Estuary protection by storm surge barriers

Estuary Protection by Storm Surge Barriers
Protection d'un estuaire par un barrage contre les raz-de-marée
Flussmündungsschutz durch Sturmflutbarrieren

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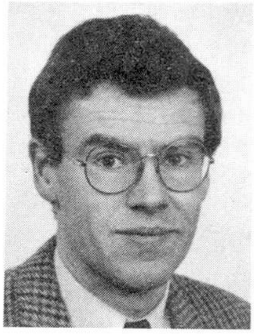

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SUMMARY
The storm surge barrier reduces flooding risks in the estuary. Design problems of barriers are analysed with respect to the effects of the sea level rise, with a rise of 1,5 meter, the probability in reaching a fixed water level which occurs once every 1000 years, will occur once every 10 years. Thus, structure safety coefficients are also affected.
The environmental impact of barriers on erosion or accretion is discussed relating to practical applications. Finally, several recommendations are made.

Protection d'un estuaire par un barrage contre les raz-de-marée

Résumé
Le barrage contre les raz-de-marée permet de maîtriser les risques d'inondations dans la région d'un estuaire. La conception d'un tel barrage est étudiée en tenant compte des effets de l'élévation du niveau de la mer. Avec une élévation du niveau de la mer de 1,5 m, la probabilité d'atteindre un niveau d'eau donné - qui se produisait tous les 1000 ans - se produit alors tous les 10 ans. Il s'ensuit que les coefficents de sécurité de la structure en sont affectés. L'influence des barrages sur l'érosion et la sédimentation est passée en revue sur la base d'expériences pratiques. Des recommandations sont proposées.

Flussmündungsschutz durch Sturmflutbarrieren

Zusammenfassung
Die Sturmflutbarrieren verringern das Ueberschwemmungsrisiko innerhalb einer Flussmündung. Analysiert werden Entwurfsprobleme dieser Barrieren unter Berücksichtigung des Anstiegs des Meeresspiegels. Ein Anstieg des Meeresspiegels um 1,5 Meter reduziert die Wiederkehrperiode des ursprünglich 1000 jährigen Hochwassers auf 10 Jahre. Aus diesem Grund sind Bauwerkssicher-heitskoeffizienten ebenfalls berührt. Der Einfluss der Barrieren auf Erosion oder Ablagerung wird diskutiert. Schliesslich werden Empfehlungen gegeben.

1. INTRODUCTION

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

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

2. STORM SURGE BARRIERS PURPOSES.

Harbour facilities, including ship loading and unloading efficiency, can be maintained by closing a barrier when a storm occurs at high tide. Nevertheless, the main aim to build such structures is to reduce flooding risks in the estuary. Very often, in regard to tidal rivers, tide effects go tens of kilometers upstream of the coast. Thus, the flooding could reach a very large region affecting thousands of people. The storm surge barrier is well the easiest method to preserve the environment without having to replace natural beaches, banks and dunes by artificial dykes, sea walls and embankments.

The design of such devices is now recognized as protection technology and is used throughout the world, in Europe and more particularly in the North Sea. Examples of such are the Thames Barrier in London, the Hull lifting gate (G-B), the moveable weirs on the Elbe and the monstrous Oosterschelde barrier in the Netherlands. Today, there are new studies of city protection projects such as Rotterdam, Antwerp and Venice. Japan is also a country where such protection devices are often used. Usual tides are relatively small (about 1m). However, typhons or tsunamis, combined with hide tides have flooded several cities during this century (Osaka, Tokyo, Nagoya). Osaka Bay with its numerous ports and river mouths has many hide tide gates such as in 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 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 suddently and poignantly focused on this problem. Thus, at this time political leaders become aware of the problem and then they quickly plan protection devices to satisfy the population. Usually such projects concerning large areas need intensive studies before starting. Above all they can become very costly. So, political leaders require several years of planning, sometimes two or three decades (the Delta plan in Netherlands was accepted in 1958 and projects were finished in 1986). Owing to influential public opinion, and leaders awareness which usually occurred just after flooding, the planned protection projects were often started hastily and as soon as possible. After several months or years the interest of public opinion decreased, the information about projects whether completed or not become less and less. The leaders had an option to continue, to reduced or to stop the planned works.

The Delta plan is good example of political leaders continously pressed by an interested public opinion. In this case government has carried the projects to a successfull 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 of Rotterdam Harbour [1]. The foreseen construction was (after completion of the Oosterschelde dam [6]) the last link of the dutch shoreline shielding against exceptional tides. Currently, related to the rise in sea-water level, studies are made to see how their existing protection devices could be modified or changed [3].

In Belgium after the 1953 and 1976 hide tides from which floods occured, the Sigma plan (1977), divided in 3 phases, was established and had to be finished in 1987. The first phase was to raise the 450km banks of the Escaut estuary, as of today 250km have been raised. The second phase concerned with the construction of flooding bassins to reduce the hide tide effect, was never realize because of inapplicability. The last phase which dealt with a storm surge barrier was also abandoned after that some feasibility studies were made [2].

Of course, one can understand that according to the high cost of these works and some unexpected economical problems (such as pretroleum crisis), governments could modify and extend the scheduled time of the completion. But it is not acceptable to stop the project .... upon the next flooding public opinion will arise. Public opinion should be aware of the irresponsability of their political leaders. The public and their representatives must pay attention 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 it is not enough, after planning they also have to revise each step of the way according to the changing public opinion.

For instance, 30 years ago, just after that Isewan typhoon flooded Nagoya, a moveable weir on the Nagara river mouth in Nagoya had already been planned. At this time the goals were for flooding protection and water ressources. Environment protection was neglected. Presently, the water ressource problem has been solved and this estuary remains the biggest and one of the rarest natural river mouths in Japan. This project, which was started recently, has recently been quickly stopped owing to public reaction (in saving the existing river environment). Two mistakes occurred. After 30 years, a planned project had to be reconsidered regarding the aims of construction and the renewed interest of the people relating to the environment. To avoid such problems, it is highly recommended to work as close as possible with public opinion and its request for evolution.

The storm surge barrier on the Oosterschelde shows us another example of changing public opinion. Construction of 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's concern for 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 progessively. The North Sea water level is subject to large variations which have one's origins in 3 phenomenons.

The first one is related to the local climate behaviour. When an atmospheric depression arrives on the North Sea, the induced north winds create a rise of sea level which produce water storage along the coasts. The reduced water depth of North Sea as well as these 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 1.5m and maybe more [5].

The third concerns geological behaviour. It is now established that in reaction to the rising mouvement of elevation 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 more then 50 cm 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 from Mexico gulf to USA (Mississippi), 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 related to marine environment are waves, winds, sea-water currents which change the motion of the bed material, the polution 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 author, aesthetic values must be considered by the designers as one of their formost worries.

Included among coastal protection structures are the fixed structures like dikes, jetties, piers, groynes, wharfs, etc. But in this study, we will be mostly 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 differentiate from the impact of sea level rise.

3.1 Impacts of the marine structures on the environment.

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

- Erosions and accretions : Sediment accretions or erosions (bank , river bed, etc.) can result from too long or too frequent closing times. The sea erosion power is, in fact, higher during storm surge. Therefore, it is important to analyse which can be the barrier closing effects on the sea-water currents (direction and velocity). Too large of a sediment accretion can induce navigational difficulties or increase dredging cost. On the other hand, erosion can produce crutial damage to the environment and compromise the stability of some marine structures (dikes, piers, jetties, etc.). For instance, to protect Niigata (city on the Japan Sea) against flooding, a derivation 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 accumulating from the high discharge from the upper part of the river, now arrives not at the natural mouth of the river but at least 10km away on the West side . So, the beach profile equilibrium was broken and the retreat of the beaches occurred changing the coastline. A large ground subsidence also amplifies this phenomenum. To restore old beach areas, zonal protective structures are now designed (Fig. 2)

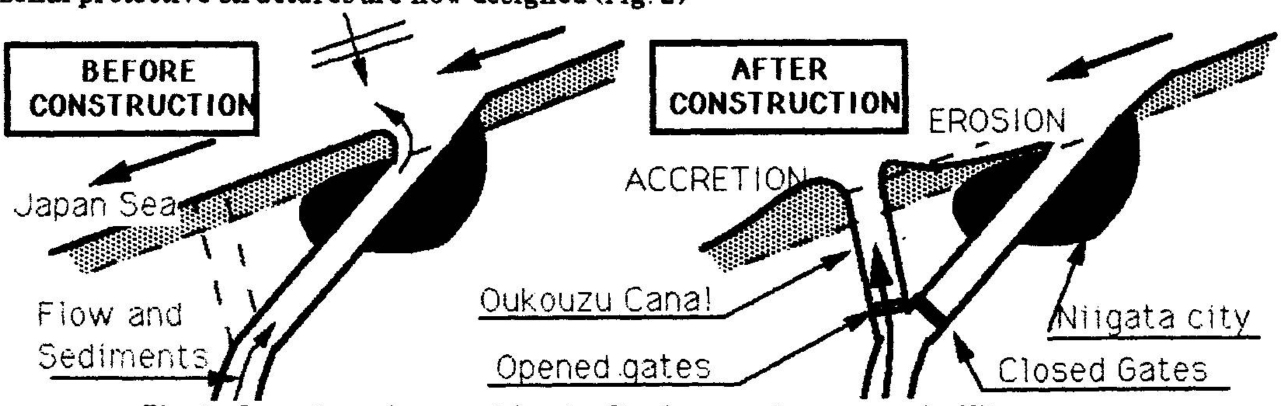

Fig. 1 : Coastal erosion resulting by flood protection system in Niigata.

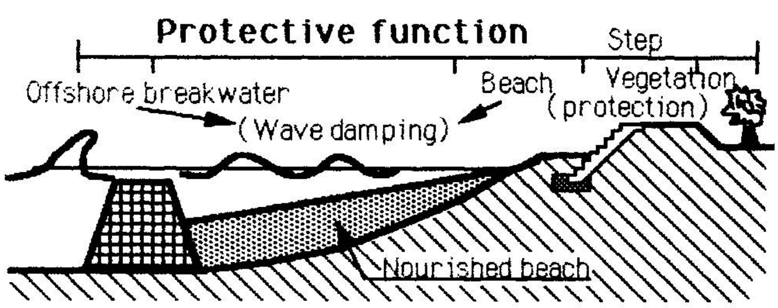

Fig. 2 : Conceptual Diagram of the Zonal Protective Method.

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 most appropriately arranged to provide disaster prevention to a given place in the vicinity of the shoreline. This method is benefical by encouraging comprehensive use of nearby on-shore areas. At the same time, these zonal protective structures have great resilence, functioning as a thick buffer against the threat of the sea.

- <u>Aesthetic values</u> : At the dawn of the 21th century, where ports and harbors are concerned, the estuary aesthetic values must be protected because they will be completely modified by the building of large structures such as storm surge barriers. As a result of this protection purpose and the small frequency of storm surge and the navigation needs, these barriers are not used during more than 99% of the time. So, whether they stay at a high suspended position as in Hull (Fig. 3a) or at Osaka (Fig. 3b), or whether they stay under the water level in the floor of the structure as the Tamise barrier in London or whether they stay along the river banks as the floating rotating barriers projected for the Antwerp (Fig. 4b) and the Rotterdam (Fig. 6) esturies protection, aesthetic appearance must be a consideration when structures are not in use. Lifting gates are not in keeping with site aesthetic values since their high frames which could sometimes reach 100m high as in an old project for Antwerp estuary (Fig.4a). On the other hand, barriers staying under water level or along the banks (Fig. 4b) are in keeping with the natural area and therefore, they are the most recommandable for further designs.

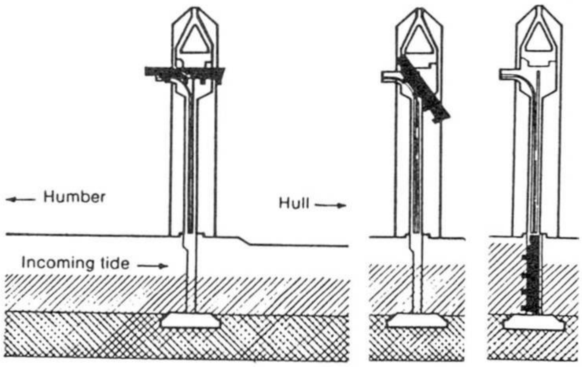

Fig. 3a : HULL lifting storm surge barrier.

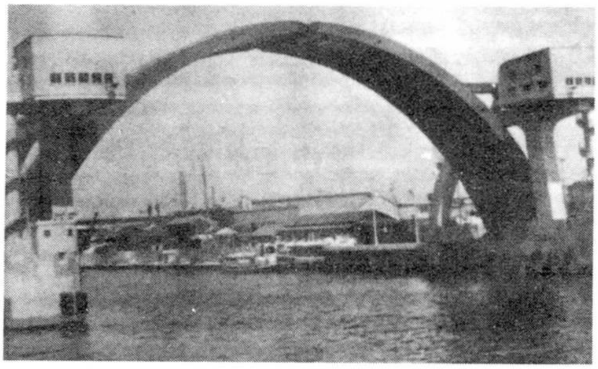

Fig. 3b : Osaka arch type gate.

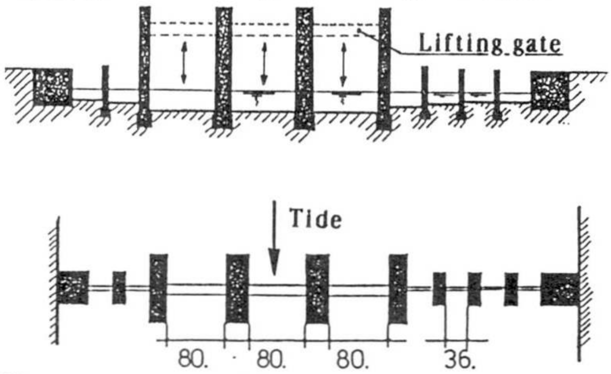

Fig. 4a: Antwerp lifting gates project.

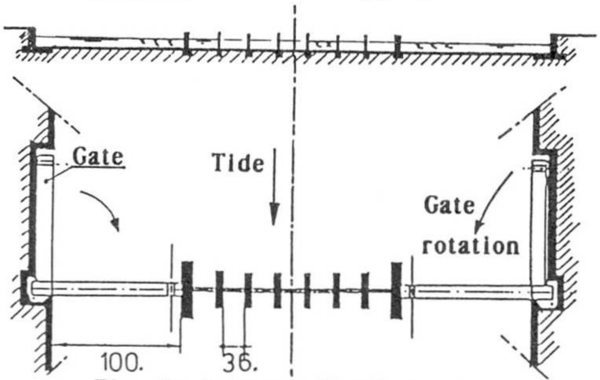

Fig. 4b: Antwerp floating gates project.

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

The recurrence period of a storm surge (mainly characterized by the highest water-level reached) will strongly be affected by the future rise in sea level. 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 curve (Fig. 5). In the North Sea this coefficient is about 1.5. Therefore, the impact on safety in low coastal area is considerable. The chance of a catastrophic event along coastal areas increases a hundred-fold by a sea level rise of 1.5m.

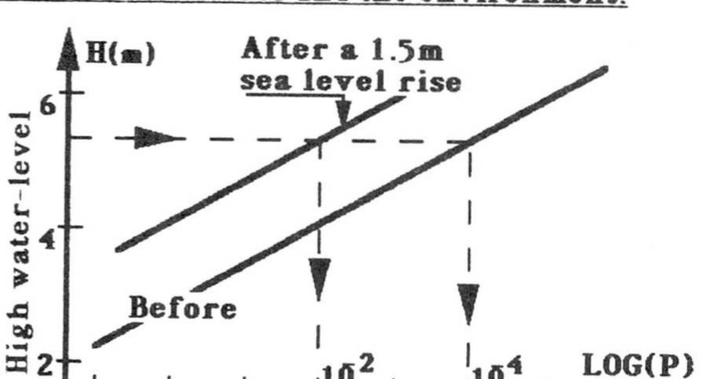

Fig. 5 : Recurrence probability of sea-water level.

The recurrence period of events such as in the case of the 1953 storm surge, would become a 3 years recurrence instead of 300 years. It means that in the future, a storm surge which was considered before only in disastrous 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 surge creates an impact on damage to the dikes, dams and coastal structures including the storm surge barriers.

The modification of the frequency of exceedance of water levels has serious consequences on the safety coefficients of the marine structures. These safety coefficients were choosen when the barriers were designed. Up to now, as in the Delta plan, a sea level rise of only 20cm 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 coefficient 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 rise but will have to be reinforced in case of 1 or 1.5m rise. "Old structures" (more than 50 years) are sometimes more economical to rebuild than to modify. With respect to the Delta plan's structures [3] , studies show that it needs 2,500 - 12,500 millions US$ to adapt protection devices in case of a sea level rise, respectively 0.5 and 1.5m . As a comparaison, these amounts are respectively 15% and 80% of the total amount of the Delta Plan's projects.

Related to the design of new structures, it may seem that their design is easy to consider. Such is not the case. Theoreticaly, it is sufficient to consider the expected sea level rise at the end of the structure's life span. In reality, the predicted sea level rise and the technical life could not be obtained with a high accuracy. Predictable of sea level rise for the next century varies on a large range (0.2m to more than 2m) according to the scientist [5]. Although the technical live span of usual marine structures is normally 50 to 100 years, in the case of storm surge barriers 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 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 decision to determine the characteritic 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 prevent the necessity of investing money, required after 50 or 100 years. So, it is recommended to combine the larger maintenance works (which are necessary owing to life span of about 100 years) with an adaptation of the structures.

3.2.2 Environment :

On the other hand, sea level rise causes effects to the environment which result in larger and sometimes irreversible damage. Loss of land of river deltas will occur as a result of erosion inundation flooding of coastal areas. As well changes in morphology and ecology increased saltwater intrusion into rivers and into saline seepage, will also occurs. 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 changing 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 it course, (in narrow coastal protected areas) will not be a better solution as natural sandy coasts will be subject to erosion and the indertidal 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 1cm level rise. Therefore a sea rise of 1m would mean about 100m of beach erosion. In the places where such retreat can not be permitted, protection devices such as the "Zonal Protective Method" as in Japan will have to be used. Sand depletions can also prevent beach and dune from retreating

3.2.3 Public opinion.

As explained, 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 the estuary protection which could take decades. Moreover, there are many other problems which compete against 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 related to sea level rise is slow or nonexistant due to the length of time period, of 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. STORM SURGE BARRIER OF ROTTERDAM AND ANTWERP.

With Rotterdam's storm surge barrier project resulting in closing of the New Waterway, the Netherlands has started a protection project for their last unprotected estuary. Several construction consortiums submitted their designs to the Dutch authorities [1, 4]. With regards to the marine environment, it is interesting to show one innovative design which remarkably protects the site aestheticism (Fig. 6).

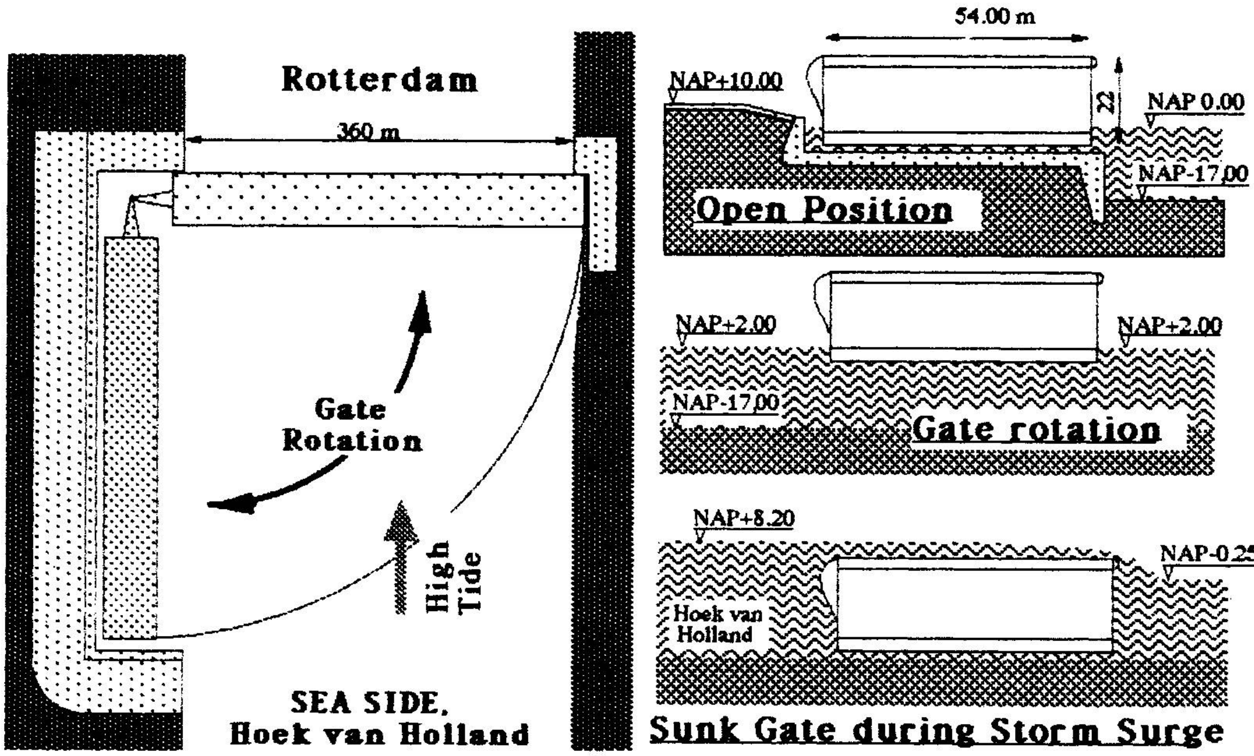

Fig. 6 : The floating storm surge barrier projected for the Rotterdam New Waterway.

In Belgium, the aim of the Sigma plan (1977) was to reduce the flooding risk to a probability of 1/10000. Completioned was planned for 10 years in the future. The main protection device was a storm surge barrier in the Oosterweel. The Antwerp's barrier had to keep two channels for the navigation of at least 60m width and 9.7m deep. In 1980, the proposed design (Fig. 4.a) was composed of 3 lift gates of 80m span and 6 radial gates of 35m span. As the requirements meant an unlimited air clearance, the projected gates had to be lifted 80m above the river water level from four towers 125m high. The excessive cost, the huge head rooms including lifting powers, and the negative effect on the environment, especially related to the site aestheticism, have caused the project to be abandoned.

Since the first step of this project, another one has been suggested which provides lower cost and higher aestheticism [6]. This design (Fig. 4.b) is composed of two 100m span floating gates, one on each side, allowing for the two directions of navigation. During the closing the floating gates have the minimum draft, thereafter they can be ballasted. The central part is composed of usual moveable weirs. This idea although not accepted at this time seems to be in 1990, the optimum one. Nevertheless, it is hoped that for the safety of this area and its population, the Belgian decision makers would at this time agree that, *an ounce of prevention is worth a pound of cure*. Thus, it is now hoped that a deep reconsideration of the Antwerp protection devices should be started soon.

5. CONCLUSIONS

With the dawing of the year 2000, interaction between the marine environment, estuary protection by storm surge barriers and sea level rise should not continue to be neglected. Therefore, the followings recommandations are made :

- Estuary protection by storm surge barrier must be considered only as a supplementary protection device for several coherent protection techniques. Dikes, banks, etc. as well as the natural environment must be able to withstand the usual sea's attacks. Moreover marine current modifications may create erosion or accretion.

- With respect to the estuary aestheticism, it is strongly recommended to plan structures as compatible to the environment as much possible, as in the case of floating tidal surge barrier.

- The most important problem of the sea level rise is the increase of the frequency of exceedance of water levels. With a rise of 1.5 meter, the probability of reaching a fixed water level which arrives 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 slow 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 indertidal area will drastically change. Moreover increased saltwater intrusion will happen. Therefore, from today, methods such as the "Zonal Protective Method" or sand depletion where beach retreat is expected, must be used.

- Because of the high risk of environment perturbation, and taking into account public opinion about estuary protection projects, high tide is particularly sensitive. Since these works have been planned for decades, an evolution of the public's opinion can occur. Then engineers are strongly advised to review periodically the uncompleted or not yet started works. On the other hand, in 1990 the sea level rise appeared to be irrelevant to public opinion. Therefore, it is also the job of the designers to anticipate such phenomenon in order for it not be necessary (for one time) for a sudden event to happen triggering countermeasures.

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