Modeling of Shutter Coastal Protection against Storm Surge for Galveston Bay

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Abstract

It is important using numerical models to evaluate the effectiveness of man made barriers to protect coastline from storm surges. Coastal protection against storm surge has become a national issue in the U.S. especially after the hurricanes Sandy, Ike and Katrina. Galveston bay with the Houston Ship channel could become potential source of concern to the region because of the industrial activities and the potential exposure to residential neighbor hoods. In the past 100 years, Galveston has had the highest number of hurricanes in Texas. In this study, Galveston Island and Houston ship channel was numerically modeled using the advanced circulation ADCIRC model for storm surge estimation and protecting using the innovative shutter concept. The modified ADCIRC can be used to numerically model and determine the effectiveness of the various heights of the shutter barrier in the Galveston Bay.

Introduction

The recent hurricanes Sandy (2012), Ike (2008) and Katrina (2005) respectively have raised the need for coastal protection for the populated coastal regions in the U.S. Hurricane Ike, in Texas Gulf Coast caused approximately $30 billion in damage and killed nearly 200 people. Galveston, Houston ship channel with the port of Houston are vital for the state of Texas and for the United State government. In fact, based on the Bay Area Houston Economic Partnership report, about 46 percent of the U.S. aviation fuel, 20 percent of the nation's gasoline supply and 40 percent of chemical-feed stocks are made in the Galveston Coast area. To prevent Galveston coast against a potential more devastating storm surge, different types of barriers are being proposed.

At present, there are only a handful of European countries that manage or have constructed large sea-resistant storm flood surge barriers. These countries include United Kingdom, Netherlands, Italy and Russia. Specially now when climate change and sea level rise are recognized facts that should be taken into account (Coastal Portal, 2010).

Through the years, numerical models have been developed to estimate the storm surges generated by hurricanes. This is done using the landing point topography, bathymetry and the hurricanes parameters including pressure, radius of max winds, location, direction and forward speeds.

The Sea, Lake, and Overland Surge from Hurricanes (SLOSH) is a computerized model developed by the National Weather Service (NWS) to estimate storm surge heights and winds resulting from historical, hypothetical, or predicted hurricanes. SLOSH is used by the National Hurricane Center (NHC) for the exclusive benefit of NWS, US Army Corps of Engineers (USACE), and Emergency Management personnel (FEMA et al, 2003). It is the primary computerized model used by US official to assess a foregoing hurricanes effect on the predicted landing point to issue emergency evacuation if required.

A more research oriented numerical model named Advanced Circulation (ADCIRC) for storm surge was developed (Luettich and Westerink, 2004) for better estimation of hurricane storm surge. The advantage of utilizing ADCIRC is its ability to map intricate shoreline and the corresponding topography needed to resolve complex fluid dynamics (Desback et al, 2010). ADCIRC unstructured grid allows modeling complex coastal regions at fine spatial scale (Chu et al, 2010)

ADCIRC Model

Coastal areas are characterized by geometrically complex features which include bathymetry, rivers, channels, bays, wetlands and man made structures (dunes, levees, harbors and transport systems). Accurate modeling of hurricane or tsunami induced coastal flooding has been limited by the use of fixed size computational domains and the lack of sufficient clarity in the grid resolution. The fixed size computational domain limits the volume of water involved in the event. Grid resolution is important to capture the varying natural features such as bathymetry and coastal profile with man made structures and barriers. ADCIRC has a large domain-unstructured grid approach to compute hurricane and storm surge. The large domain allows the storm surge to naturally and accurately propagate from deep waters on to continental shelf and adjacent coastal region. The use of unstructured grid resolves important flow features on a localized basis, accurately solving the flow features on a localized basis. In order to develop proper and adequate coastal protection, it is critical to capture the flow features and transport of sediments as the storm surge propagates and recede thorough the Galveston bay and Houston Ship channel.

Local Modeling

The use of basin size domains with highly localized grid resolution significantly improves the predictive ability of computational models of hurricane storm serge in very complex flood plains.

ADCIRC-SMS Model Controls

SMS is used to input the important parameters to the ADCIRC model. There are six different tabs that are used to input the data. The tabs include the following: (1) General, (2) Timing, (3) Files, (4) Tidal/Harmonics, (5) Wind and (6) Sediment options.

(1) General Tab: it includes the model, initial condition, Carioles option (forces due to the latitude), solver type, number of iterations per time step, generalized properties (lateral viscosity) and bottom friction(for greater than 10 m use a value of 0.005 and for shallow water use a value of 0.02).

Modeling approach

For this study of hurricane storm surge in the Gulf of Mexico around Galveston the model encompassed the domain between longitudes 93.0 W to 96.3 W and latitude 27.6 N and 30.0 N as shown Fig. 1.

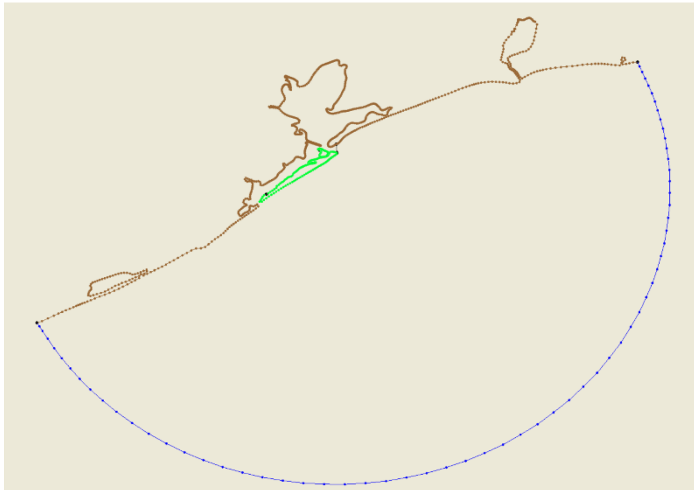

Figure 1. Shoreline and ocean boundary.

In this study, the global effect of the hurricane around Galveston with and without shutter was investigated. ADCIRC two-dimensional depth integrated (2DDI) model was used and Surface Water Modeling System (SMS) was used for preprocessing and post-processing the datas.

Coastline

The coastline data were imported from National Geographical Data Center (NGDC). Model 1 shoreline has a resolution of 1:250,000.

Bathymetry

The bathymetry data were also imported from National Geographical Data Center (NGDC). The resolution of the bathymetry data extracted can also be variable with a limitation on the maximum matrix of data that can be extracted at once. The bathymetry of model 1 has a resolution of 1 minute, (Fig. 2).

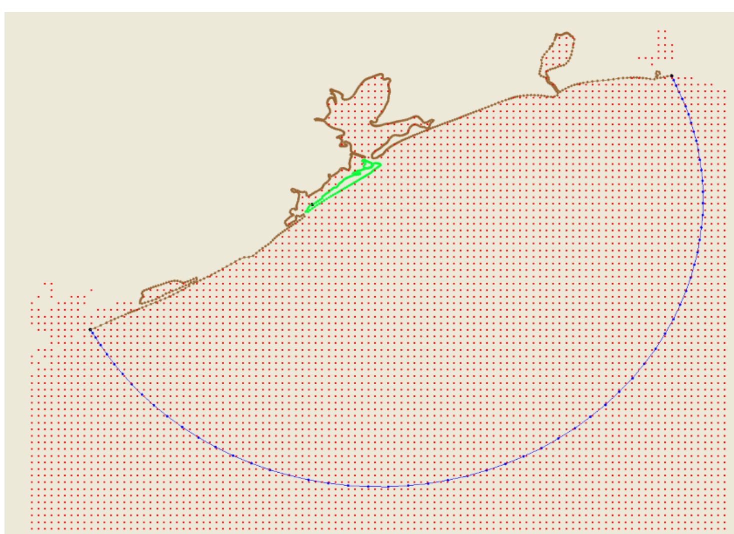

Figure 2. Shoreline, ocean and bathymetry

Protection Systems

Different methods are proposed to protect the coastal area from storm surge and coastal flooding. The immediate focus is on evaluating the potential of Ike Dike and the new shutter system (Vipulanandan et al. 2010) separately and together. In order to see the effects of shutter the model was analyzed with and without the shutter with different elevations. The objective was to determine the difference in elevation and velocity of the waves behind the shutter.

Analysis

In the analysis section, the mesh is generated over the domain as in Fig. 3. Total of three model were analyzed; the first model was for the domain without any shutter, second model was for the shutter with the elevation of 1 meter and the third model was for the domain the elevation of 3 meters. Another model was analyzed with the shutter with elevation of 5 meters.

The boundary conditions assigned to the shutter was Island Barrier. The length of the shutter is about 4.6 km and the thickness of the shutter was about 65 meter. The thickness of the shutter was limited by the selected scale of the model.

The Island Barrier boundary condition considers the flow if the barrier is overtopped and zero normal flow is assumed if the barrier is not overtopped. For this boundary condition two nodestrings are required with an equal number of nodes.

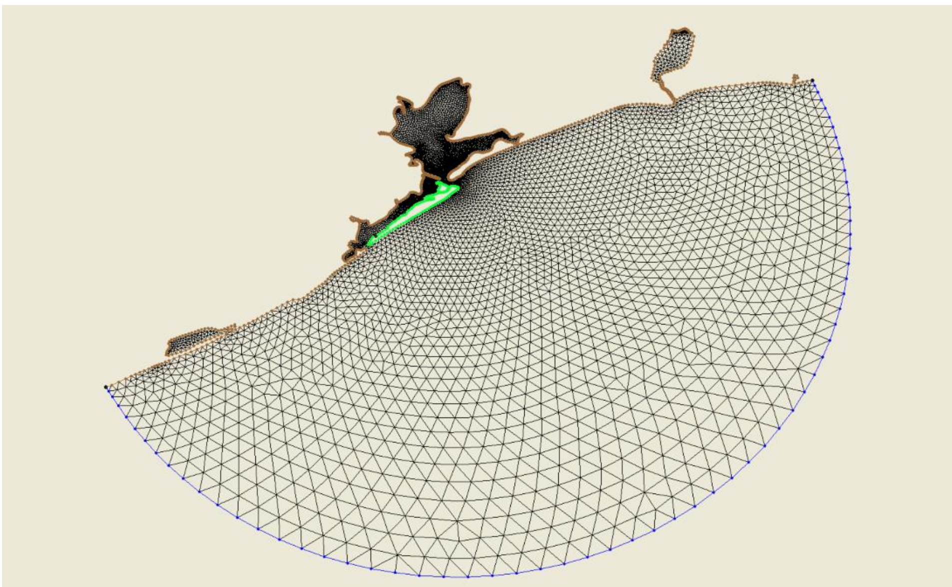

Figure 3. Mesh generation

Recording stations for water surface elevation contour was specified with and without shutter in the figure 5 and 4, respectively. The recording station in the left and right are specified as the "Back Recording Station" and "Right Recording Station", respectively.

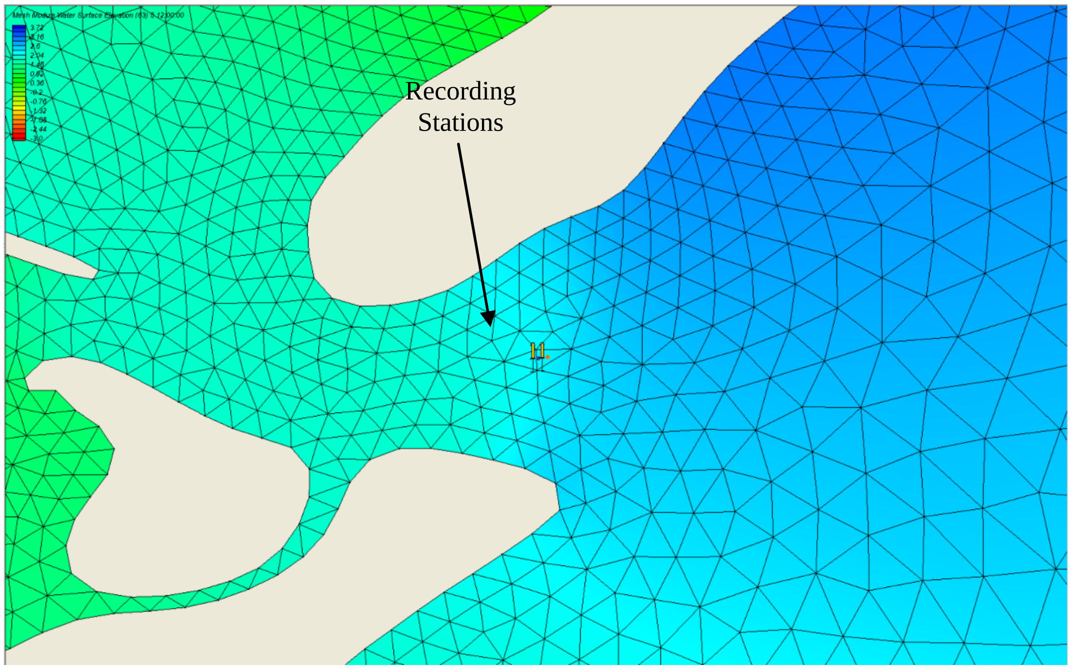

Figure 4. Recording stations on water surface elevation contour (without shutter)

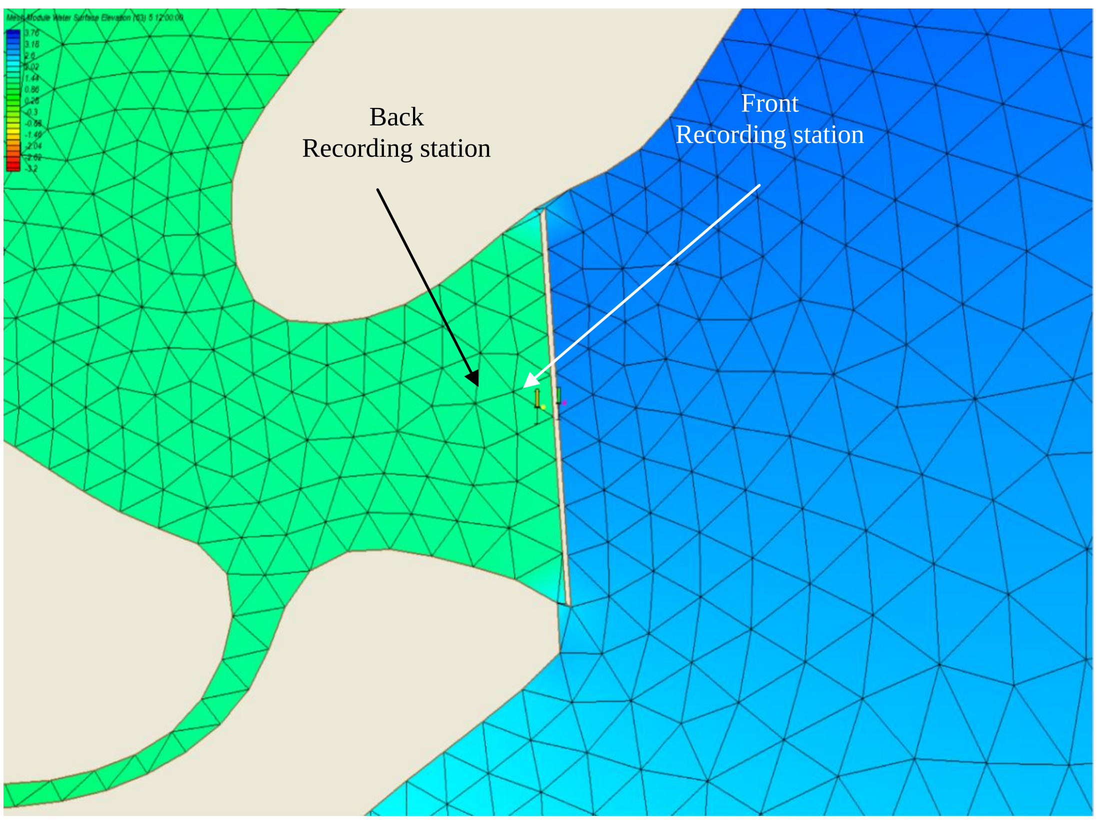

Figure 5. Recording stations for water surface elevation contour (with shutter)

In the Fig. 6, water surface elevation for the model 1 (without any shutter) was compared in the two recording stations. The surface elevations were pretty close.

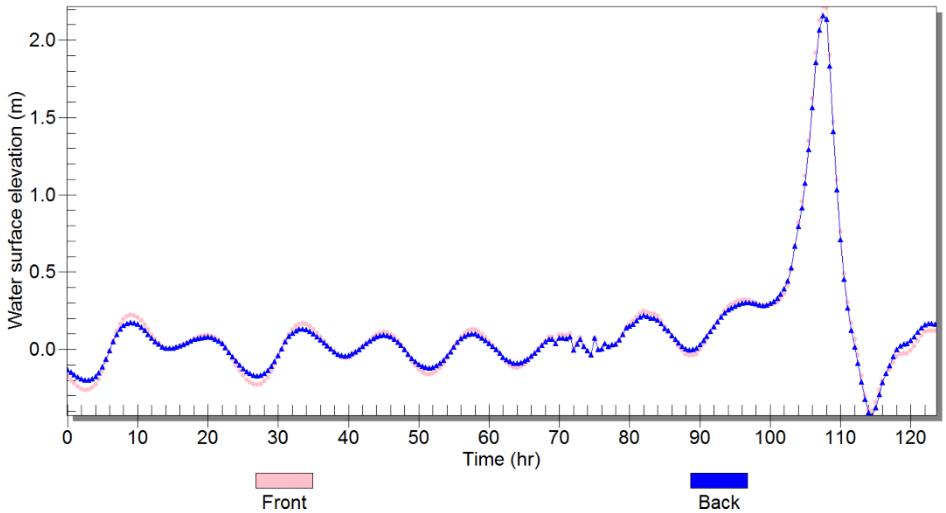

Figure 6. Water surface elevation for the model 1 (without shutter)

In the Fig. 7, water surface elevation for model 2 (shutter elevation of 1 meter) are compared in the "Back Recording Station" and "Right Recording Station".

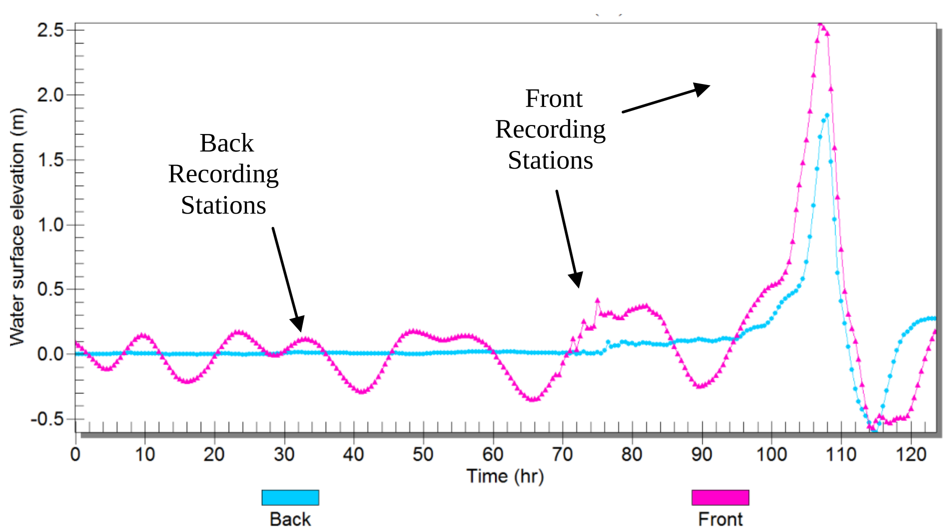

Figure 7. Water surface elevation for the model 2 (H=1 m)

In the Fig. 8, water surface elevation for model 3 (shutter with the elevation of 3 meter) are compared in the two recording stations.

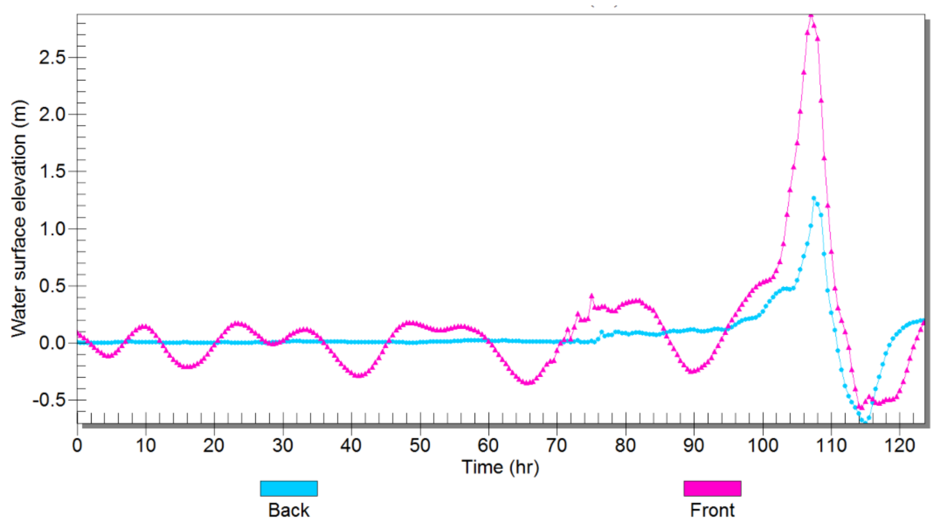

Figure 8. Water surface elevation for the model 3 (H=3 m)

In Fig. 9, the water surface elevation at the "Back Recording Station" for the three model are compared. When the shutter elevation was 1 meter, the water surface elevation was reduced from 2.2 meter to 1.8 meter, a reduction of 18 %. When the shutter was 3 meter, the back water elevation was 1.3 meter, a reduction of 41 %.

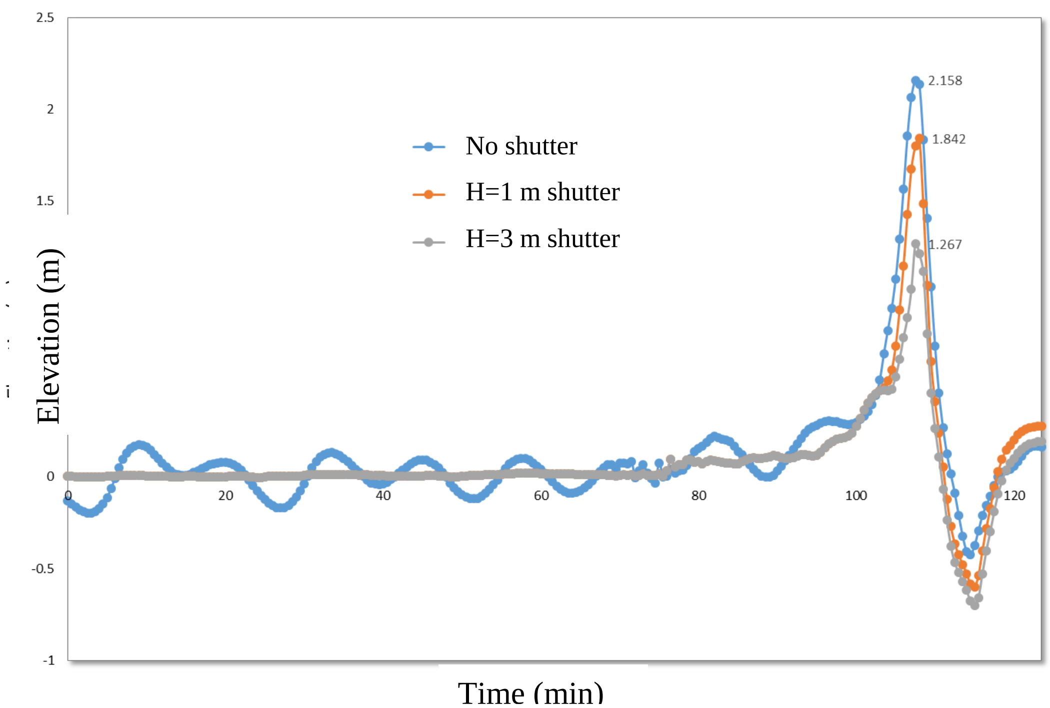

Figure 9. Comparison of water surface elevation for model 1, 2 and 3 in the "Back Recording Station"

The depth-average velocity contour in the model 3 (H=3 m) is shown in the following figure.

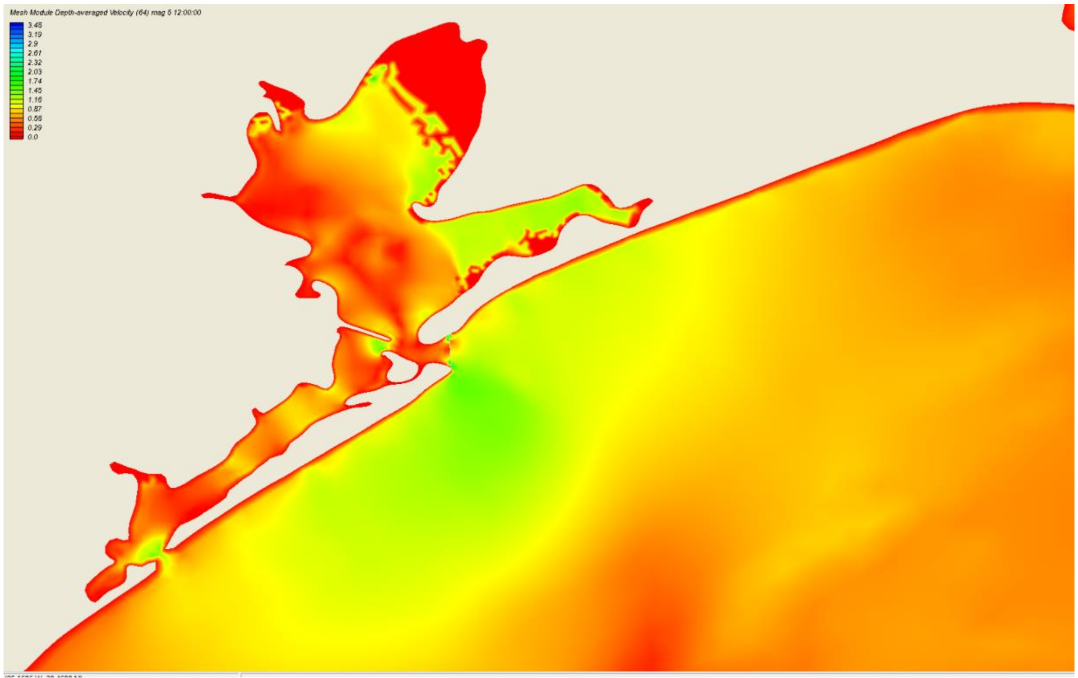

Figure 10. Depth-average velocity contour (with shutter model 3: H=3 m)

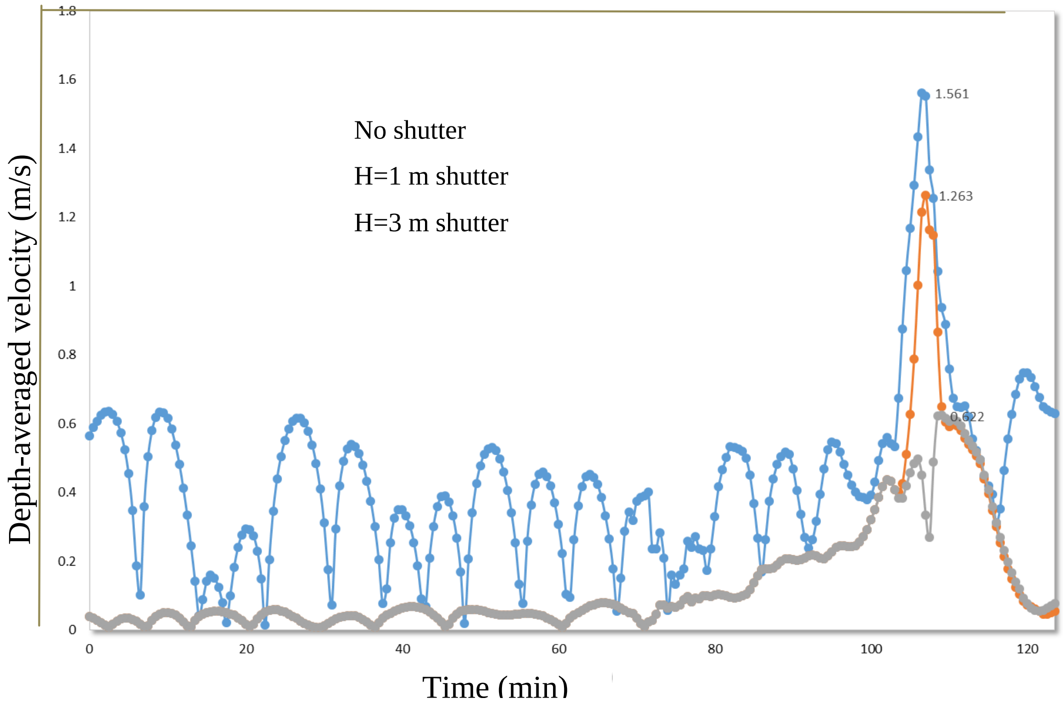

Figure 11. Comparison of depth-averaged velocity model 1, 2 and 3 in the "Back Recording Station" (time = 106.5 hr)

Based on three models it was observed that the maximum depth-average velocity (time = 106.5 hr) decreased by 60% at the "Back Recording Station" during the storm surge. When the shutter height was 3 meter (model 3).

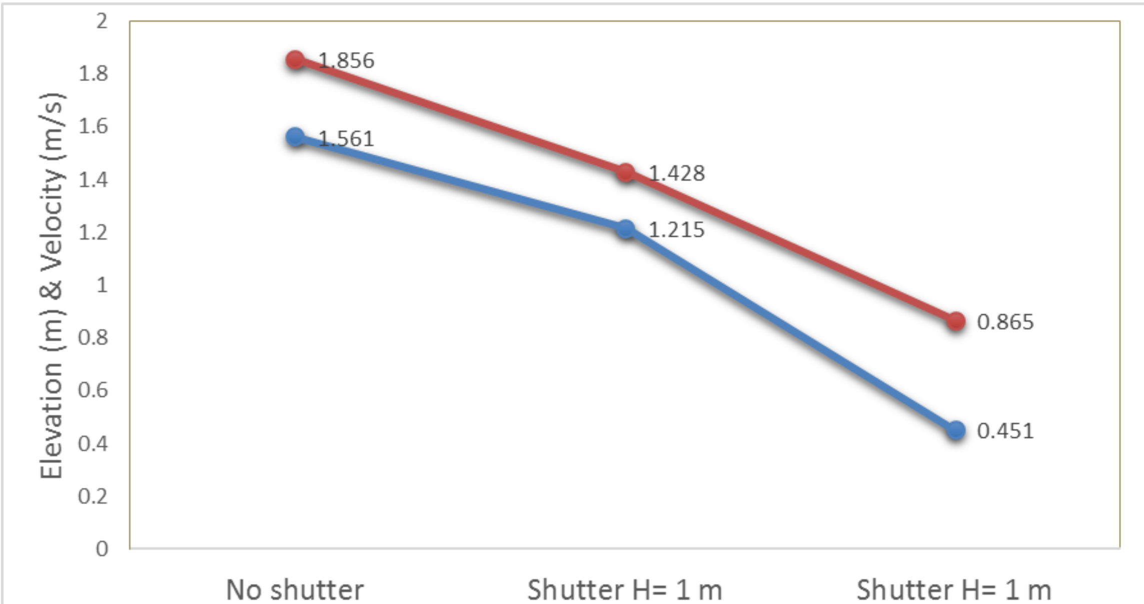

Figure 12. The elevation and velocity of waves at the critical time of t=106.5 hr in the "Back Recording Station"

As shown in Fig. 12, the shutter (H=3 m), at the critical time of t=106.5 hr decreased the elevation by 50% and the velocity by 70%.

Conclusion

It is crucial to review potential protection system of texas coast, especially Galveston and Houston ship channel, against hurricane storm surge to avoid major losses and an economic catastrophy. ADCIRC program is a very useful tool for parametric study of potential solution.
Embedded shutter with varying heights were placed at one location in Galveston Bay and analyzed with hurricane Ike simulation. The shutter height was sensitive to the velocity and elevation of storm surge waves.
in Galveston Bay is a great option to protect Texas coast, especially Galveston and Houston ship channel, against hurricane storm surge to avoid an economical catastrophy. The velocity and elevation of waves decreased

Acknowledgment

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