The success of the hurricane protection around Chevron’s refinery at Pascagoula, MS, during Katrina

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Conference theme: Emergency Preparedness and Response (if this theme includes hurricane protections) or Navigation (if protection of industry is more appropriate here).

Abstract
Chevron’s refinery along the Gulf Coast at Pascagoula is one of the largest refineries in the US. It was partly flooded by hurricane George in 1998. After a thorough modelling and economic evaluation, a decision was made to provide hurricane protection around the processing area of the Refinery, an area of 825 acres. This protection was designed and then constructed in 2000. The south and east sides of the refinery are partly protected by more than a mile of marsh and wetlands, about 4 feet above mean sea level. The hurricane protection did not experience any waves until Katrina in 2005.

The protection consists of grassed earthen levees, earthen levees with sheet piles, vertical concrete walls, various steel gates and a pipeline corridor crossing. Katrina appeared to be a condition very close to the design situation or even a little worse. This means that the protection was tested to its limits. The main fact and large success was that the refinery did not flood, where large parts of Pascagoula were destroyed or at least flooded. It shows also that a risk based evaluation and design is a good approach and can protect a major industrial complex from significant damage. Note that the surge at the refinery for George was estimated at about 8 ft, where Katrina gave around 15 ft. The refinery would have been significantly longer down after flooding by Katrina than it was for George. Now the refinery was the first along the Gulf Coast to become operational after Katrina.

The “testing” by Katrina of various types of hurricane protection gives valuable insight into the behaviour under design conditions. Of course damages occurred and even a small breach was formed at the end of the storm. But the damage was not severe enough to create flooding. Damages observed were essentially:
- erosion at the sea side by wave attack at earthen levees (actually giving nice evidence of the maximum surge level)
- erosion at the rear of vertical walls by severe wave overtopping
- damaged sheet piles by large logs and other floating debris in the water
- a small breach at the transition of earthen levee to vertical wall
- undermining of the pipeline corridor

The paper will describe the design of the hurricane protection (design conditions and design procedures, typical cross-sections), the damages observed during Katrina, and the lessons learned including repairs and upgrades performed post-Katrina.
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Contents

✓ Location, history
✓ Design protection 2000
✓ Katrina 2005
  ❖ the success
  ❖ damages, lessons learned, repair
Location
Pascagoula with refinery and marsh
Hurricane protection
Aerial view
Marsh
History

- 1969, Camille: large, but further away, low surge at refinery
- 1998, George: small, but landfall at the most severe point, just west of the refinery; surge about 8 ft; significant loss MM’s $
- 2000: design and construction of new hurricane protection; costs ≈ 10 MM $
- 2000-2005: dry, no surge, no waves
- 2005: Katrina
2000. Design of hurricane protection

Based on cost benefit analysis

✓ Surge and wave height near the coast in deeper water

✓ Surge and wave height up to the toe of the dike, including:
  ❖ extra surge
  ❖ wave breaking – depth limitation
  ❖ allowable wave overtopping at the dike

✓ Expected damages + construction costs

✓ Actual heights and cost optimum by cost benefit analysis; figures are confidential
2000: Surge vs Mean Return Period
In front of marsh

Lack extreme event data!

Statistical methods used to characterize 21 severe storms during the last century

Weibull fit: $k = 2.00$
Extra surge on marsh; Katrina at peak surge
## Allowable wave overtopping

<table>
<thead>
<tr>
<th>Accepted flood level</th>
<th>Total volume (ft³)</th>
<th>Allowable overtopping discharge ft³/s per ft</th>
<th>l/s per m</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 inches</td>
<td>10 million</td>
<td>0.2</td>
<td>20</td>
</tr>
<tr>
<td>6 inches</td>
<td>15 million</td>
<td>0.3</td>
<td>30</td>
</tr>
<tr>
<td>8 inches</td>
<td>20 million</td>
<td>0.4</td>
<td>40</td>
</tr>
<tr>
<td>1 foot</td>
<td><strong>30 million</strong></td>
<td><strong>0.6</strong></td>
<td><strong>60</strong></td>
</tr>
<tr>
<td>2 feet</td>
<td>60 million</td>
<td>1.2</td>
<td>120</td>
</tr>
<tr>
<td>3 feet</td>
<td>90 million</td>
<td>1.8</td>
<td>180</td>
</tr>
<tr>
<td>4 feet</td>
<td>120 million</td>
<td>2.4</td>
<td>240</td>
</tr>
</tbody>
</table>

Duration of peak surge: 3 hours

Allowable overtopping the Netherlands: 1 l/s per m
Dike height and profile assumption

- Levels RD = Refinery Datum
- Key point: SW
- Waves on south and east side
- No waves north side
- Lower waves west side
- Dikes; vertical walls; combinations
- Height: 60 l/s per m overtopping (0.6 cuf/s per ft)
- Various return periods; choosing cheapest option
Design south dike; space limitation (Refinery Datum)
North dike
Hurricane Katrina

Chevron, Pascagoula
Katrina by ADCIRC

The graph illustrates the surge (cm) and wind direction (deg. N) over time (hours) for Katrina. The time scale is set to 0 = 280000. The surge is represented in blue, wind direction in red, wave direction in green, and wind speed in pink. The wind direction changes from west, south, to east as indicated by the labels on the graph. The wind speed reaches a peak around 25 m/s.
Location of damages

- wave erosion + overtopping erosion behind sheet-pile
- wave erosion + overtopping
- piping failure
- overtopping erosion
- severe erosion
- breakage of PVC sheet-piles
- wave erosion + overtopping erosion
Surge at crest, no waves
Erosion by waves; trash on crest
Less erosion, trash on crest
No waves; severe erosion of gravel
Estimation surge level: 16’ – 17’ RD

crest level +17.5’

Post Katrina
1962
Germany

Estimated surge level
16.5’ – 17.5’ RD

erosion profile

surge level

19.5’

2’-3’
Hardly damage, gathering of trash
Small damage, overtopping, trash

Post Katrina
Wave erosion outer side (shadow line)

Estimation surge level 15’
PVC sheet-pile

Erosion of inner slope by overtopping;
Breakage sheet-pile
Breakage of sheet-pile by floating logs
Severe damage sheet-pile SW corner

Post Katrina
Severe overtopping, vertical wall
Overtopping damage west side
Post Katrina
Vertical wall
Piping underneath vertical wall
Sand? Cable?
Erosion at transition wall into dike
Similar spot at W corner

✔ Larger waves
✔ More erosion
✔ Overflow of water
✔ This lasted maximum 1-2 hours, when the surge decreased
Failure mechanism

- Reflection of waves along the wall, increasing to the north
- Erosion and overflow directly at end of wall
- South westerly incident waves
- Severely attacked: slope of head of levee, leading to erosion
Solution: reflection wall

- Top of levee 16.75' up to here
- +/-45 degrees
- Diffraction of waves
- South westerly incident waves
- Reflection of waves back from wall
- Sheltered area
Post Katrina: reflection wall
Conclusions

- The hurricane protection was tested to its limits = design conditions
- Success: the refinery did not flood!
- Flooding: Katrina’s surge would have resulted in 6’ more salt water inside the refinery than George
- and far more damage
- Refinery returned to full operation in 1/3 of the time required for George, critical path being wind damage repair
Lessons learned

- Surge level: \( S = 15' \) RD, \( N = 16'-17' \) RD. Local variation in shallow water
- PVC sheet-piles can cope with waves, but not with floating logs
- Acceptable wave erosion was foreseen
- Overtopping and falling water (vertical wall) needs erosion protection
- Transitions are weak points
- Piping was not foreseen
- Severe overtopping gave no damage on dikes