impact of marine structures will be differentiated from the impact of sea-level rise.

3.1 Impacts of marine structures on the environment

The barrier closure frequency must be limited to exceptional storm surges. In other circumstances, the environment must be able to withstand the attacks of the sea. The protection of the estuary by storm surge barriers must be considered only as a supplementary protection element, and only one of many. The barrier is the keystone of several coherent techniques of protection. Therefore, downstream banks, beaches and coasts in the vicinity of the barriers must be able to resist the same high tides. Moreover, storm surge barriers remind us not to forget the protection role of the upstream river banks along which the tide acts. River banks must continue to hold out against usual high tides.

Erosions and accretions

Sediment accretions or erosions (bank, river bed, etc.) can result from too long or too frequent closing times. As the sea's erosion power is, in fact, higher during storm surges, it is important to analyse what can be the barrier closure effects on sea-water currents (direction and velocity). Too large sediment accretion can induce navigational difficulties or increase dredging costs. On the other hand, erosion can produce crucial damage to the environment and compromise the stability of some marine structures (dikes, piers, jetties, etc.). For instance, to protect Niigata (city on the Sea of Japan) against flooding, a diversion was built on the West side of the city (Fig. 1). Water level and discharge are regulated by moveable weirs. Main coastal currents act in an East to West direction. Therefore, the sandy beach which was usually

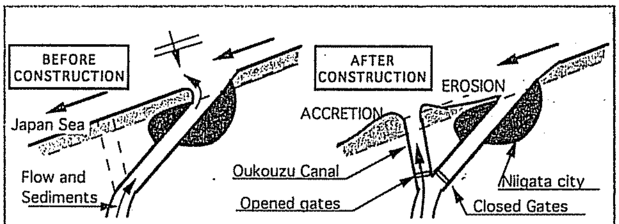

Figure 1 - Coastal erosion resulting from the flood protection system in Niigata (Japan)

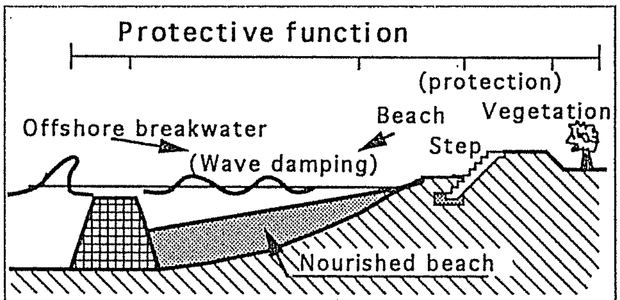

Figure 2 - Conceptual Diagram of the Zonal Protective Method

accumulating from the high discharge from the upper part of the river, now forms no more at the natural mouth of the river but at least 10 km away to the West. So, the beach profile equilibrium was broken and a retreat of the beaches occurred which changed the coastline. A large ground subsidence also amplifies this phenomenon. To restore old beach areas, zonal protective structures were designed (Fig. 2).

To meet the growing interest in the quality of the environment, Japan has promoted a new system of coastal protection [7] which combines environmentalism and safety. This system called "Zonal Protective Method" is shown in Fig. 2. This is a coastal improvement method, whereby multiple shoreline protection facilities are arranged in the most appropriate way to prevent disaster at a given place in the vicinity of the shoreline. This method is beneficial by encouraging comprehensive use of nearby on-shore areas. At the same time, these zonal protective structures have great resilience, functioning as a thick buffer against the threat of the sea.

Aesthetic values

At the dawn of the 21th century, where ports and harbors are concerned, the estuarine aesthetic values must be protected because they could be completely modified by the construction of large structures such as storm surge barriers. As a result of this protection purpose, the small frequency of storm surges and navigation needs, these barriers are not used for more than 99% of the time (standby stage). So the aesthetic appearance of the gate when the structures are not in use must be an important consideration.

Typically, gates stay in a high suspended position as in Hull (Fig. 3a) or in Osaka (Fig. 3b), or stay under the water level in the floor of the structure as for the Thames barrier in London or stay along the river banks as the floating and rotating barriers projected for Antwerp (Fig. 4b). Lifting gates are not in keeping with site aesthetic values since their high frames could sometimes reach 100 m high as in an old project for the Antwerp estuary (Fig. 4a). On the other hand, barriers staying under water or along the banks (Fig. 4b) are in keeping with landscape protection and are, therefore, the most recommendable for further designs.

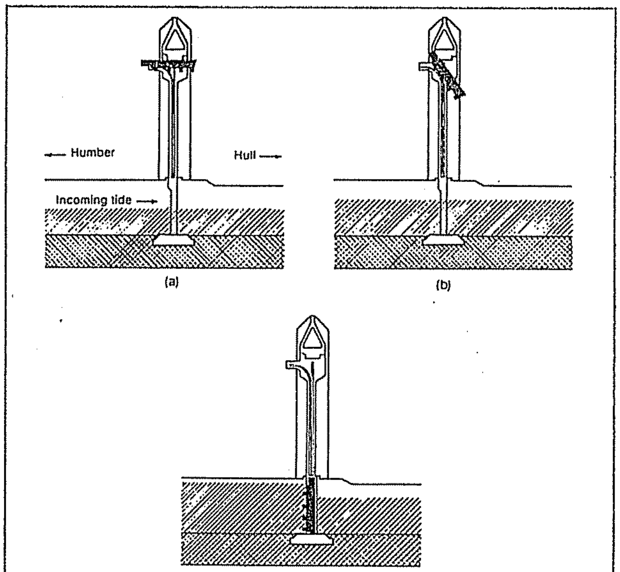

Figure 3a - Hull lifting storm surge barrier

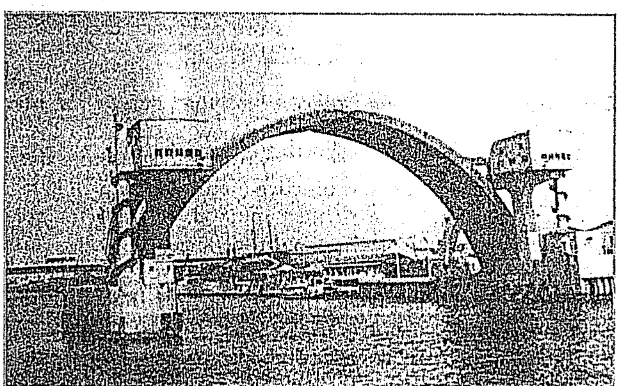

Figure 3b - Osaka arch type gate

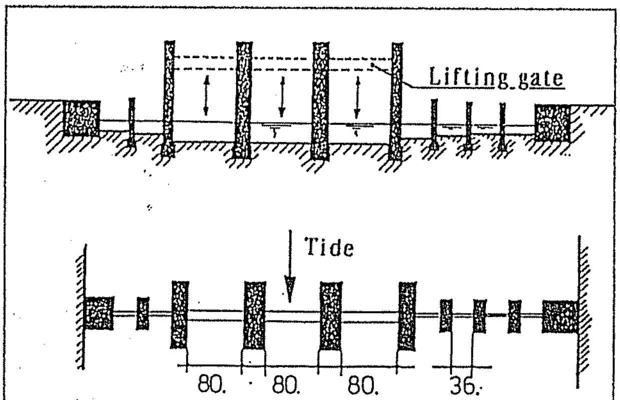

Figure 4a - Antwerp lifting gates project

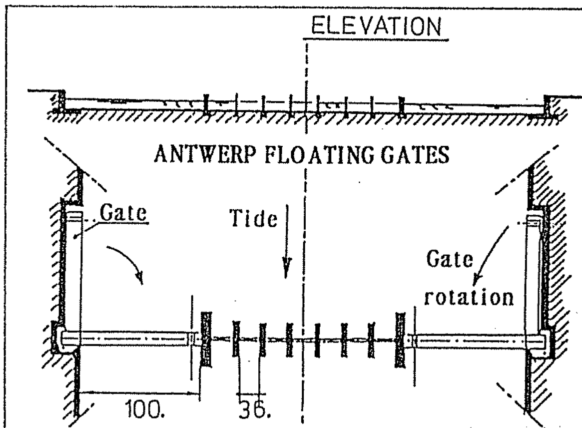

Figure 4b - Antwerp floating gates project

3.2 Impacts of sea-level rise on marine structures and the environment

The recurrence period of storm surges (mainly characterized by the highest water level reached) will strongly be affected by the future sea-level rise. The relationship between frequency of overtopping and sea-level is assumed to be log-linear, and is expressed by a coefficient which indicates the inclination of the probability curve (Fig. 5). In the North Sea this coefficient is about 1.5. Therefore, the impact of sea-level rise on safety in low coastal areas is considerable. The chance of a catastrophic event along these coastal areas increases a hundred-fold by a sea-level rise of 1.5 m.

The recurrence period of events such as the 1953 storm surge, would become a 3-year recurrence instead of 300 years. This means that in the future, a storm surge which was considered before only in disaster scenarios, must be now considered as highly probable.

3.2.1 Structures

The impact of sea-level rise automatically has a direct relevance to coastal lowlands. Increased storm surges have an impact on the dikes, dams and coastal structures, including storm surge barriers.

The modification of the frequency of exceeding water levels has serious consequences on the safety coefficients of marine structures. These safety coefficients were chosen when the barriers were designed, considering, in the best cases, a small sea-level rise. For instance, for the Delta Plan, a sea-level rise of only 20 cm per century has been taken into account.

With respect to the existing structures, the impacts of sea-level rise are not easily estimated. Reduced safety coefficients taken in the past for exceptional water levels must be strongly reconsidered. Without modifications, "young structures" (10 to 20 years) can often withstand small sea-level rises but will have to be reinforced in case of a 1- or 1.5-m rise. It is sometimes more economical to rebuild than to modify "old structures" (over 50 years). With respect to the Delta Plan's structures [3], a study of 1989 shows that it needs US$ 2,500 - 12,500 million to adapt protective structures in case of a sea-level rise of respectively 0.5 and 1.5 m. For comparison, these amounts are respectively 15% and 80% of the total amount of the Delta Plan's projects.

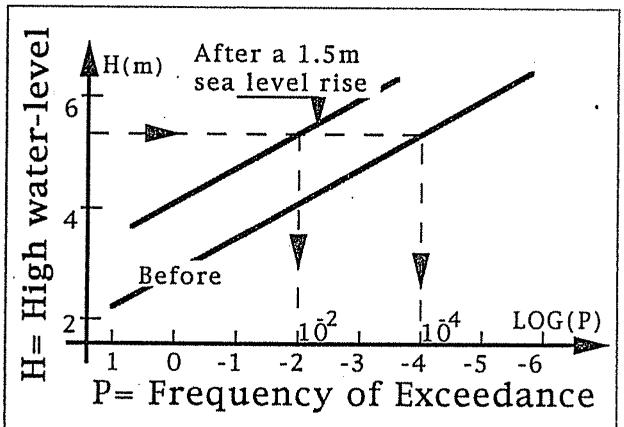

Figure 5 - Recurrence probability of sea-water level

Related to the design of new structures, it may seem that the selection of their "security level" is easier to consider. This is not the case. Theoretically, it is sufficient to consider the expected sea-level rise at the end of the structure's life span. In reality, sea-level rise and technical life could not be predicted with a high accuracy. Predictions of sea-level rise for the next century vary within a large range (0.2 m to more than 2 m) depending on the scientists [5]. Although the technical life span of usual marine structures is normally 50 to 100 years, in the case of storm surge barriers and considering their high costs, 100 years or more can be acceptable (200 years for the Eastern Scheldt storm surge barrier in Rotterdam). Moreover, it is not possible to anticipate what the engineers will decide tomorrow. It is not uncommon to see structures still in use after their life span has elapsed, yet structures are often replaced before their life span has elapsed. Therefore, it is one of the most difficult decisions to determine the characteristic storm surges (recurrence of 1/10000, 1/100 and 1/10) for later consideration in barrier design.

From an economic point of view and related to sea-level rise, it might be interesting to make step-by-step adaptations to the structures, in order to avoid investment of money now which is only required 50 or 100 years later. So, it is recommended to combine the larger maintenance works (which are necessary owing to a life span of about 100 years) with an adaptation of the structures.

3.2.2 Environment

Sea-level rise causes effects on the environment which suffers larger and sometimes irreversible damages. Loss of land in river deltas will occur as a result of erosion, inundation and flooding of coastal areas. Changes in morphology and ecology, increased saltwater intrusion into rivers and saline seepage, will also occur. It will also affect fresh water intake for irrigation and domestic water supplies.

Geological records indicate that the natural environment has a great capacity to adapt to very slow changes in conditions without the extinction of any species or organisms. Nevertheless, in the case of protected coasts, the consequences of inland migration of wetlands being obstructed by dikes or sea walls, may result in certain types of natural environment being reduced in size or disappearing altogether.

Allowing nature to run its course (in narrow coastal protected areas) will not be a better solution, as natural sandy coasts will be subject to erosion and the intertidal areas will radically change. As the equilibrium beach profile will follow rising water levels, the shoreline will ultimately retreat inversely proportional to the submerged slope. Beach retreat is usually about 1 m for 1 cm level rise. Therefore, a sea rise of 1 m would mean about 100 m of beach erosion. In places where such retreat can not be permitted, protection devices such as the "Zonal Protective Method" in Japan will have to be used. Sand supply can also prevent beaches and dunes from retreating.

3.2.3 Public opinion

As explained before, such a sea-level rise will have many effects on society but in terms of daily problems, the effects may appear to be irrelevant. The same can not be said for structural engineering investments as an estuary protection, which could take decades. Moreover, there are many other problems which compete with sea-level rise for the attention of decision-makers and public opinion. Experience shows that only a sudden event or disaster will trigger countermeasures (for example : the Sigma plan was planned after the great flood in 1953). Therefore, to ensure an effective and timely response, scientists and engineers must join forces to consider consequences on today's and tomorrow's structures, even if public opinion and decision-makers seem unconcerned.

The public opinion on sea-level rise is slow or nonexistent due to the period of time between cause and effect (at least in the near future). Nevertheless, engineers must be courageous in taking into account such parameters which increase the investments. They must not wait for nature to show what it can do.

4. FLOATING AND ROTATING STORM SURGE BARRIER

With Rotterdam's storm surge barrier project resulting in the closure of the New Waterway, the Dutch authorities have started a protection project for their last unprotected estuary. Several construction consortiums submitted their designs to these authorities [1, 4]. With regard to the marine environment, it is interesting to show one innovative design which is cost-effective and reliable (Fig. 6a to Fig. 6d). The

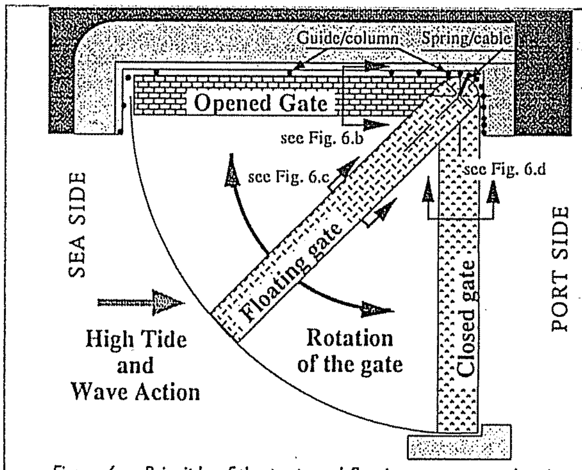

Figure 6a - Principle of the proposed floating storm surge barrier proposed solution remarkably protects the site's aestheticism and avoids any costly bed improvement and expensive mechanical systems. Since 1988, experiences have been made in many aspects with this system, based on the principle of a floating gate. Manoeuvrability and feasibility tests were performed, including gate rotation, tank ballasting (Fig. 7), wave and current actions, and control of natural heave and roll motions (Fig. 8). 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.

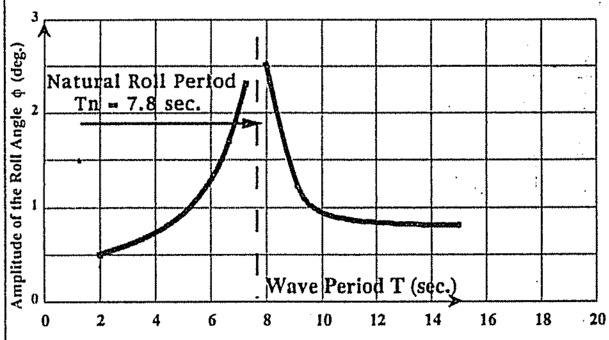

Figure 8 - The measured natural roll motion

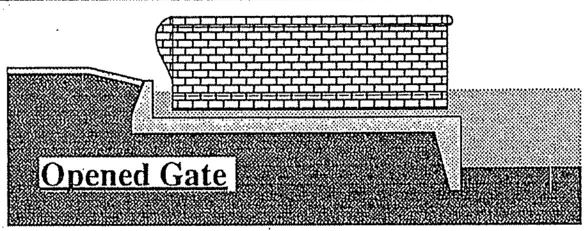

Figure 6b - Opened position :
The gate stays along the river bank and rests on its end supports

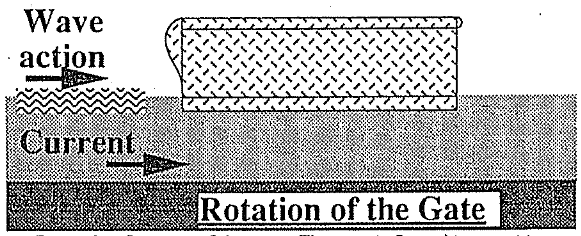

Figure 6c - Rotation of the gate : The gate is floated into position

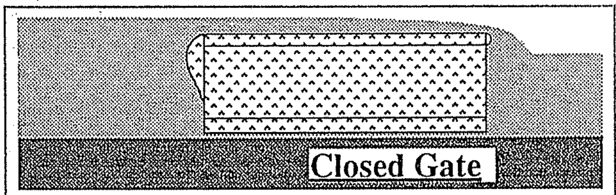

Figure 6d - Closed position :
The gate is sunk by filling the ballasts

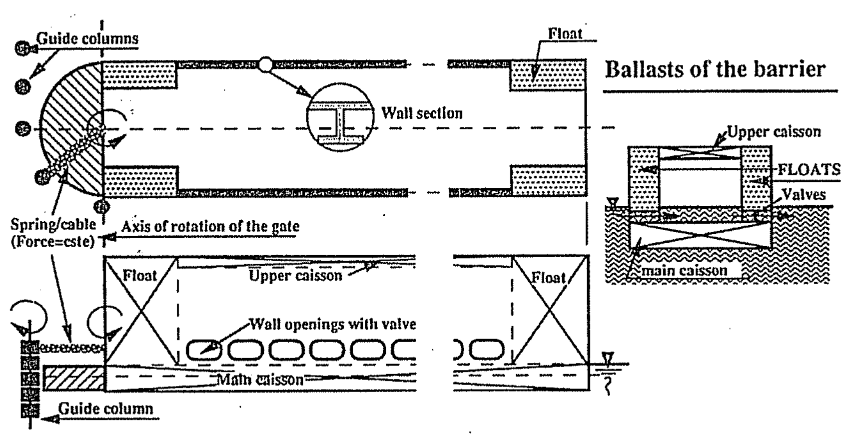

Figure 7 - Details of the floating barrier (cross-section, plan view and front view)

In Belgium, the aim of the Sigma Plan (1977) was to reduce the flooding risk to a probability of 1/10000. Completion was planned 10 years later. The main protection device was a storm surge barrier in the Oosterweel. The Antwerp barrier had to keep two channels for navigation at least 60 m wide and 9.7 m deep. In 1980, the selected design (Fig. 4a) was composed of 3 lift gates with a 80-m span and 6 radial gates with a 3.5-m span. As the requirements implied an unlimited air clearance, the projected gates had to be lifted 80 m above the river water level with the help of four towers of 125 m. The high cost, the huge headrooms including lifting towers, and the negative effect on the environment, especially related to the aestheticism of the site, have probably led the project to be abandoned.

Since the first step of this project, another one has been suggested of lower cost and higher aestheticism. This design (Fig. 4b) is composed of two 100-m-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 100-m-wide navigation channels. The central part is composed of usual moveable weirs which control discharge and water levels after closure of the two main floating gates.

The advantages of such floating gates are as follows :

- **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** such as rail, carriage, big ball 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 [8];
- **very little sensitivity to wave action,** thanks to its large width [6];
- **sustainable structure as it can easily be controlled, assessed, 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 (scale 1/70);

- **reliable structure** since the design of the structure is not sophisticated, the construction process is standardized and the gate structure looks like a usual floating dock;
- **can easily be completely prefabricated** since the gate can float;
- ...

The idea of a floating storm surge barrier, although not accepted at this time, seems to be in 1995 the optimum design.

Anyway, we now hope that the Antwerp protection plan should be deeply reconsidered soon.

5. CONCLUSIONS

With the dawning of the year 2000, the interaction between the marine environment, estuary protection by storm surge barriers and sea-level rise should not continue to be neglected. Therefore, the following recommendations are made [11] :

- Estuary protection by storm surge barriers must be considered only as one supplementary protective structure of several coherent protection techniques. Dikes, banks, etc. as well as the natural environment must be able to withstand the usual attacks of the sea. Moreover, marine current modifications may create erosion or accretion.
- With respect to the estuary's aestheticism, it is strongly recommended to plan structures as compatible with the environment as possible, as suggested with the floating storm surge barrier.
- The most important problem of the sea-level rise is the increase of the frequency of exceeding water levels. With a rise of 1.5 meter, the probability of reaching a fixed water level which occurs once every 1000 years, will become once every 10 years. From an economic viewpoint, it is recommended to combine the overall maintenance of the structure with a step-by-step structural adaptation in relation to the rise in sea-level.
- The natural environment has a great capacity to adapt to very slowly changing conditions without the extinction of any species or organisms. Nevertheless, sandy coasts being subject to erosion, loss of land will occur by inundation and the intertidal area will drastically change. Moreover, saltwater intrusion will increase. Therefore, from today, methods such as the "Zonal Protective Method" or sand accretion where beach retreat is expected, must be used.
- Because of the high risk of perturbation of the environment, and the large impact of estuary protection projects on public opinion, high tides are particularly sensitive. As large protection works have to be spread over decades, an evolution of the public's opinion can occur. The engineers are strongly advised to periodically update the uncompleted works. On the other hand, in 1995 the sea-level rise appeared to be irrelevant to public opinion. Therefore, it is also the job of the designers to anticipate such a phenomenon rather than to wait once again for the next sudden event to trigger countermeasures.

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RESUME

Barrages marée-tempête et environnement maritime

La solution la plus facile pour préserver l'environnement sans substituer des digues ou berges artificielles aux plages naturelles, berges et dunes, est le barrage marée-tempête. Ce type d'ouvrage peut être l'élément principal d'un plan de protection. La clôture d'un barrage par marée-tempête permet de continuer le chargement/déchargement des navires dans les ports avec la même efficacité. La raison d'être principale d'un tel ouvrage reste cependant la réduction des risques d'inondation dans l'estuaire. Les effets des marées se faisant souvent sentir à des dizaines de kilomètres en amont de la côte dans les fleuves à marée, une inondation pourrait affecter une très vaste région et des milliers de personnes. Les effets d'un barrage marée-tempête en projet ont été analysés en considérant également l'interaction entre l'environnement et l'ouvrage. Deux types d'analyse ont été faites :

1. **Les effets du barrage marée-tempête sur l'environnement** (impact des ouvrages sur l'environnement). La fermeture du barrage interrompant le débit d'eau douce, le niveau d'eau du fleuve pourrait monter au point de causer une inondation, si le barrage reste fermé très longtemps. La clôture du barrage modifie la direction des courants près de l'estuaire et du barrage, ce qui peut induire des effets d'érosion ou de sédimentation. De plus, il faut respecter des contraintes d'esthétique.
2. **Les effets du relèvement du niveau de la mer sur les ouvrages hydrauliques** (impact de l'environnement sur les ouvrages). Les causes de l'élévation du niveau des mers sont analysées plus spécifiquement pour la région de la Mer du Nord. Ses effets sur les ouvrages maritimes anciens (barrages) aussi bien que nouveau sont analysés. Une attention particulière est accordée aux probabilités de période de retour de très fortes tempêtes. L'incertitude sur la durée de vie réelle des ouvrages complique l'évaluation de l'élévation du niveau de la mer à prendre en compte.

De nombreuses années déjà, notre laboratoire propose un nouveau type de barrage marée-tempête flottant composé d'une coque raidie principale, flottante et étanche, et de petits flotteurs, créant un effet de catamaran à double coque. Le barrage tourne autour d'une de ses extrémités. Si l'on considère la protection de la nature, et plus particulièrement la préservation de l'aspect naturel de la région de l'Escaut, un barrage flottant ouvre de nouvelles perspectives au projeteur. Nous proposons donc un ouvrage composé de deux barrages flottants, un par berge, et d'une partie centrale composée de plusieurs vannes mobiles permettant l'évacuation des débits. Après mise en place par flottaison, les barrages sont ballastés en position fermée pour protéger la ville et le port.

ZUSAMMENFASSUNG

Sturmflutsperrwerke und die marine Umwelt

Ein Sturmflutsperrwerk ist der einfachste Weg des Umweltschutzes ohne die Notwendigkeit natürliche Strände, Sandbänke und Dünen durch künstliche Dämme, Deiche und Ufer zu ersetzen. Es kann das Fundament eines Schutzvorhabens sein. Wenn ein Sturm mit einem hohen Gezeitenwasserstand zusammenfällt, kann die Leistungsfähigkeit der Belade- und Löscheinrichtungen einer Hafens durch das Schließen eines Sperrwerks aufrechterhalten werden. Nichtsdestoweniger ist der Hauptgrund für die Konstruktion eines solchen Bauwerks die Reduzierung des Überschwemmungsrisikos in einem Ästuar. In tidebeeinflußten Flüssen erstrecken sich die Gezeiteneinflüsse im Oberstrom oft auf mehrere Zehner Kilometer Entfernung von der Küste. Daher kann eine Überschwemmung ein sehr großes Gebiet und viele Tausend Menschen betreffen. Die Folgen eines Sturmflutsperrwerksprojektes wurden unter Berücksichtigung der Wechselwirkungen zwischen der Umwelt und dem Bauwerk analysiert. Zwei Sichtweisen sind entwickelt worden.

Erstens, **die Auswirkung einer Sturmflutsperrwerkes auf die Umwelt** (Auswirkung von Bauwerken auf die Umwelt). Ist das Sperrwerk geschlossen, wird der Süßwasserabfluß unterbunden. Wenn das Sperrwerk lange geschlossen bleibt, kann der Wasserspiegel des Flusses soweit steigen, daß Überschwemmungen auftreten können. Durch die Veränderung der Strömungsrichtung in der Nähe des Sperrwerks können auch Erosions- und Sedimentationsprozesse auftreten. Diese Veränderungen sind auf das Schließen des Sperrwerkes zurückzuführen. Darüber hinaus gibt es auch ästhetische Randbedingungen.

Zweitens, **die Auswirkungen des Meeresspiegelanstiegs auf Wasserbauwerke** wie sie Sturmflutsperrwerke darstellen (Umwelteinflüsse auf Bauwerke). Die Ursachen des Meeresspiegelanstieges werden speziell im Hinblick auf die Nordsee behandelt. Konsequenzen auf bestehende Küstenbauwerke (Sperrwerke) wie auch für neue Projekte werden ausgeführt. Besondere Aufmerksamkeit wird der Wiederkehrwahrscheinlichkeit schwerer Stürme gewidmet. Geringe Meeresspiegelanstiege haben große Konsequenzen auf diese Wahrscheinlichkeit. Darüber hinaus verursachen Unsicherheiten bezüglich der tatsächlichen Lebensdauer Schwierigkeiten bei der Abschätzung des zu berücksichtigenden Meeresspiegelanstieges.

Seit vielen Jahren hat zich unser Labor für ein neues System von Sturmflutsperrwerken eingesetzt. Es handelt sich um ein Schwimmsperrwerk mit einem schwimmenden wasserdichten Kastenträger und kleinen Schwimmplattformen zur Erzielung eines Doppel-Katamaran-Effektes. Das Sperrwerk vollführt eine drehende Bewegung um einer seiner äußersten Enden. Unter Berücksichtigung vom Umweltschutzgesichtspunkten, insbesondere der Naturschutzaspekte in der Schelderegion, geben Schwimmsperrwerke dem Konstrukteur neue Möglichkeiten an die Hand. Deshalb wird ein vollständiges Bauwerk vorgeschlagen, das aus zwei Schwimmsperrwerken, eines auf jeder Seite, besteht. Der mittlere Teil ist aus mehreren beweglichen Wehren, die den Abfluß des Wassers erlauben, zusammengesetzt. Nach Drehung mit einem minimalen Kraftaufwand können die Schwimmsperrwerke in geschlossener Position geflutet werden, um die Stadt und den Hafen zu schützen.

RESUMEN

Barrera contra la sobreelevación del mar y el entorno marino

Una barrera contra la sobreelevación del mar constituye la manera más fácil de preservar el entorno sin tener que reemplazar las playas naturales, riberas y dunas con diques artificiales y terraplenes. Podría constituir el elemento clave de un plan de protección. Se mantiene la eficacia de las operaciones y descarga de buques en los puertos, cerrando una barrera cuando se produce una tormenta que coincida con la marea alta. Sin embargo, el motivo principal de la construcción de tal estructura es reducir el riesgo de inundación en el estuario. Frecuentemente, en los ríos donde entra la marea, la influencia de la ésta se extiende río arriba en decenas de kilómetros. Por tanto, las inundaciones podrían afectar a una zona muy extensa y a miles de personas. Se analizaron las consecuencias de un proyecto de una barrera contra la sobreelevación del mar, teniendo en cuenta la interacción entre el medio ambiente y las estructuras. Se han desarrollado dos tipos distintos.

Primero, **los efectos de una barrera sobre el medio ambiente** (el efecto de las estructuras en el entorno). Cuando se cierra la barrera se interrumpe la descarga de agua dulce. Si la barrera queda cerrada durante mucho tiempo puede que el nivel del río suba tanto que dé lugar a una inundación. También puede producirse la erosión o la sedimentación debido a la modificación de la dirección del flujo en la proximidad del estuario y la barrera. Tales modificaciones resultan del cierre de la barrera. También existen exigencias estéticas.

Segundo, se presenta **el efecto del aumento del nivel del mar en las estructuras hidráulicas** tales como barreras contra la sobreelevación del mar (efecto del entorno sobre las estructuras). Se realiza un análisis específico de las causas del aumento del nivel del mar en la zona del Mar del Norte. Se desarrollan las consecuencias para las estructuras marinas antiguas (barreras) así como para los proyectos nuevos. Se ha prestado atención especial a la probabilidad del periodo de retorno de tormentas severas. Pequeños aumentos del nivel tienen consecuencias importantes para dicha probabilidad. Además, la incertidumbre en cuanto a la vida real ocasiona dificultades en relación con la evaluación del aumento en el nivel del mar que se ha de considerar.

Desde hace muchos años nuestro laboratorio ha promovido un sistema nuevo de barreras contra la sobreelevación del mar. Es una barrera flotante con una viga de cajón principal y hermética que flota y está dotada de flotadores pequeños que proporcionan un efecto de catamarán doble. La barrera realiza un movimiento giratorio apoyada en una de sus extremidades. Teniendo en cuenta la protección medioambiental y específicamente la preservación del aspecto natural de la región de la Scheldt, las barreras flotantes ofrecen al proyectista nuevas posibilidades. Por tanto, se propone una estructura completa compuesta por dos barreras flotantes, una en cada lado. La parte central se compone de varías compuertas movibles que permiten la evacuación del agua. Después de girarse a calado mínimo, se pueden lastrar las barreras flotantes en su posición mínima para que protejan la ciudad y el puerto.

RIASSUNTO

Barriera contro il sovralzo di tempesta ed ambiente marino

Una barriera contro il sovralzo di tempesta è il modo più semplice per preservare l'ambiente senza dover sostituire spiagge naturali, secche e dune con dighe artificiali, muri di sponda e moli. Potrebbe essere la chiave di volta di un programma di protezione. L'efficenza del carico e scarico nave nei porti può essere protetta chiudendo una barriera quando arriva una tempesta ad alta marea. Tuttavia la principale ragione per costruire una simile struttura è di ridurre i rischi di inondazioni lungo un estuario. Molto spesso sulle onde dei fiumi, gli effetti onda si estendono per decine di chilometri controcorrente dalla costa. Così l'allagamento può colpire un'area molto vasta e migliaia di persone. Sono state analizzate le conseguenze di un progetto di barriera contro sovralzo di tempesta tenendo conto dell'interazione tra ambiente e strutture. Sono stati sviluppati due tipi.

In primo luogo, **gli effetti di una barriera a sovralzo di tempesta sull'ambiente** (effetto di strutture sull'ambiente). Quando la barriera è chiusa, il flusso di acqua dolce è interrotto. Se la barriera rimane chiusa per lungo tempo il livello dell'acqua del fiume può salire in modo tale da poter causare un'inondazione. Possone avvenire fenomeni di erosione o di sedimentazione determinati dal cambiamento della direzione della corrente vicino all'estuario ed alla barriera. Questi cambiamenti sono il risultato della chiusura della barriera.

In secondo luogo, **gli effetti dell'innalzamento del livello del mare sulle strutture idrauliche** quali sono le barriere a sovralzo di tempesta presentate (effetto dell'ambiente sulle strutture). Le cause dell'innalzamento del livello del mare sono analizzate considerando la regione del Mar del Nord. Vengono sviluppate le conseguenze sulle vecchie strutture marine (barriere) così come i nuovi progetti ed una particolare attenzione è stata concentrata sulla probabilità di occorrenza di violenti tempeste. Lievi innalzamenti di livello producono significative conseguenze nel calcolo di questa probabilità. D'altronde l'incertezza sul reale tempo di durata rende difficile valutare l'innalzamento del livello del mare da considerare.

Per molti anni il nostro laboratorio ha promosso un nuovo impianto di barriere a sovralzo di tempesta. Si tratta di una barriera galleggiante con trave scatolare galleggiante stagna e con piccoli galleggianti per creare un doppio effetto catamarano. La barriera fa un movimento rotatorio intorno ad una delle sue estremità. Tenendo presente la protezione ambientale e specialmente la preservazione dell'aspetto naturale della regione della Schelda, le barriere galleggianti danno al progettista nuove possibilità. Viene proposta una struttura completa composta da due barriere galleggianti, una per ogni lato - la parte centrale è composta di diversi sbarramenti mobili che permettono di evacuare l'acqua. Dopo aver nuotato alla minima profondità, le barriere galleggianti possono essere zavorrate in posizione chiusa per proteggere città e porto.

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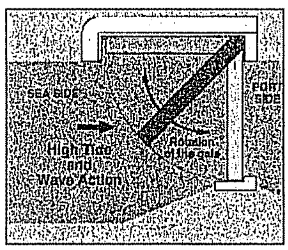

Cover picture : Storm-surge barrier schematic

Photo de couverture : Schéma d'un barrage marée-tempête