HURRICANE IKE SURVEY ASSESSMENT AND DAMAGES

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Abstract

Hurricane IKE was the third most destructive hurricane to ever make landfall in the United States. It was the ninth named storm, fifth hurricane and third major hurricane of the 2008 Atlantic hurricane season. Hurricane IKE was blamed for at least 195 deaths. In the United States, 112 people were killed, and 34 are still missing. Damages from IKE in US coastal and inland areas are estimated at $24 billion (2008 USD), with additional damage of up to $4 billion in Cuba, $200 million in the Bahamas, and $60 million in the other surrounding areas, amounting to a total of $28.26 billion in damages. Hurricane IKE was the third costliest U.S. hurricane of all time, after Hurricane Andrew of 1992 and Hurricane Katrina of 2005. Hence it is critical to analyze the information collected from the hurricane survey. Our research is based on the survey undertaken (http://www.egr.uh.edu/hurricane/files/assessment.pdf) by the Texas Hurricane Center for Innovative Technology (THC-IT) to determine the damages to residential structures and utilities in the region. Over 550 responses were received so far on the Hurricane IKE survey. In this survey residential structures were categorized as wood, brick or concrete. Utilities investigated included water and power. The damages were grouped into three classes (minor, moderate and major) for analyses. From the response, reliability of the residential structures with different types of building materials was analyzed. A nonlinear mathematical model have been developed and verified with the collected data from the Hurricane IKE survey. The nonlinear model relates the degree of structural and utility damages with wind speed, distance from Hurricane IKE path to each zip code and density of trees. Also based on past data, reliability based model to predict the hurricane frequency along Texas coast have been developed.

Introduction

Hurricanes are among the greatest natural hazards affecting communities in the United States. In recent years, windstorm catastrophes have caused enormous economic losses and placed tremendous burdens on the insurance industry. Despite significant improvements in predicting, tracking and warning the public about hurricanes, there has been relatively little progress in our ability to estimate expected hurricane losses. These losses can be in the form of structural damage, damage to utilities or lifelines, or business interruptions. A number of models have been developed to predict losses due to hurricanes; however, these models are largely proprietary and are not available to the public. As such, they are of little value to individuals or organizations other than those for whom the models were developed such as insurance companies. After hurricane IKE, a survey was undertaken by the Texas Hurricane Center for Innovative Technology (THC-IT) to determine the damages to residential structures and utilities in the region. The response to the survey has been very good.

Natural hazards in general and hurricanes in particular, lead to loss of life and tremendous property damage and indirect economic loss for the United States annually (Mileti 1999). The earliest hurricane report comes from Christopher Columbus, who encountered a tropical storm near Hispaniola, on one of his voyages to the New World. According to statistics published by the Munich Re Group for the year 2001, windstorms were responsible worldwide for 55 % of the $36 billion in economic losses and 88% of the $11.5 billion in insured losses due to all natural disasters combined (Cope et al. 2003). The main form of losses will be the structural damage, utilities or lifelines lost or business interruption. The prediction of the impact of the hurricane in economic losses is not only be beneficial to the public, but it could also be used for the insurance company as the reference to decide their policies (Huang et al. 2001). And it's also very important for the building company to design appropriate building structure based on these information at different locations. The government could also make regulations to restrict the building wind withstanding design.

In this study, reliability of the residential structures and utilities (power and water) during hurricane IKE was investigated. A nonlinear mathematical model was developed to relate the frequency of degree of damage to structural and utilities to wind speed, distance from hurricane Ike path to each zip code and tree distribution. Also the reliability of various types of structures and the hurricane frequency along Texas coast was investigated.

Objectives

The objective was to investigate the frequency of hurricanes in Texas and failures of residential structures, power and water during the hurricane IKE that passed through Galveston and Houston, Texas on September 13, 2008. Specific objectives are as follows: (a) use NOAA database to determine the history of hurricanes in Texas; (b) analyze the Hurricane IKE survey to quantify the failures; and (c) to develop a damage model (DM-THC) to represent the damages to residential structures and utilities.

Texas Hurricane History

Reviewing the hurricane history showed that, since 1900 the Texas Gulf coast has had 42 hurricanes in the past 109 years. The population along the Texas coast has grown from 230,000 in 1900 to over 6.2 million in 2006. Hence one-third the Texas population lives along the Texas coast and have to be prepared for a hurricane every 6 months. In the past fifty years, the highest death was during hurricane Rita in 2005 and the highest damage of $28 billion was after hurricane Ike in 2008. Also of interest to note that Texas did not have any category 5 hurricane since 1900 or in the last 109 years (Texas Hurricane Center for Innovative Technology Website: http://egr.uh.edu/hurricane).

By analyzing 100 data from NOAA, the hurricane frequency has been parametrically modeled using Poisson distribution as follows:

$$f(h)=\exp(-\lambda)*\lambda^h/h!; \qquad (h=0,1,2,\ldots), \qquad (1)$$

where, h is the number of hurricane per year, λ is the expected number of hurricanes during a year. Hence based on 100 data from NOAA, the parameter λ for Texas was 0.54 (Table 1) (Liu and Vipulanandan, 2009). Interpreting the data shows that Texas can expect one hurricane every two years.

Table 1. Actual and Predicted Frequency of Hurricanes

Number of Hurricanes in a year (h)	Count	Hurricane Frequency (Real date)	Predicted Hurricane Frequency (Poisson distribution)
0	59	59.00%	58.29%
1	36	36.00%	31.46%
2	5	5.00%	8.49%
Total	100	100.00%	98.24%

Hurricane IKE Assessment Survey

Two weeks after the hurricane passed through Texas, an assessment survey was distributed to the communities in the affected regions and in the near by regions to determine the damages and how well the community was ready to receive the hurricane. The three page survey asked the participants to provide the information about their location in terms of the zip code, preparedness, evacuation, hindrance to recovery and many others. The survey also requested for information on residential structure types and the degree of damage to utilities and residential structures. The survey was supported by The Texas Hurricane Center for Innovative Technology (THC-IT) at the University of Houston. (http://www.egr.uh.edu/ hurricane/files/assessment.pdf). Based on over 550 responses, damage degree and reliability of residential structure and utility during Hurricane IKE were analyzed in terms of the wind speed and the distance from the hurricane path.

Preliminary analyses of the hurricane IKE survey data indicated that 24% of the survey participants evacuated to safer areas, which agreed with the reported overall data for the region where about 1 million evacuated from a population of over 4 million living in the Houston and Galveston areas. Of the survey respondents, about 3% indicated major structural damage to their residence.

(a) Wind Speed Distribution

Information was collected related to the wind speed data of hurricane IKE from the National Hurricane Center for each zip code in Houston area on Saturday September 13, 2008. The probability distribution function for the wind speed was fitted to normal distribution. The Fig. 1 compares the normal distribution with mean of 82 mph and standard deviation of around 2.4 mph is the best fit for the wind speed PDF distribution. The wind speed varied from 76 to 88 mph. It must be noted that the current design wind speed for the region varies from 130 mph (coastal) to 90 mph with 3 second gust (ASCE No. 7). So the reported wind speeds due to hurricane IKE didn't exceed the design wind speed for the region.

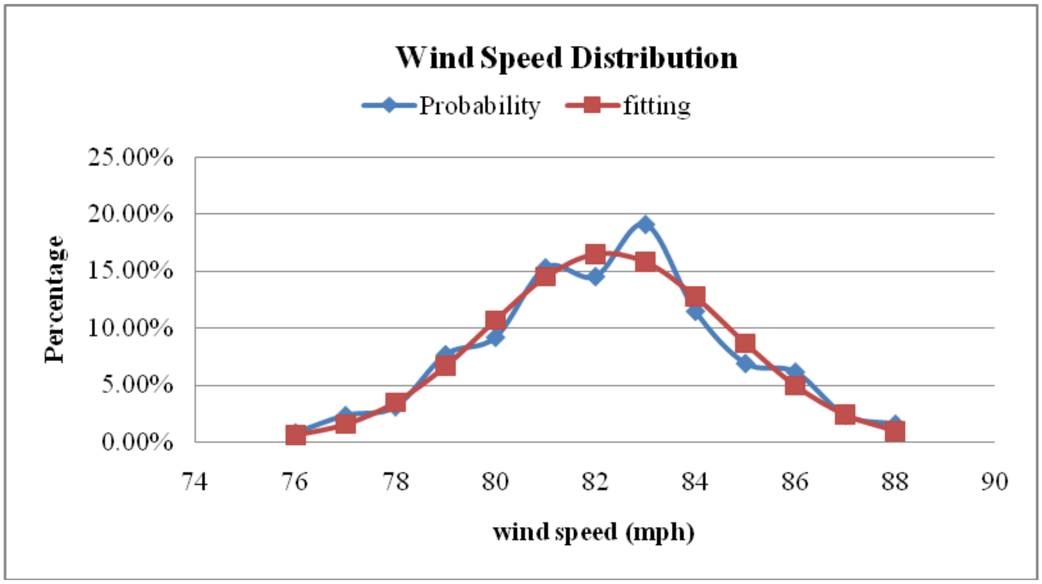

Figure1. Actual and Predicted Probability Distribution Function for Wind Speed

(b) Damage Analysis

The survey respondents were requested to categorize their structural and utility damages as follows: Category 1: None to minor damage; Category 2: Moderate damage/habitable/usable; and Category 3: Major damage/inhabitable/unusable. For the analyses, it was assumed that Categories 2 and 3 as failure. It must noted that the analyses were based on the residential structural type (wood, brick, concrete) as selected by the respondents. Based on the analyses, there was less than 20% structural failures of which 3% were category 3 (major damage). These failures were observed even when the hurricane wind speeds were below the design wind speeds of 90 mph and higher. It was clearly the power utility failure that dominated the reported failures (Fig. 2). Except for the apartments, the power utility failure in all types of structures were 70% or higher. The reported drinking water utility failure varied from 20 to 35% based on the residential structure type.

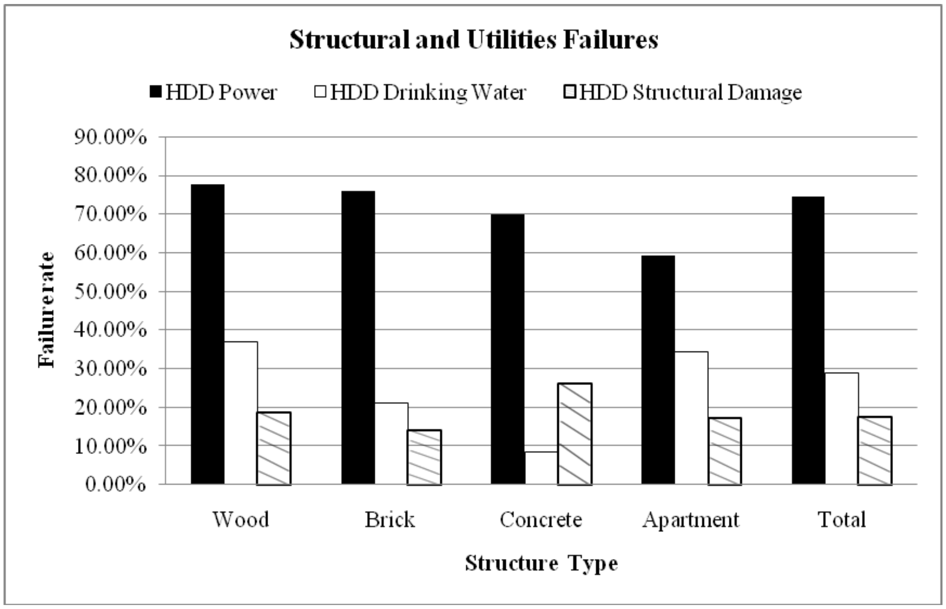

Figure 2. Structural and Utility Failure Rate for Different Structural Types

(c) Wind Speed and Structural Performance

The reliability analysis involves in the stress- strength model. Considering a single stress placed on a system during a relatively short time period, the stress is the load producing failure. The failure occurs if the stress exceeds the strength of the system. The strength is the highest stress value which the system can afford without failing. So the reliability is a static function and not a function of time (Ebeling 1997). For a random stress and random strength system, the reliability of the system is represented as follows:

$$R=P\{X<Y\}=\int_0^{\infty}\left[\int_0^{y} f_x(x)\,dx\right]f_y(y)\,dy \qquad (2)$$

where $f_x(x)$ is the probability density function of the stress and $f_y(y)$ is the probability density function of the strength (Ebeling 1997). In this project, the wind load is stress and the withstand wind speed of structure is the strength. We assume that the strength is a constant and the stress is random since all structure should follow a standard to build while the wind speed in a large area should be different due to the terrain, the location and the building densities. As a reminder, the reliability for a system with constant strength and random stress is R=$F_x(k)$ where k is the constant strength. For a normal distributed stress (wind speed) the reliability is represented as follows:

$$R=\Phi\left(\frac{k-\mu_x}{\sigma_x}\right) \qquad (3)$$

where μ_x and σ_x are the mean and standard deviation of the wind speed. By fitting the wind speed to get a probability distribution and use this as the random stress in the model to calculate the strength which is the actual residential structure wind withstanding parameter.

Brick Structures: Of the 240 respondents, 7 and 27 indicated structural damages as category 3 and 2 respectively. Hence the reliability of brick structures was 86% (Eqn. 3) and it withstands a wind speed of 86 mph.

Concrete Structures: Of the 19 respondents, 2 and 3 indicated structural damages as category 3 and 2 respectively. Hence the reliability of concrete structures was 74% (Eqn. 3) and it withstands a wind speed of 74 mph. This may indicate that wind speed may not be the only cause for structural failure.

Wood Structures: Of the 75 respondents, 1 and 13 indicated structural damages as category 3 and 2 respectively. Hence the reliability of concrete structures was 81% (Eqn. 3) and it withstands a wind speed of 86 mph.

Apartment Structures: Of the 66 respondents, 5 and 11 indicated structural damages as category 3 and 2 respectively. Hence the reliability of concrete structures was 76% (Eqn. 3) and it withstands a wind speed of 85 mph.

(d) Damage Model (DM-THC) for Structures and Utilities

During a hurricane the damage to the structures and utilities are caused by number of factors, hence this should be captured in any realistic damage model. The category of damage will not only depend on the wind speed, but also the trees around and the distance from the hurricane path. Using the data from survey, structural and utility damage category frequencies were related to the wind speed (V), distance to IKE path to each zip code (d) and tree distribution (T). Hence the damage model (DM-THC) relationship is as follows:

Frequency of Damage category = a[wind speed] ^{m} x [distance to hurricane path] ^{n} x [tree distribution] ^{l},

$$[\text{FD Cat-1,2 or 3}] = a\,[V]^{m} \times [d]^{n} \times [T]^{l} \qquad (4)$$

where parameters a, m, n and l will be determined based on the damage frequency and other data available.

(i) Residential Structure Damage (SD)

For this analyses all the type of structures are grouped together. Analyses showed that for category 1 (none to minor damage) the wind speed and tress contributed. The relationship is as follows:

$$[\text{Frequency of SD-1}] = 12 \times 10^{-8} * [\text{wind speed}]^{4.09} * [\text{Tree distribution}]^{0.27} \qquad (5)$$

Hence wind velocity, distance and tress are three important parameters. The predicted results using Eqn (5) are compared to the actual data in Fig. 3. The agreement is good.

Analyses showed that for category 3 (major damage) the wind speed and the distance from the hurricane path contributed. The relationship is as follows:

[Frequency of SD-3] $=306 \times 10^{-11}$ * [wind speed] ^3.7 * [distance to IKE route] ^0.08 (6)

Hence wind velocity and distance are two important parameters. The predicted results using Eqn (6) are compared to the actual data in Fig. 4. The agreement is good.

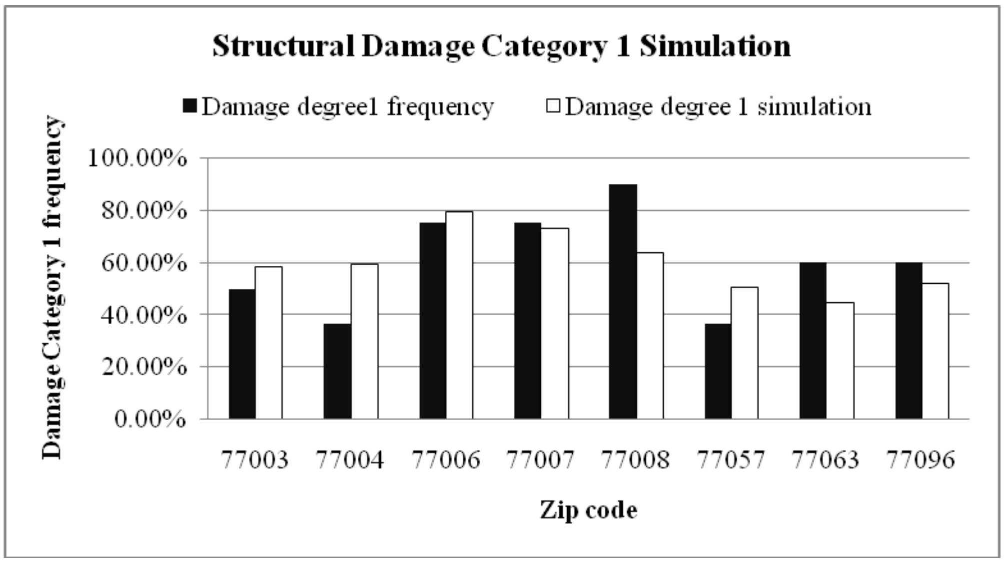

Figure 3. Actual and Predicted Structural Damage Category-1

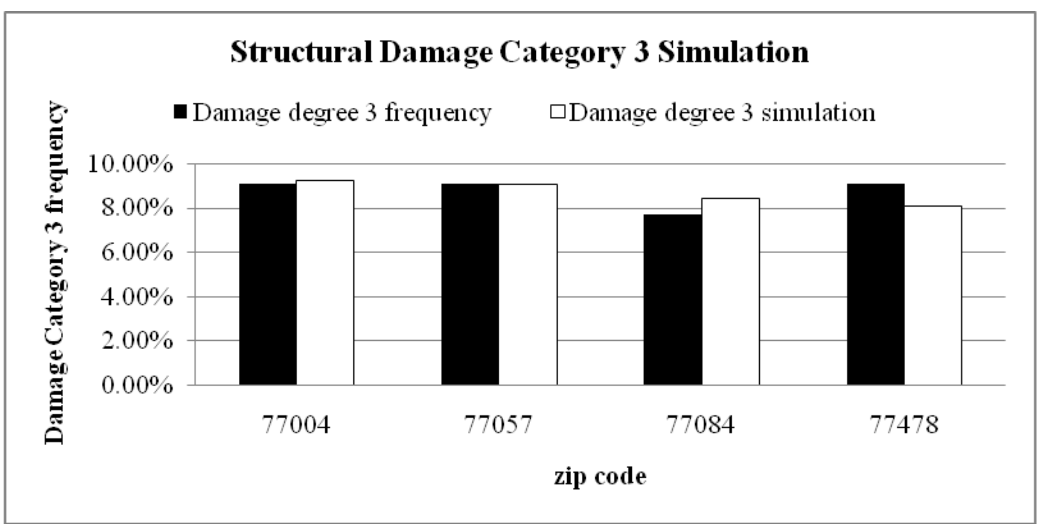

Figure 4. Actual and Predicted Structural Damage Category-3

(ii) Power Utility Damage (PU)

Analyses showed that for category 1 (none to minor damage) the wind speed, distance from hurricane path and tress contributed. The relationship is as follows:

$$[\text{Frequency PU-1}]= 23\text{x } 10^{-9} * [V]^{\wedge}3.871 * [d]^{\wedge}0.05 * [T]^{\wedge}0.1018 \qquad (7)$$

Hence wind velocity, distance and tress are three important parameters. The predicted results using Eqn. (7) is compared to the actual data in Fig. 5. The agreement is good.

Analyses showed that for category 3 (major damage) the wind speed and the distance from the hurricane path contributed. The relationship is as follows:

$$[\text{Frequency PU-3}]=133 \text{ x } 10^{-9} * [V]^{\wedge}2.91 * [d]^{\wedge}0.2 \qquad (8)$$

Hence wind velocity and distance are two important parameters. The predicted results using Eqn. (8) are compared to the actual data in Fig. 6. The agreement is good.

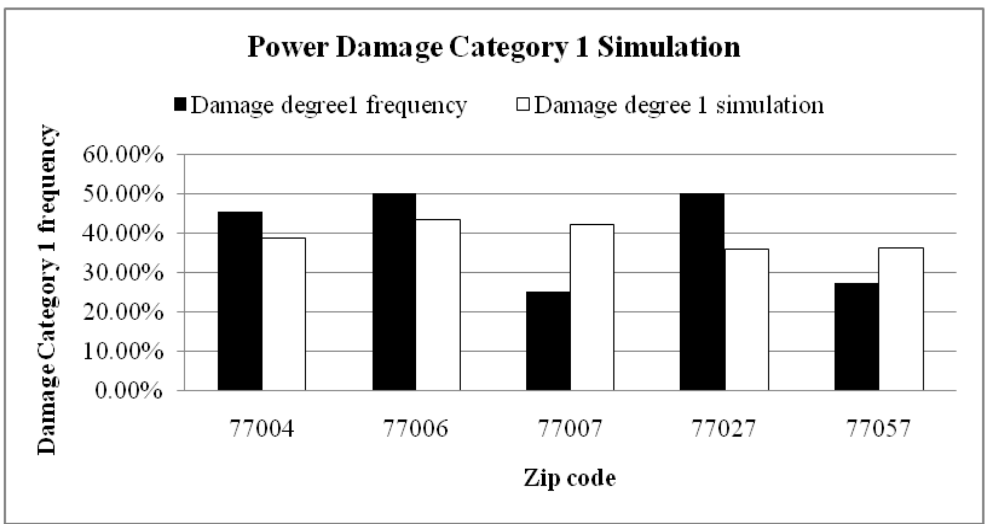

Figure 5. Actual and Predicted Power Damage Category 1

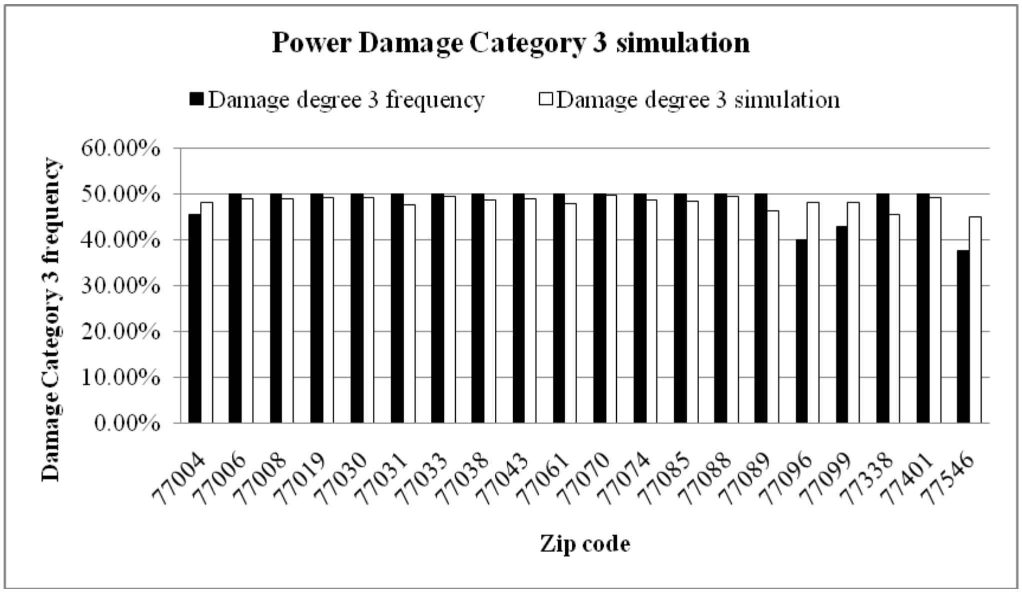

Figure 6. Actual and Predicted Power Damage Category 3

iii) Water Utility Damage (WU)

Analyses showed that for category 1 (none to minor damage) the wind speed, distance from hurricane path and tress contributed. The relationship is as follows:

$$[\text{Frequency WU-1}]= 98 \times 10^{-9} * [V] \wedge 2.867 * [d] \wedge 0.32 \, [T] \wedge 0.0782 \qquad (9)$$

Hence wind velocity, distance and tress are three important parameters. The predicted results using Eqn. (9) is compared to the actual data in Fig. 7. The agreement is good.

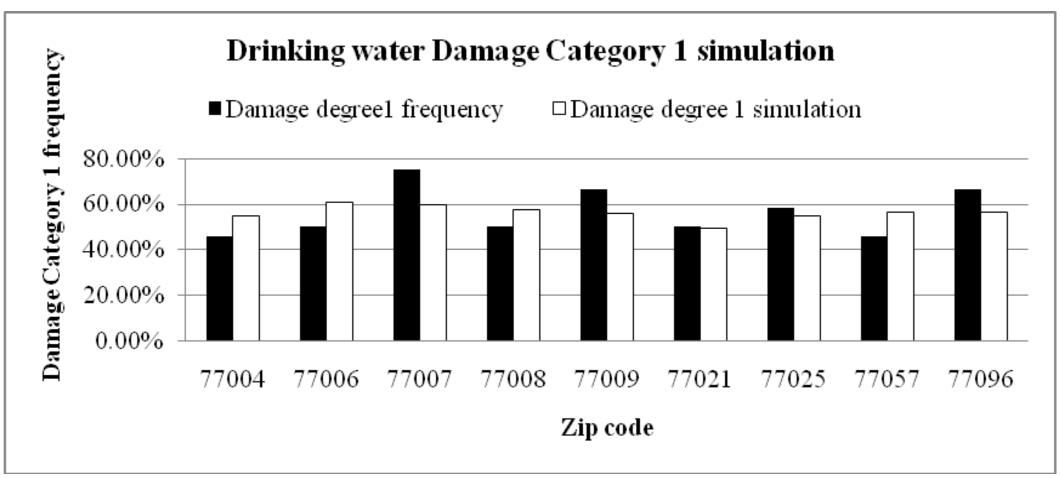

Figure 7. Actual and predicted Drinking Water Damage Category 1

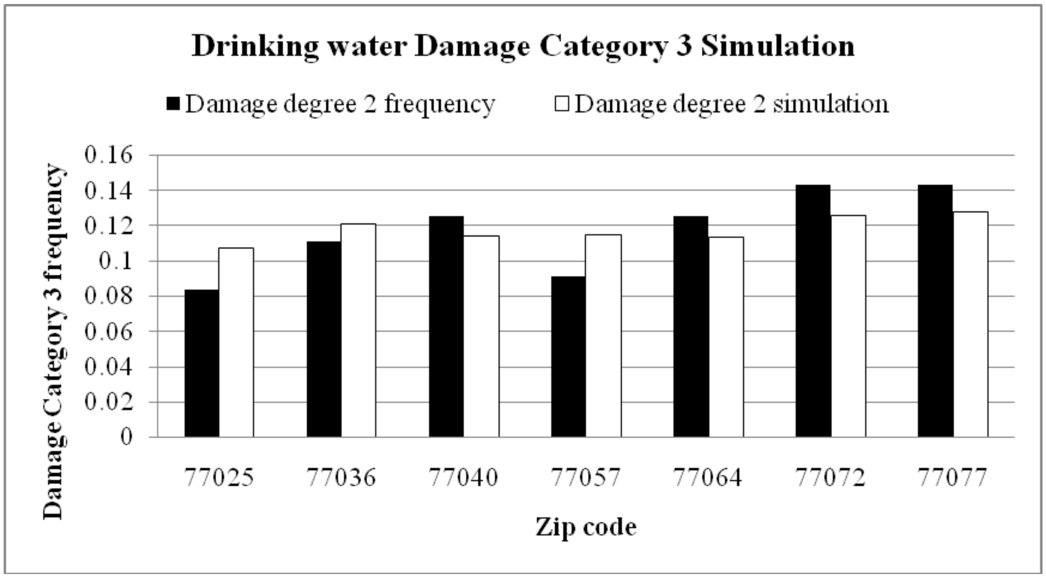

Figure 8. Drinking water Damage degree 3 simulation

Analyses showed that for category 3 (major damage) the wind speed and the distance from the hurricane path contributed. The relationship is as follows:

$$[\text{Frequency WU-3}] = 1\text{x } 10^{-9} * [V] \hat{}2.4 * [d] \hat{}0.7 \qquad (10)$$

Hence wind velocity and distance are two important parameters. The predicted results using Eqn. (10) are compared to the actual data in Fig. 8. The agreement is good.

CONCLUSIONS

Based on the data collected from the Hurricane IKE survey and NOAA and the analyses following conclusions are advanced:

(1) Frequency of hurricanes reaching the Texas Gulf coast can be represented by Poissons distribution. Texas has had maximum of 2 hurricanes in a year and no category 5 in the last 100 years.
(2) The wind speed, due to hurricane IKE (category 2 hurricane), varied from 76 to 88 mph with a normal distribution in the Houston area.
(3) Hurricane IKE survey indicated varying degree of structural and utility damages. Several factors other than the wind speeds caused the damage.
(4) A damage model (DM-THC) is proposed to predict the structural, power and utility damages due to a hurricane. Model predictions agreed well with the actual data and also helped in identifying the important parameters for various categories of damages.

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