Design Criteria for Temporary Structures in Uncertain Extreme Natural Hazard Load Environments

Eman Saleh
Hashemite University, Zarqa, Jordan
&
Jamshid Mohammadi
Illinois Institute of Technology, Chicago, USA

Definition

Temporary structures:

are systems that are used for short period applications such as in maintenance and retrofit applications or for staged performances.

Examples of its applications:

are tents, scaffoldings, and other facilities that have a short service life. Structures under construction and structures under serviceability conditions also fall under this category of structures; because their service time period is only limited to the duration of the construction, which is much shorter that the lifetime of the finished structure.

Motivation

The design of temporary structures can be altered in response to a forecasted hurricane. This should be a basis in deciding the required temporary bracings and for estimating the adequate catastrophe cover such as insurance premiums and reinsurance of steel frames under construction during the hurricane season.

Research objective

Suggest three stages of stochastic optimization formulation that could help in choosing the appropriate design wind load, given that the wind load is uncertain. The method presented evaluates the expected cost of the contingency plan against hurricane wind load.

Catastrophe based Model of Hurricane Risk for Temporary Structures Design

Before bidding, contractors must identify the cost of a contingency plan if erecting is to be during the hurricane season in order to decide whether the risk is acceptable or a catastrophe risk transfer measures are necessary. Communications between the contractor, owner and erector are necessary ideally before bidding to ensure that the cost of a contingency plan is not prohibitive.

Catastrophe based Model of Hurricane Risk for Temporary Structures Design - Model Formulation

In the design of temporary structures, a recourse decision after observing of uncertainties may be possible which represents an opportunity for contractors to reach a more optimal design. Stochastic optimization provides one of the tools for optimizing the design while considering the effect of uncertainties.

Catastrophe based Model of Hurricane Risk for Temporary Structures Design – Model Formulation

Problems facing the contractor, in case of steel structure construction in hurricane season, can be summarized as follows:

- At the beginning of the project, the erector needs to decide on a certain design wind speed x1. This is the decision stage and can also be denoted as [here-and-now] decision that implies a cost A(x1).
- After forecasting a hurricane, the erector may decide on the installation of additional temporary bracings. This new decision is made after forecasting implies an additional cost B(x1, x2, ξ1) that is a function of the construction sequence, ξ1, first stage decision, x1, and second stage decision, x2.

Catastrophe based Model of Hurricane Risk for Temporary Structures Design - Model Formulation

- Depending on the realized wind (or hurricane), $\xi 2$ and the stage of construction, $\xi 1$ the demand is $d(\xi 1, \xi 2)$.
- Since the installation of temporary bracings was based on the forecasting of an incoming hurricane and not the actual wind speed, an additional cost of failure, $D(x1, x2, \xi 1, \xi 2)$ may apply that depends on the altered design wind speed (i.e., after the installation of additional temporary bracings) and the actual demand $d(\xi 1, \xi 2)$.

Catastrophe based Model of Hurricane Risk for Temporary Structures Design - Model Formulation

Consequently, the total cost for each here-and-now variable

$C(x1, x2, \xi1, \xi2) = A(x1) + B(x1, x2, \xi1) + D(x1, x2, \xi1, \xi2)$ is a random variable.

For practical purposes, the formulation is approximated by a scenario tree (see Fig. 1) and using the generated scenarios, the expected value of the total cost can be optimized and the formulation can be solved for the optimum [here-and-now] decision variable (i.e., design wind speed at the beginning of the construction period).

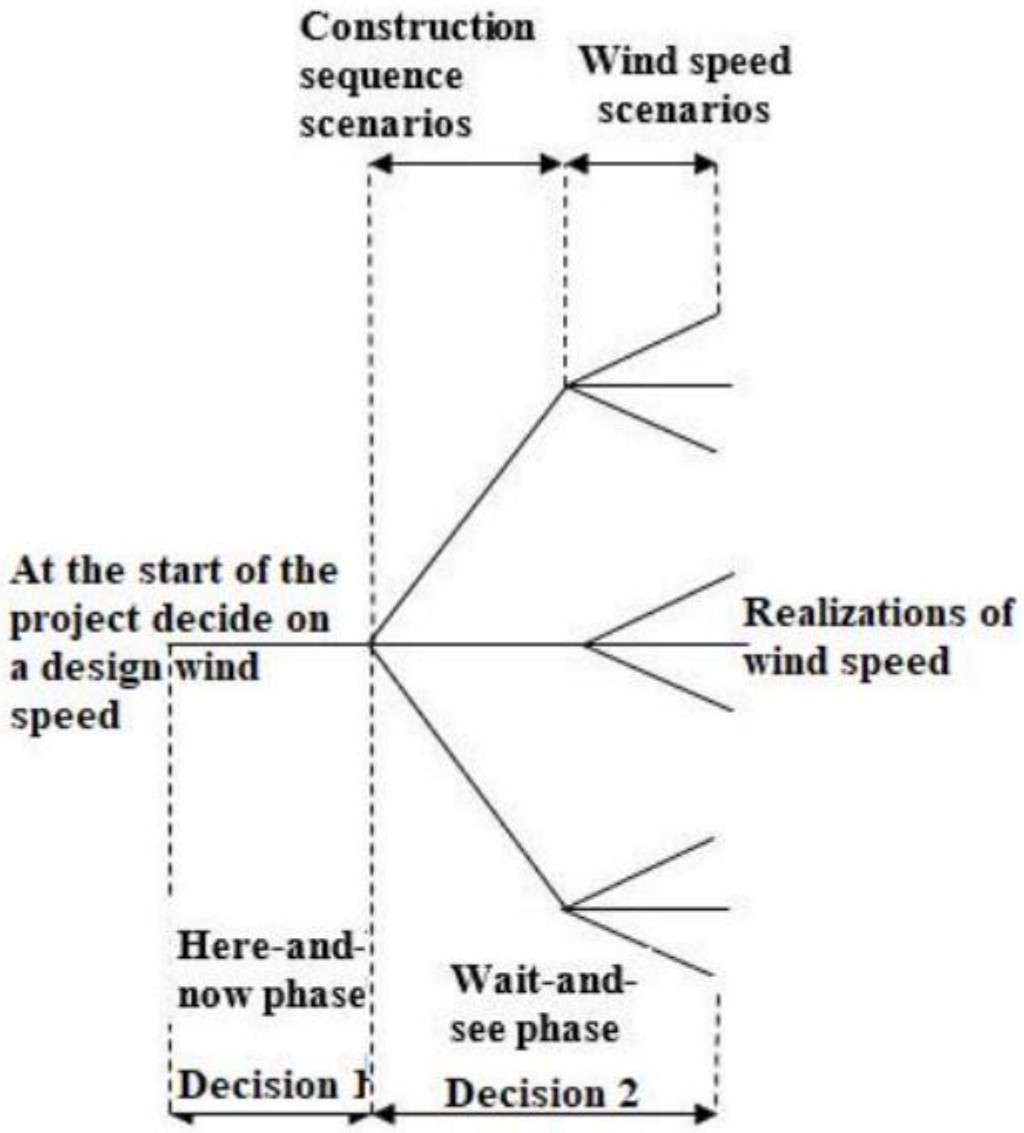

Fig. 1: Scenario tree of the decision problem

Model Formulation

Using the generated scenarios, the stochastic optimization formulation could be rewritten as follows

$$\min_{x_1 \geq x_1^l} c_0 x_1 + \sum_{i_1 \in \Omega_1} p_{i_2} \, \mathrm{Q}_1(\mathrm{x}, \xi)$$

Where:

$$\mathrm{Q}_1(\mathrm{x}, \xi) = \sum_{i_1 \in \Omega_1} p_{i_1|i_2} \left\{ \begin{array}{c} \min[\, c_1\left({\xi_1}^{i_1}\right) x_2\left(x_1, {\xi_1}^{i_1}, {\xi_2}^{i_2}\right) + c_2\left({\xi_1}^{i_1}\right) w\left({\xi_1}^{i_1}, {\xi_2}^{i_2}, x_1, x_2\right)] \\ s.t \\ x_1 + x_2\left(x_1, {\xi_1}^{i_1}, {\xi_2}^{i_2}\right) \geq k\left({\xi_1}^{i_1}, {\xi_2}^{i_2}\right) \\ x_2\left(x_1, {\xi_1}^{i_1}, {\xi_2}^{i_2},\right) \leq \left(e - \Pi\left({\xi_1}^{i_1}, {\xi_2}^{i_2}\right)\right) M \\ x_2\left(x_1, {\xi_1}^{i_1}, {\xi_2}^{i_2},\right) \geq 0 \end{array} \right\}$$

i_1 *and* i_2 are the scenario generated of the construction sequence, and wind speed, respectively.

p_{i_1} and p_{i_2} are the probability of being in the construction sequence i_1, and the probability of realizing a wind speed i_2, respectively.

${\xi_1}^{i_1}$ is a realization of a construction sequence such that $i_1 \in \Omega_1$, where Ω_1 is the space construction sequence scenarios.

${\xi_2}^{i_2}$ is a realization of a wind speed forecast such that $i_2 \in \Omega_2$, where Ω_2 is the space of wind speed scenarios.

x_1^l is the lower bound of first stage design wind speed that could be based on the daily expected wind speed.

$p_{i_1|i_2}$ is the conditional probability of realizing construction sequence i_1 at realized wind speed i_2.

$c_0(\xi_1)$ = cost coefficient that converts first stage design variable x_1 to monetary value. To consider the dynamic nature of construction where the cost of temporary bracings does not apply until the start of the new construction sequence, this coefficient is assumed to be a function of the construction sequence ξ_1.

$c_1(\xi_1)$ = cost coefficient that converts second stage design variable x_2 to the monetary value that is a function of the construction sequence.

$c_2(\xi_1)$ = cost coefficient that converts the deficiency of meeting the actual demand that is a function of the construction sequence.

$k(\xi_1, \xi_2)$ = the forecasted demand at the second stage (i.e., after forecasting a hurricane) that is a function of construction sequence and forecasted wind speed.

e is a vector of ones (i.e., $e_s = 1$ for all construction sequence, s)

$\Pi(\xi_1, \xi_2)$ is equal to 1, if the contractor cannot fulfill the required design wind speed at a certain construction sequence in the time limit of response (generally the response time for a hurricane is between 3 to 4 days) and $\Pi(\xi_1, \xi_2)$=0 if he can install the additional temporary bracings in the time limit for response. This value is assumed to be dependent on the construction sequence, and forecasted wind speed.

M is a large positive constant (e.g., 1×10^9). There is only one restriction on M, i.e., M should guarantee that some feasible x_2 always exists, such that the time constraint for taking a response action can be met.

Example. Steel frame under construction during the hurricane season

Consider this situation:

The contractor needs to decide on a design wind speed value before the starting of the construction where the construction falls in the hurricane season. In this example, the construction was decomposed into 16 construction sequences as shown in Fig. 2

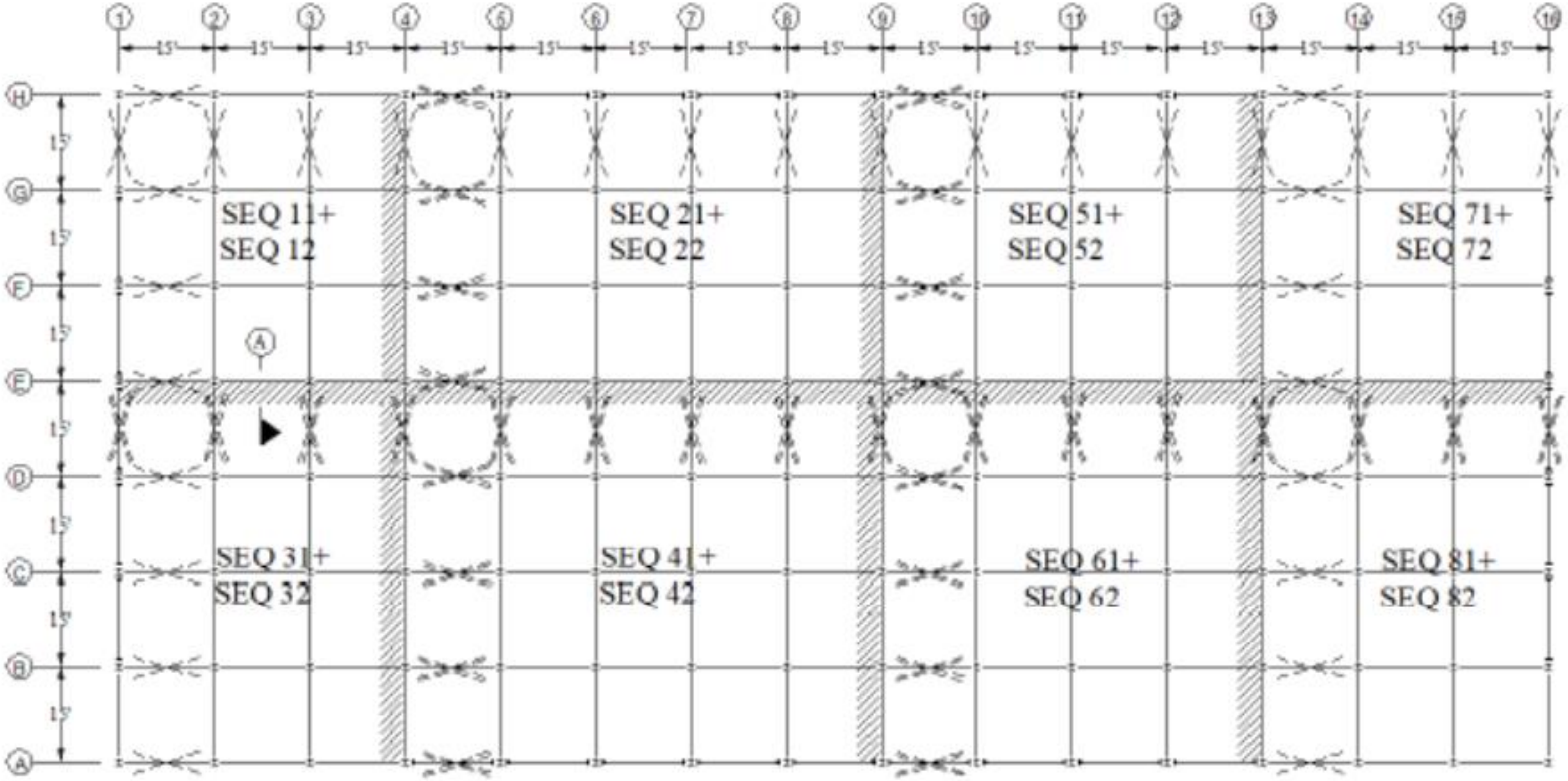

Fig. 2: The sequence plan of construction

Economic information

- The cost coefficient of initial temporary bracings, $c_0 = 100$

- The cost coefficient of the additional temporary bracings needed once a hurricane is forecasted can be higher than the initial unit cost if the surge in the prices once a hurricane is forecasted is considered. In this example, we use $c_1 = 150$

- The cost of failure if the demand was not met varies with the construction sequence is also needed,
- The cost of failure of each sequence is assumed to be equal to $10,000.

For simplicity in the optimization, $w\left(\xi_1, \xi_2, x_1, x_2\right) = \max[d\left(\xi_2\right) - (x_1 + x_2), 0]$. This condition implies that the cost of failure only applies if the demand $d\left(\xi_2\right)$ was higher than the new altered design wind speed of the sequence. The probability of being in any construction sequence is assumed to be equally likely.

Other required information

- The conditional probability is evaluated assuming independence between wind speed and construction sequence, that is $p_{i1|i2} = p_{i1}$. However, if construction is to be partially conducted in the hurricane season, it may be necessary to consider the interdependence between the wind speed and the construction sequence, because the forecasting of the hurricane may delay or alter a particular construction sequence.

- Our construction is assumed to be located in Miami-Dade County (in the State of Florida, in US), where the associated hurricane probabilities are as follows (Klotzbach et al., 2009):

  – Probability of tropical storms bringing a wind speed that exceed 40 mph = 33.2%

  – Probability of hurricanes bringing a wind gust that exceed 75 mph to the county =11.7%

  – Probability of intense hurricanes bringing a wind gust that exceeds 115 mph to the county =4.5%.

The above probabilities are equivalent to the probability of forecasting a certain event that requires a response plan. A distribution model based on these probabilities is shown in Fig. 3. This probability distribution is constructed based on the assumption that wind speeds are equally likely to occur within the aforementioned ranges.

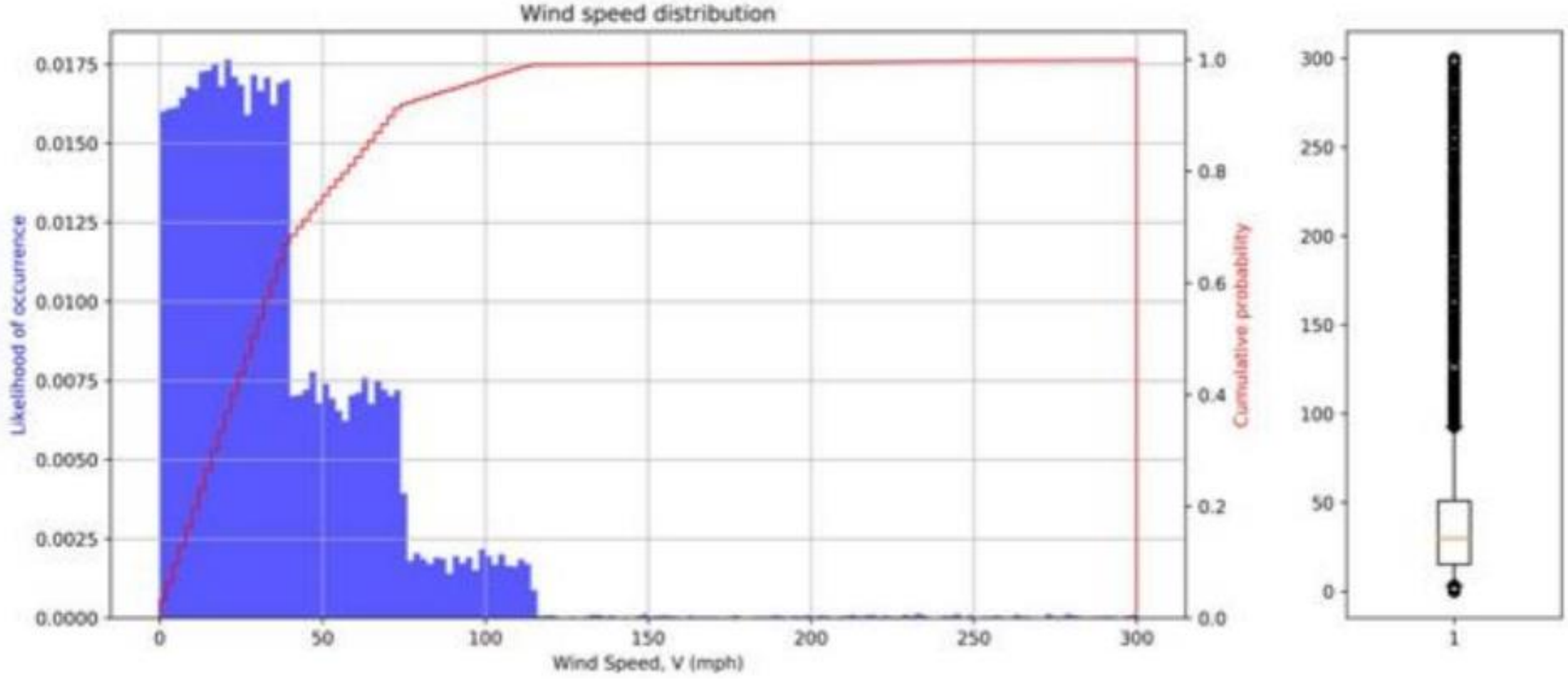

Fig. 3: Distribution of 100,000 random samples of wind speed

Optimization result

Assigning a lower bound at the first stage based on expected daily wind equal to 40 mph, the optimization model yields an expected cost of temporary bracings = \$11,200. It is noted that the optimization model finds that the lower bound of the first stage wind speed (i.e., 40 mph) is the optimum decision at all stages. This result is understandable because of the low failure cost and the use of a "neutral" risk measure (i.e., the expectation). If the failure cost is greater or a more conservative risk measure is used, a change in the decision is expected.

Concluding Remarks

- Using the suggested three-stage stochastic optimization formulation, the uncertainty in future wind effects, especially when weather forecasts predict of potentials for upcoming storms, can be incorporated in the decision-making process for a plan to safeguard against temporary structural failure especially during construction.
- The method can also be used in developing various levels of wind velocity versus failure probabilities with and without contingency plans. This type of information can then be used in selecting an appropriate design wind velocity level based on an accepted risk and anticipated cost related to the cost of failure.

Recommendation for the future work

Several issues need to be considered to extend this work:

- In our work, we presented a three-stage stochastic optimization formulation that could help in choosing the appropriate design wind load, given that the wind load is uncertain. This optimization model can be refined by considering measures of risk other than the expectation operator, if the contractor feels that a more conservative decision-making process is required. Some measures of risk that can be used are (1) conditional value at risk (C-VAR); (2) value at risk (VAR); (3) chance constraints; and (4) the worst-case scenario optimization, which seems only reasonable in highly sensitive applications such as in the case of nuclear power plant works.
- Graphs representing the wind velocity versus probability of failure for a variety of conditions and cost of failure will need to be developed specific to various costal regions that are prone to seasonal hurricane effects.

Questions?