Hurricane vulnerability of aboveground storage tanks in coastal Louisiana

Background: Coastal Louisiana houses several ports, oil and gas facilities, and petrochemical industry installations. Aboveground storage tanks (ASTs) are widely used in these industries to store a variety of substances, such as crude oil, petrochemicals, and other hazardous substances. ASTs are susceptible to failure during hurricanes, which can disrupt the oil and gas supply chain. At the same time, hazardous spills due to AST failure can be catastrophic to the surrounding eco-systems and communities. For example, during the infamous Murphy oil spill (Figure 1), the failure of just one AST in Meraux, LA, during hurricane Katrina released over 25,000 barrels of mixed crude oil into the surrounding environment—rendering over 1700 houses un-inhabitable. Due to the lack of provisions in design guidelines such as American Petroleum Institute (API) 620 [1] and API 650 [2] to prevent AST failures during hurricane surge and flood events, recurring failures have been observed during past hurricanes such as Katrina and Rita [3], Ike and Gustav [4], and more recently during hurricane Laura [5]. Figure 1 shows ASTs damaged in Cameron, LA, after hurricane Laura [5].

Figure 1. Aerial view of Murphy Oil spill (Source: www.archive.epa.gov/katrina/web/html/index-6.html).

Figure 2. Damaged ASTs near Cameron, LA, after hurricane Laura (picture taken by the PI).

At present, implementation of any measures for storm surge failure prevention of ASTs is left to the owners' discretion. Furthermore, flood mitigation plans in Louisiana, such as the Coastal Master Plan, do not consider damage to such infrastructure to inform mitigation actions.

Existing studies have developed physics based fragility models using finite element simulations for hurricane induced flotation [6], sliding [7], wave [8] and surge [9] buckling, and wind buckling failure modes [9]. Khakzad and van Gelder [10,11] and Qin et al. [12] developed system fragility models for ASTs subjected to floods events for flotation, sliding, and buckling failure modes. Additionally, empirical models are available to assess the likelihood of spills [13].

Knowledge Gaps: (1) Even though coastal Louisiana is dotted with large number of ASTs, there is limited understanding of likelihood of AST failure during hurricanes in coastal Louisiana (2) The effectiveness of regional risk mitigation measures, such as the Coastal Master Plan, in preventing AST failure is unknown, and (3) Limited research exists on structural engineering-based mitigation measures that can prevent hurricane surge induced failures of ASTs. <u>This research will focus on the first two knowledge gaps</u>.

Objective: Assess the hurricane vulnerability of ASTs in coastal Louisiana and estimate the effectiveness of the regional hurricane risk mitigation measures, such as the Coastal Mater Plan, in preventing failure of industrial infrastructure such as ASTs.

Relevance to CPRA: The knowledge on the probability of AST failures can be used for 1) identifying regional risk mitigation measures to reduce the risk of AST failures and 2) better quantification of cost to benefit ratios for regional risk mitigation measures due to consideration of reduction in vulnerability of industrial infrastructure, Overall, the proposed research will help maintain a working coast, a key priority in the Coastal Master Plan, by reducing the likelihood of AST failures which would reduce disruptions to the petrochemical industry, avoid potential environmentally catastrophic spills, and adverse social consequences.

Methodology: To achieve the research objective, five research tasks are proposed which will help compare the probability and consequences of hurricane failure (wind, surge, and wave induced) for ASTs in coastal Louisiana for various return period events considering current and future conditions (including sea level rise and subsidence) with and without the risk mitigation measures.
Task 1: Identify location and geometry of ASTs in a case study site: Cameron, LA, is proposed as a tentative case-study site since AST failures were observed during hurricane Laura in 2020 and will help validate the proposed research. At present, there is no publicly available dataset that provides information on the location, size, and contents of ASTs. Therefore, aerial images will be used to identify the location and diameter of ASTs in Cameron, LA. Next, along with the location of ASTs, digital elevation and surface maps will used to identify the height of ASTs. Additionally, aerial images will be used to identify the roof type as either fixed or floating.
Task 2: Determine hurricane hazard at AST locations: In this task, the results from the ADCIRC hurricane simulations conducted to inform the CMP considering different mitigation measures and future sea level conditions will be used. Specifically, at each AST's location the maximum wind speed, storm surge inundation depth, current velocity, and significant wave height will be obtained. In addition to these hazard measures, using the significant wave height estimate and water depth, the shallow water wave height estimates will be probabilistically generated using the general Weibull probability distribution proposed by Elfrink et al. [14].
Task 3: Estimate the failure probability of ASTs: Fragility models for flotation [6], sliding [7], wave [8] and surge [9] buckling, and wind buckling failure modes [9] will be used to determine the failure probability of ASTs in the case study region with and without CMP's mitigation measures. In this process, uncertainty in the fill level of ASTs, the density of stored contents, and wave heights will be propagated through the fragility models using Monte Carlo Simulations and numerical integration. The overall failure probability, considering all failure modes, will be evaluated using a series system assumption [15].
Task 4: Quantify the effectiveness of CMP's flood mitigation measures: The failure probability estimates will be used to quantify the consequences of AST failure such as repair costs and spill volumes [9] for the case study area for all the hurricane scenarios. The mean and standard deviation estimates of these performance metrics will be compared for different flood mitigation measures in the CMP for varying future sea level conditions. Based on this analysis, the most effective set of mitigation measures in the CMP will be identified.
Task 5: Generalization to other areas in Coastal Louisiana and elsewhere: A general framework for the assessment of ASTs' failure probabilities and evaluation of mitigation measures will be established. This framework will consist of a flow chart to enable future analysis of existing ASTs not captured in the study and for newly proposed sites.

Expected contributions: The proposed research could improve predictions of flood damages to ASTs which could directly impact how risk and storm damages are modeled in CLARA, ultimately benefiting the coast. At present, wind damage is not considered and the damage assessment methodology is limited on how storm damage to critical infrastructure is quantified. Therefore, this research will fill a knowledge gap that could be directly implement future planning efforts.

References

[1] API. 620: Design and Construction of Large, Welded, Low pressure Storage Tanks. Wash DC API 2002.

[2] API. 650: Welded steel tanks for oil storage. Wash DC API 2013.

[3] Godoy L. Performance of Storage Tanks in Oil Facilities Damaged by Hurricanes Katrina and Rita. J Perform Constr Facil 2007;21:441–9. https://doi.org/10.1061/(ASCE)0887-3828(2007)21:6(441).

[4] Sengul H, Santella N, Steinberg LJ, Cruz AM. Analysis of hazardous material releases due to natural hazards in the United States. Disasters 2012;36:723–43. https://doi.org/10.1111/j.1467-7717.2012.01272.x.

[5] Roueche D, Kameshwar S, Marshall J, Mashrur N, Kijewski-Correa T, Gurley K, et al. Hybrid Preliminary Virtual Reconnaissance Report-Early Access Reconnaissance Report (PVRR-EARR). Designsafe-CI; 2021. https://doi.org/10.17603/DS2-NG93-SE16.

[6] Kameshwar S, Padgett JE. Storm surge fragility assessment of above ground storage tanks. Struct Saf 2018;70:48–58. https://doi.org/10.1016/j.strusafe.2017.10.002.

[7] Bernier C, Padgett JE. Neural Networks for Estimating Storm Surge Loads on Storage Tanks 2019. https://doi.org/10.22725/ICASP13.015.

[8] Bernier C, Padgett JE. Buckling of aboveground storage tanks subjected to storm surge and wave loads. Eng Struct 2019;197:109388.

[9] Kameshwar S, Padgett J. Fragility and Resilience Indicators for Portfolio of Oil Storage Tanks Subjected to Hurricanes. J Infrastruct Syst 2018;24:04018003. https://doi.org/10.1061/(ASCE)IS.1943-555X.0000418.

[10] Khakzad N, Van Gelder P. Fragility assessment of chemical storage tanks subject to floods. Process Saf Environ Prot 2017;111:75–84.

[11] Khakzad N, Van Gelder P. Vulnerability of industrial plants to flood-induced natechs: A Bayesian network approach. Reliab Eng Syst Saf 2018;169:403–11.

[12] Qin R, Zhu J, Khakzad N. Multi-hazard failure assessment of atmospheric storage tanks during hurricanes. J Loss Prev Process Ind 2020:104325. https://doi.org/10.1016/j.jlp.2020.104325.

[13] Landucci G, Antonioni G, Tugnoli A, Cozzani V. Release of hazardous substances in flood events: Damage model for atmospheric storage tanks. Reliab Eng Syst Saf 2012;106:200–16. https://doi.org/10.1016/j.ress.2012.05.010.

[14] Elfrink B, Hanes DM, Ruessink BG. Parameterization and simulation of near bed orbital velocities under irregular waves in shallow water. Coast Eng 2006;53:915–27. https://doi.org/10.1016/j.coastaleng.2006.06.002.

[15] Melchers RE, Beck AT. Structural reliability analysis and prediction. John Wiley & Sons; 2018.