Chapter 7. Bolivar Roads Storm Surge Barrier

General findings

This chapter focuses on the Bolivar Roads storm surge barrier. The study of the barrier is comprehensive and state-of-the-art, and it is very complete in the sense that it covers a lot of aspects (technical, environmental, financial, planning). The way of online presentation and visualization of the barrier and features is innovative, and it makes the planning efforts insightful and accessible for a broad audience.

The study is clearly rooted in linked to previous studies by USACE, GLO, TAMUG / TU Delft and others, also utilizes international experience from the international I-Storm network. The constriction of the proposed storm surge barrier (7-10%) is very small compared to other barriers around the world thus leading on relatively limited effects on tidal range and flows in Galveston Bay. Based on this it would be expected that the effects on environment in Galveston Bay are minimized. This is supported by comprehensive environmental flow modelling.

Yet, there are a number of issues that need to be considered in further design and planning of the barrier:

1. The reported cost estimate of the Bolivar Roads barrier is 13.8 B$. This seems (very) high. A cost estimate of the same barrier design has been made using a recently developed method which is based on the costs of existing barriers around the world, and the dimensions of the various barrier features. This leads to a cost estimate of 4.6 B$ (bandwidth 2.4 B$ - 6.8 B$). It is recommended to (re)consider the cost estimate and optimize the design (see below).
2. The proposed floating sector gate is vulnerable for back surge. It is recommended to consider alternatives, such as a barge gate.
3. In the current plan two main navigation channels with navigational gates (each 650 ft wide) are proposed. One channel with reliable gates is expected to be reliable and sufficient for navigation. This solution will also contribute to lower costs.
4. It is required to further address longer term management, funding and maintenance of the surge barrier system (and other system features).

These topics are further elaborated in the following paragraphs. In this report reference is made to the engineering appendix of the USACE / GLO report (USACE, 2020), unless stated otherwise.

Cost estimate

The reported cost estimate of the Bolivar Roads barrier is 13.8 B$ in project first costs (FY2019)[1]. This seems very high when compared with cost estimates obtained with other methods. A cost estimate of the same barrier design has been made, using a recently developed method (Kluijver et al. 2019) which was developed in collaboration with the NY District of USACE and used for cost estimates for barriers in the New York – New Jersey harbour and tributaries study (USACE, 2019). The model is based on the costs of existing barriers around the world, and the dimensions of the

[1] Appendix D, Annex 22, p.2

various barrier features. It utilizes the following formula:

$$Cost = €157{,}000 \times Navigable\ Area + €102{,}000 \times Auxiliary\ Area + €26{,}000 \times Dam\ Area$$

Auxiliary area refers to the environmental gates; all areas in m^2; price levels in 2019 Euros. The exchange rate at this moment is € 1 = $ 1.20 and this value has been assumed here.

Note: The above formula does include planning, engineering and design costs. One difference with the USACE method might be that the above formula produces an expected (50%) cost value and also has values of the three unit cost constants for the 90% confidence interval[2]. The method by USACE includes contingencies which adds a margin of 28% to the estimated cost (appendix D; Annex 22_. It is not clear at this moment whether this contingency refers to a "variation from the mean" or some other metric.

Comparison of cost estimates

Application of the above method with the proposed barrier dimensions leads to a cost estimate of 4.6 B$ (and a bandwidth between 2.4 B$ and 6.8 B$). The distribution of the costs over various barrier features is shown in table 7-1 below. Further reference is made to appendix B and the Excel spreadsheet "Appendix_Bolivar_costs.xls" for calculations and assumed dimensions.

Table 7-1. Cost estimate of the Bolivar Roads storm surge barrier as proposed by USACE, using the recent cost estimation method from Kluijver et al (2019)

Section	**Amount of gates**	**Width per gate (ft)**	**Avg. height (ft)**	**Total costs (M$)**
Combi wall	1	5300	20	338
Environmental gate shallow	16	96	26.5	463
Environmental gate large 20ft	8	300	30	819
Environmental gate large 40ft	7	300	50	1195
Navigational gate - large	2	650	70	1594
Navigational gate - small	2	125	50	219
Total				4627

Also a simpler rule of thumb has been used. From the analysis of previous barrier projects around the world it is found that the costs per meter width of opening are 2.96 M$/m (=2.47 M€/m) (Mooyaart and Jonkman, 2017; Kluijver et al., 2019). Application of this more simple rule of thumb leads to an expected costs of 6.8 B$ (and a bandwidth between 2.8 B$ and 11.1 B$). The more recent and advanced method gives a lower estimate (4.6 B$), as the gates for Bolivar Roads are relatively small and shallow. As a reference, costs of some other barriers are included in the table below.

[2] This equation corresponds with the mean. A 90% confidence interval can be defined based upon the dataset analyzed with the following slope intervals: +/- €60,000 on the Navigational area (NA) term coefficient, +/- €54,000 on the Auxiliary flow area (AA) term coefficient and +/- €13,500 on the Dam or static term (DA) term coefficient (Kluijver et al 2019).

Table 7-2. Properties and costs (2019 M$'s) of selected barriers[3]

	Barrier properties – width of various sections (m)			
Barrier	**Navigation gates**	**Environmental gates**	**Dam length**	**Cost (M$)**
Maeslant	360	-	-	972
New Orleans IHNC	220	-	2600	1580
Eastern Scheldt	-	2790	5074	5800
Bolivar Roads	473	1840	1616	USACE: 13882 Our estimate: 4627

It is recommended to (re)consider the costs of the storm surge barrier, and compare various cost estimation methods. It is noted that cost estimates are uncertain as these are unique projects, and costs will be much dependent on the exact design, market circumstances, material prices etc.

Gate selection: Floating sector or barge gate?

In the current plan floating sector gates have been chosen for the navigational channels. This gate solution has been used in the Maeslant barrier in the Netherlands (see Figure 7-3). This type of gate is vulnerable for "back surge" (higher water level on the back side: here Galveston Bay than on the Gulf of Mexico). This situation can occur due to the rapidly rotating wind fields associated with hurricanes. Figure 2-34 in the engineering appendix (copied below as Figure 7-1) shows that negative heads occur in many of the 170 sampled storms. Cases with a negative value on the vertical axis are associated with negative head

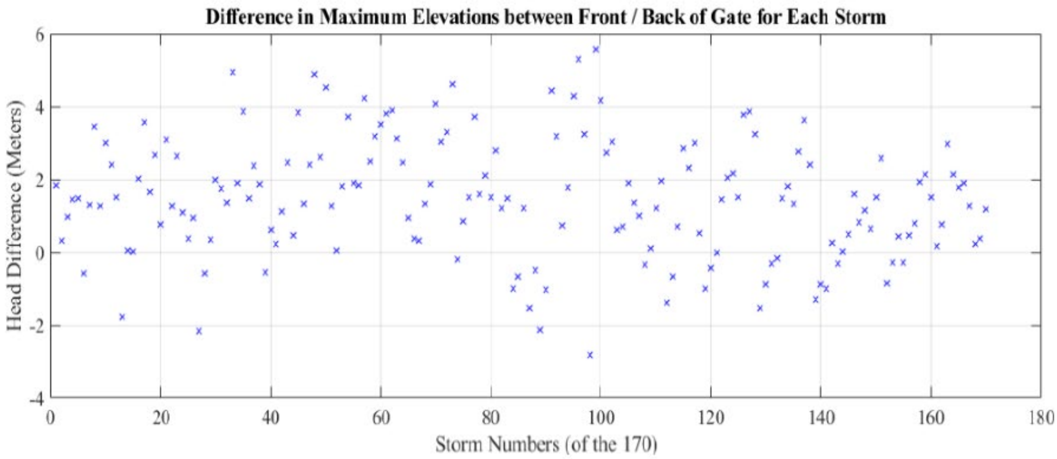

Figure 7-1. Figure 2-34 from the engineering report: Difference in elevations between front and back side of surge barrier (USACE, 2020)

[3] Source: dataset published as: Kluijver, Maarten; Dols, C. (Chris); Jonkman, Sebastiaan N.; Mooyaart, L.F. (Leslie) (2019): Dataset in support of Advances in the Planning and Conceptual Design of Storm Surge Barriers. 4TU.ResearchData. Dataset. https://doi.org/10.4121/uuid:9820d43f-9e20-48a6-a791-59e634fab30e

In case of back surge the sector gates could be "pushed out" of their hinges. The ball joint hinge is strong for pressure, but less strong for tensile forces associated with back surge.

Therefore the barge gate was selected as a preferred concept in previous design studies for the coastal spine concept (Jonkman et al., 2015) – see Figure 7-2. Such a gate could "self-open" (or at least be more easily controlled) in case of a back surge.

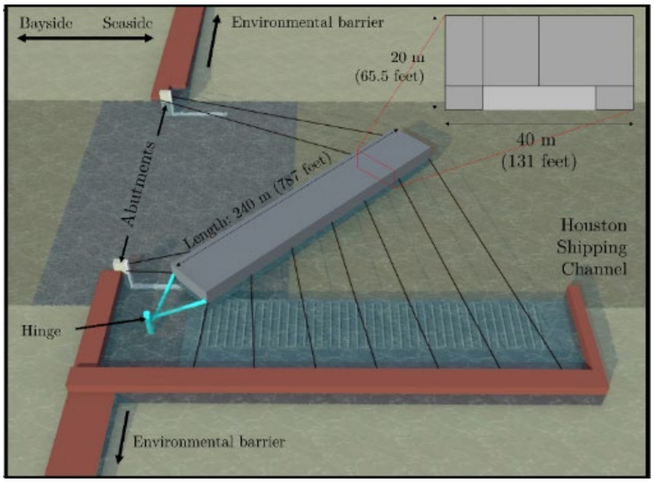

Figure 7-2. Conceptual design drawing of a floating barge gate designed for Bolivar Roads storm surge barrier (Smulders, 2015; Jonkman et al.). A structural design has been made in S355 steel for an opening of 787 ft. The weight of the barrier would be around 32,000 tons.

Other topics related to the barrier design

- Gate operation and closure frequencies:
  - It is stated on the project website that barriers will not likely be closed for a 50 year storm[4]. This is surprising as it is expected that a barrier (in combination with a good dune system) could prevent a lot of surge and damage for more frequent hurricanes (anywhere in the 5 – 50 years return period range). As a comparison, the Maeslant barrier in the Netherlands is expected to close every 5 to 10 years and the Eastern Scheldt barrier on an annual basis.
  - No further gate closure levels or frequencies have been given yet (section 9.5). This is an important aspect for operation, navigation and ports. It is recommended to give an indication by considering the expected number of hurricanes that lead to storm surge in the Galveston Bay area and gate closure. In that respect it could be useful in section 9.5 to mention to closure frequencies for the reported international barriers as well, not only closure water levels.
  - As introduced in chapter 2 of this report, it will be critically important to keep the hurricane surge including the forerunner out of the bay. The closure procedure should be optimized to achieve this.
- Scour protection (Section 6.7) my need further attention as it is also an important cost driver. This is important as very high flow velocities (~10 m/s) can occur below the floating sector gates, and when lift gates fail to close. So robust scour protection may be needed to withstand such flows and to avoid failure of support structures. Scour protection is an important cost driver.

[4] https://storymaps.arcgis.com/stories/14c41d68d8984b129edb4c133b719de3; explanation next to 50 year storm.

One or two main channels?

In the current plan 2 main navigational channels (650 ft wide) with an island in the middle have been proposed. This creates an island between the two channels thus increasing likelihood of ship groundings and collisions. Choosing for two large gates also increases the costs significantly. The main arguments for this solution focus on the added redundancy and reducing the risk of not opening after a storm (page 6-16 & 9-7).

The current width of the navigation channel is about 800 ft and required width would be about 656 ft (table 6-7). It is recommend to explore if a solution with a single large navigational barrier for the main channel would be feasible. This would also contribute to considerable cost savings.

The choice for a barge gate will reduce the risk of not opening. Also, maintenance of gates can be done in dry docks if needed. It is noted that a one barrier solution has been chosen for the Maeslant barrier which has a total channel width of about 360m (1080 ft) – Figure. 7-3.

Figure 7-3. Maeslant storm surge barrier in the Netherlands - Width: 360m (1180 ft); Depth: 17m (56ft)

Longer term management, maintenance and funding of the Bolivar Roads storm surge barrier system

It is positive that attention has been paid to OMRR&R (chapter 9). Particularly the management, maintenance and operation of storm surge barriers is important and complex. These roles still need to be assigned.

The design life of a movable barrier is generally 100 years. During this long period of time, it is important to keep the barrier in good condition in such a way that it meets the requirements, in particular the required safety level, at an acceptable cost. Besides aging of the civil structure, the mechanical parts and the electrical systems, the relatively short life cycle of software and the relatively short memory of the O&M organization form major challenges. Account should also be taken of changing circumstances during the lifetime of the barrier, including environmental changes (i.e. changing intensity of hurricanes, sea level rise) and other developments (e.g. changes in available funding and organization). This makes the O&M of a movable flood barrier a complex task, which requires a careful and object-specific approach.

Barriers in the Netherlands have been designed in a risk-based way. This implies that the barrier is designed for a certain reliability level. Also, O&M is risk-based, i.e. maintenance investments, frequencies and strategies (failure-based, time-based or condition-based maintenance) are set up in such a way that risks are minimized. It is challenging to keep a well-equipped O&M organization as the number of actual storm closures is rare.

Experiences from other barrier and flood protection systems (New Orleans, Netherlands and other locations) can be utilized to develop the management schemes. It is also important to secure and plan longer term funding streams for management and maintenance. From experience with previous barriers, it is expected that annual maintenance costs could be up to 0.5% of the construction costs.

Overall, management and maintenance of a storm surge barrier requires considerable expertise, and guaranteed funding. Given the above factors (need for expertise, longer term funding, national and international exchange), USACE seems most suited to manage storm surge barriers.

Also, the maintenance of the dune system is important, as a lot of maintenance dredging will be needed to account for coastal erosion in regular conditions and during storms. Furthermore, operation and management of the Galveston ring system will be a challenging task as it includes a lot of moveable gates, pumps etc. It would be good to define the responsible authority.

References

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