Structural Integrity of Storage Tanks

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Hurricane Katrina and Rita
Hurricane Ike and Gustav
Impact of Tank Failure

• Spillage of hazardous material (e.g. 8 Million gallons of petroleum products during Katrina)
• Environmental impact due to spilling of hazardous material
• Clean up costs and losses due to irrecoverable produce
• Repair and replacement costs of ASTs
Outline

• Failure modes of above ground storage tanks (ASTs) in severe storms
• Code provisions
• Houston ship channel region
• Basic failure analysis
• Preliminary recommendations and future work
Failure Modes: Flooding
AST Uplift/Displacement Mechanism
Failure Modes: AST Buckling

• Due to external water pressure on tank shell caused by flooding
• Due to debris and wave impact and external wind pressure

• **Welded Tanks for Oil Storage**
  – 5.2.1 I(1): *Design for external pressure* and flotation to be *decided by purchaser*.
  – E6.2.1 & F1.3: *Anchorage* to prevent uplift and overturning due to *earthquakes and internal pressure* only.

• No mandatory provisions for shell buckling and prevention of tank uplift due to flooding.
Houston Ship Channel Region: Location of Tanks
“Draft” 500 Year Return Period Surge Height Estimates (FEMA\(^1\))

- Out of 4197 tanks in the region, 1485 tanks lie within 500 feet.
- 35% tanks susceptible to flooding.

Analysis of Tank Dimensions

• Inventory analysis through ArcGIS using areal imagery
• Roof type (fixed, floating, open)
• Tank diameter
• Tank height (difference of full feature and bare earth digital elevation model)
Analysis of Tank Dimensions

Fixed roof Tanks

Floating roof Tanks
Preliminary Analysis: Typical Tank

- Fixed roof tank (flat roof)
- Aspect ratio (H/D) : 0.4
- Tank height : 25’

- Tank diameter : 62’
- Shell thickness : 0.394”
- Vary S and L

D: Tank diameter
H: Tank height
L: Liquid level inside tank
S: Surge height

Liquid pressure

D: Tank diameter
H: Tank height
L: Liquid level inside tank
S: Surge height
Flotation Analysis

Self weight + Liquid weight > Weight of water displaced

\[
\left( 2\pi DH + \frac{2\pi D^2}{4} \right) t \rho_s + \frac{\pi D^2}{4} L \rho_l > \frac{\pi D^2}{4} S \rho_w; \ S < H
\]
Flotation Analysis

Rule of thumb
To avoid uplift height of liquid inside the tank should at least equal external surge height. Exact amount of liquid height needed may vary depending on liquid density.
Possible Solution: Anchoring Tanks

• Provide equally spaced anchors around the base
• May require large number of anchors for large tanks and sufficient foundation
Shell Buckling

Bifurcation buckling analysis

Flat roof (62.5x25), internal liquid: water

No buckling (safe)

Tank buckles (unsafe)
Shell Buckling (Internal Liquid)

Flat roof (62.5x25), internal liquid: water

Flat roof (62.5x25), internal liquid: lighter than water (50lb/ft³)
Shell Buckling (Tank Dimension)

Flat roof (62.5%×25), internal liquid: water

Flat roof (50%×50), internal liquid: water

D=62.5’

H=25’

D=50’

H=50’

Surge height (H) (feet)

Liquid height (L)
Possible Solution: Stiffening Rings

Stiffening rings
Conclusions and Recommendations

• Past events show vulnerability of ASTs to hurricane events and in particular to surge.
• Predominant failure modes include flood induced displacement, shell buckling and rupture.
• Houston Ship Channel ASTs are in a hazard prone region that poses a major threat.
Conclusions and Recommendations

• Fill entire tank with water prior to the storm, if possible.
• Fill the tank with produce, at least 4-5 feet higher than expected surge.
• Anchor tanks to prevent uplift.
• Use stiffener rings to prevent buckling from surge and wind loads.
• Conduct detailed risk assessment to evaluate impact of mitigation strategies in the face of uncertainties.
Future Work

• Probabilistic study and parametric analysis on tank floatation and shell buckling during flooding events.

• Non-linear buckling analysis and stochastic modeling of imperfections.

• Dynamic wave impact study on tanks.

• Quantification of the impact of risk mitigation strategies (protective, structural, procedural).
THANK YOU!

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