Coastal Master Plan's effect on hurricane safety of aboveground storage tanks in Louisiana

Background: About 21% Louisiana's gross domestic product and 13% of jobs were attributed to the petrochemical industry in 2021 [1]. These industries are concentrated in the coastal areas of the state that are vulnerable to hurricanes, sea level rise, subsidence, and land loss. Above ground storage tanks (ASTs) are a key component of the petrochemical facilities. These tanks are used to store a wide variety of substances such as crude oil, petrochemicals, and other hazardous products. However, ASTs are known to be susceptible to damage from hurricane induced wind, surge, and waves. The hurricane vulnerability of ASTs is evidenced by past failures during hurricanes Katrina and Rita [2], Ike and Gustav [3], Laura [4], and more recently during hurricane Ida [5,6]. Figure 1 shows a flooded storage tanks (on 09/04/2021) in the aftermath of Hurricane Ida at a chemical company in Jefferson Parish [6].

Failure of ASTs can disrupt the oil and gas supply chain and thereby disrupting the economy of the state. 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, 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.

The economic benefits of the mitigation measures in the Coastal Master Plan (CMP) have been quantified for houses and other buildings. However, the benefits of the regional storm surge mitigation measures in the CMP in terms of preventing failure of above ground storage tanks are unknown. Furthermore, for ASTs that are not protected by the mitigation measures in the CMP, structural mitigation measures need to be evaluated since design guidelines such as American Petroleum Institute (API) 620 [7] and API 650 [8] lack provisions to prevent AST failures during hurricane surge and flood events. Consequently, the implementation of any measures for storm surge failure prevention of ASTs is left to the owners' discretion. Therefore, knowledge on future risk considering sea level rise, subsidence, and mitigation measures from the master plan can also be useful for risk informed decision making to protect AST from failure during hurricane induced floods in the future.

Figure 1. Flooded storage tanks at a chemical company in Jefferson Parish after Hurricane Ida (09/04/2021).

Overview of existing research: Several studies have used simplistic models to assess the probability of failure (i.e., fragility models) for above ground storage tanks during hurricanes for different failure modes such as displacement and buckling [9], buckling, flotation, sliding, flood buckling and roof sinking [10], flood, wind, and hail [11]. Advanced finite element simulation based fragility models have also been developed for hurricane induced flotation [12], sliding [13], wave [14] and surge [15] buckling, wind buckling failure modes [15], and bottom plate failures [16]. Combining multiple failure modes, Khakzad and van Gelder [17,18] and Qin et al. [19] 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 [20] and studies have also explored calculated critical filling level (CFL) to prevent failure of ASTs during hurricanes surge [21] and wind [22].

At the reginal scale, there are limited studies that assess the probability of failure of ASTs during hurricanes. Existing studies have primarily focused on assessing the vulnerability of ASTs in the Houston Ship Channel [15,23,24]. Some of these studies have also assess the social vulnerability of communities adjacent to the Houston Ship Channel [23]. Furthermore, some of these studies have also assessed the effectiveness of regional and structural mitigation measures [15,24] in reducing the failure probability of ASTs. Most recently, as a part of an ongoing Coastal Science Assistantship Project (CSAP), Mr. Santosh Ghimire (M.S. student) and PI-Kameshwar assessed the vulnerability of storage tanks in Cameron Parish, LA during future hurricanes with and without the 2017 version of the CMP. Cameron Parish was selected as a case study region due to availability of data on tank failures from hurricane Laura, which was used for validation of the proposed approach. The results showed that the 2017 CMP has minimal impact on the failure of ASTs in Cameron Parish as the 2017 CMP did not have major storm surge reduction measures for the area. Furthermore, structural mitigation measures such as anchoring tanks reduced the vulnerability up to 50%. Furthermore, the results provided insights in to the risk of hurricane induced ASTs failure in the future. However, similar understanding of the risks and benefits (or lack thereof) of the CMP for other parts of coastal Louisiana is lacking.

Knowledge Gaps: (1) Even though coastal Louisiana is dotted with large number of ASTs, there is limited understanding of the relative vulnerability of ASTs in different parts of coastal Louisiana. (2) The additional benefits of regional risk mitigation measures, such as the Coastal Master Plan, in terms of preventing AST failure is unknown, and (3) The effectiveness of structural engineering-based mitigation measures that can prevent hurricane surge induced failures of ASTs is not well understood. <u>This research will focus on the first two knowledge gaps</u>.

Objective: Quantify the probability of failure for all ASTs in coastal Louisiana due to damage caused by hurricane wind, surge, and wave induced forces for various return period events under current and future sea level conditions and determine the effect of the Coastal Mater Plan's (CMP) flood mitigation strategies on the failure probability of ASTs.

Methodology: To achieve the research objective, the proposed research will use a framework developed as a part of ongoing the CASP research mentioned above, which is expected to be completed by summer 2024. The framework is shown in Figure 2. This framework has already been applied to Cameron Parish, LA. The proposed research aims to apply this framework to the entire Louisiana coast. Following the framework five research tasks are proposed.

<u>*Task 1: ldentify location and geometry of ASTs in Coastal Louisiana (Step 1)*</u>: Aerial images will be used to identify the location and diameter of ASTs in each coastal Parishes in Louisiana. 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. Since the methodology for this process has already been established and implemented for Cameron Parish, I anticipate that for each new parish this process will take a week. So, for all the remaining coastal parishes, this task is expected to take about 16 weeks.

<u>*Task 2: Determine hurricane hazard at AST locations (Step 2)*</u>: In this task, the results from the ADCIRC hurricane simulations conducted to inform the 2023 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. [25].

Task 3: Select fragility models (Step 3): Fragility models for flotation [12], sliding [13], wave [14] and surge [15] buckling, wind buckling failure modes [15], and bottom plate failure [16] will be considered to determine the failure probability of ASTs. Based on the severity of the various hurricane hazards at a given location, appropriate fragility models will be selected following the approach established during the ongoing CSAP research. This task will provide location specific recommendations for selection of fragility models.

Task 4: Quantify the probability of failure and its consequences (Steps 4 and 5): Using the appropriate fragility models identified from the previous task, first, ASTs' probability of failure for each hurricane scenario will be quantified. The probability of failure will be used to further determine the consequences of failure such as spill volumes, repair costs, and cleanup costs [15]. 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.

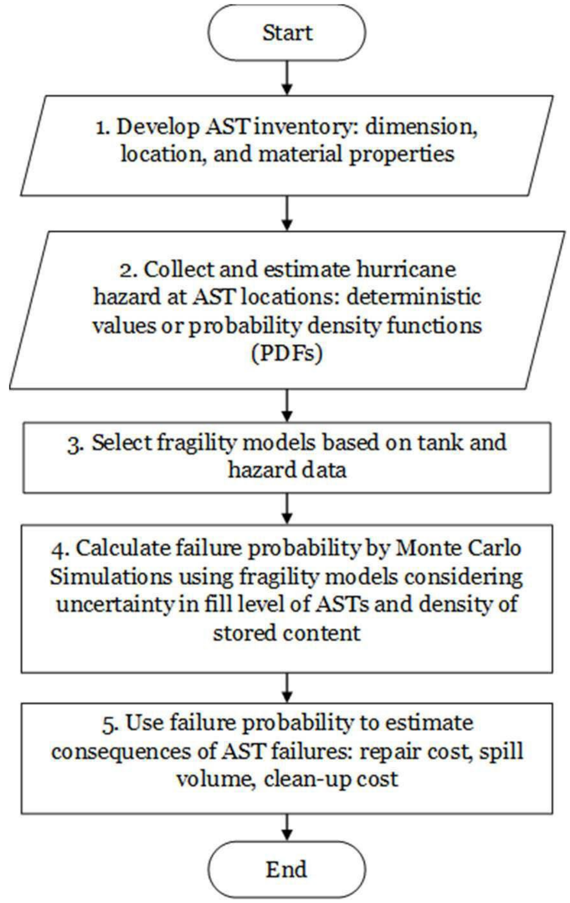

Figure 2. Framework for regional level assessment of AST's hurricane induced failure probability.

Task 5: Quantify the benefits of 2023 CMP's flood mitigation measures: The mean and standard deviation estimates of failure probabilities and associated consequences of failure, listed above, will be compared across different regions with and without the different flood mitigation measures in the 2023 CMP for varying future sea level conditions. Based on this analysis, the regions with most vulnerable ASTs and the additional benefits of the 2023 CMP in terms of reducing the failure of ASTs will be quantified.

Relevance to CPRA and expected contributions: At present, hurricane damage to ASTs is not considered in the CMP. The proposed research could help include estimates of hurricane damages to ASTs, which could lead to better quantification of cost to benefit ratios for regional risk mitigation measures due to additional benefits from the consideration of reduction in vulnerability of ASTs. This effort could directly impact how risk and storm damages are modeled in CLARA. Furthermore, the research findings will provide insights on regions with high vulnerability of ASTs, which could help select mitigation measures that reduce vulnerability of ASTs along with infrastructure that is already considered in CMP. This research will fill a knowledge gap on vulnerability of ASTs in coastal Louisiana that could be directly implemented in future planning efforts.

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