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Short Note

Application and validation of an asphalt shingle roofing damage estimation method

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ABSTRACT

Asphalt shingle roofing that is widely used in US has been observed to be prone to wind damage. Also roofing damage often creates the opening that leads rain water into the building and may cause significant further loss to interior contents. Correctly estimating wind damage for asphalt shingle roofing has its significance from the perspective of wind loss mitigation and wind risk management. This paper focuses on the application and validation of the asphalt shingle roof damage estimation method presented in the previous paper (Huang et. al, 2015, “Data-based probabilistic damage estimation for asphalt shingle roofing.” J. Struct. Eng., http://dx.doi.org/10.1061/(ASCE)ST.1943-541X.0001300, thereafter denoted as DBPDE method). Firstly, the DBPDE method is employed to estimate the asphalt shingle roofing damage for a single residence. Secondly, the estimation procedure is extended to a group of residences in an area. Finally, the shingle resistance estimation and the validation of the damage estimation method are conducted using field survey data.

1. Introduction

Every year, extreme wind events such as hurricanes cause tremendous damages to low-rise buildings (e.g., Sparks et al., 1994). Asphalt shingle roofing widely used in US has been observed to sustain much of the damage, as shown in Fig. 1 for typical shingle roofing damage. Field damage surveys of hurricanes Andrew (1992) and Opal (1995) revealed that roof covering underwent the most frequent wind damage (Crandell, 1998). Furthermore, the damage to roof covering creates openings on buildings that often result in rain water penetration, causing substantial damage to interior contents, which is one of the largest contributors to hurricane loss (Pinelli et al., 2008). For these reasons, modeling shingle roofing damage is naturally an interesting topic and could potentially provide practical applications to engineers, insurance risk managers, and government agencies.

Recently, Huang et al. (2015) developed a data-based probabilistic damage estimation (DBPDE) method for asphalt shingle roofing using wind tunnel data from the University of Western Ontario (Ho et al., 2003). In this method, the Hermite polynomial model is firstly employed to estimate the probability distribution of wind pressure coefficients for the shingle associated with the pressure tap. Then the translation process method is adopted to evaluate the probability distribution of the corresponding peak wind pressure. Furthermore, the failure probability for each shingle as well as the damage ratio defined as the percentage of shingles in failure out of all shingles on the entire roof is determined. Finally, an artificial neural network (ANN) is trained to forecast damage ratio for the asphalt shingle roofing, taking into account various influential factors such as wind speed, wind angle of attack (AOA), building size (length, width and height), roof slope and terrain roughness.

It is noteworthy that not every damage influential factor is accounted for in the model. For instance, the Significant Individual Obstructions (SIOs) from neighboring buildings that could alter the wind flow and consequently affect peak wind pressures on shingles are not considered. The absence of these damage influential factors in the model is primarily because of lack of data. The uncertainty and complexity of these influential factors also deter their inclusion in the model. The model presented is believed to suit a portfolio of wind risk exposures better than individual exposure. For individual exposure, particularly for those under special circumstances (e.g., a house surrounded by higher buildings in close proximity), it is advised not to take outputs of this model without further scrutiny.

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Fig. 1. Example of asphalt shingle roofing damage(Punta Gorda, FL, Hurricane Charley, 2004)

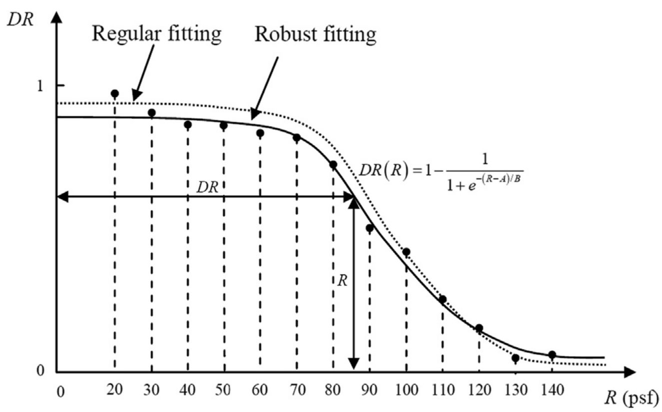

Fig. 2. Illustration of robust regression.

Validation and refinement of the estimation model for wind damage are an important task for wind engineers. Pinelli et al. (2008) validated and calibrated the engineering module of Florida Public Hurricane Loss Model (FPHLM) using hurricane damage and claim data. The vulnerability module of FPHLM was addressed by Pinelli et al. (2011). Similar work should be carried out for the aforementioned DBPDE method. This study focuses on the application and validation of this DBPDE method. Firstly, the DBPDE method is applied to estimate asphalt shingle roofing damage for a single residence, where the robust regression is adopted to obtain a resilient fitting. Then the estimation procedure is extended to a group of residences in an area. Finally, the shingle resistance estimation and the validation of the DBPDE method are carried out using field data collected from hurricane damage surveys.

2. Shingle roofing damage estimation for a single residence

For a given residential building, the damage ratio *DR* is a function of asphalt shingle resistance *R*. The points (*R*, *DR*) can be calculated by the ANN model given the wind speed, *AOA* and terrain roughness. However, a few points may be substantially biased due to the uncertainty embedded in the ANN model. To reduce this bias, a regression of points (*R*, *DR*) is required. In this study, the data points (*R*, *DR*) from the ANN model are fitted by a robust regression procedure which is less sensitive to outliers. The robust regression procedure gives weighting to each data point depending on how “uncooperative (different)” it is from the rest. The more “uncooperative (different)” the point is, the less weighting it is assigned in the regression. Appendix A gives mathematical details on the robust regression. A typical collection of data points (*DR*-*R*) is shown in Fig. 2, where asphalt shingle resistance varies from 20 psf to 140 psf with an increment of 10 psf. The comparison shows that robust regression outperforms the regular regression.

Observing the shape depicted by the points (*R*, *DR*) from the ANN model, the following function is proposed to represent the *DR*-*R* relationship

$$DR(R) = 1 - \frac{1}{1 + e^{-(R-A)/B}} \tag{1}$$

in which *A* is the location parameter and *B* is the scale parameter. A robust regression procedure using an iteratively re-weighted least squares algorithm is adopted to fit this function to those data points (*R*, *DR*) generated by the ANN model, as shown in Fig. 2.

This fitted curve has multiple applications. The damage ratio *DR* for a particular shingle resistance *R* can be calculated from this curve. On the other hand, the resistance *R* can be obtained given the damage ratio *DR*. Suppose shingle resistance *R* is a random variable and follows the Gaussian distribution $p(R)$. The mean and standard deviation of *DR* can be estimated in following equations, respectively:

$$E(DR) = \int_{-\infty}^{\infty} DR(R)p(R)dR \tag{2}$$

$$\sigma(DR) = \sqrt{\int_{-\infty}^{\infty} DR^2(R)p(R)dR - [E(DR)]^2} \tag{3}$$

A Graphic User Interface (GUI) MATLAB program is developed to estimate asphalt shingle damage for a single residential building. Eight influential factors including shingle resistance *R*, wind velocity *V*, attacking angle *AOA*, building length *L*, building width *W*, building height *H*, roof slope *S* and exposure roughness height z_0 are selected as the input parameters of the ANN model. Shingle resistance *R* is treated as a random variable, and thus both of its mean and standard deviation shall be input to the damage estimation model. The output is the estimated mean and standard deviation of damage ratio. The asphalt shingle damage ratios and the corresponding regression curve are shown in Fig. 3.

In the DBPDE paper, the 10-min mean wind speed at the building roof eave height is selected as the reference wind speed. If the wind speed is measured at other height, it can be easily converted to that at the building roof eave height based on the wind vertical profile associated with the terrain roughness that is specified in ASCE 7-10 (ASCE, 2010). Furthermore, for wind speed with other duration, it can be converted to 10-min wind speed using Durst's curve (Simiu and Scanlan, 1996).

3. Shingle roofing damage estimation for a group of residences in an area

In practice, the asphalt shingle roofing damage estimation for a group of residential buildings in an area can be very interesting to insurance companies, roofing manufacturers and building standard makers. One typical example of a group of residential buildings is shown in Fig. 4. The following question arises: given building geometries (building sizes and roof slopes), parameters of the upcoming wind and the surrounding environment, what level of damage can be expected for asphalt shingle roofing in the area of interest?

To estimate the damage level for a group of residential buildings, input parameters for the estimation model shall be determined. Apart from the influential factors used for a single building, additional parameters such as building orientation and the number of buildings are required, as listed in Table 1. The building width *W* is replaced by the building aspect ratio α multiplied by the building length *L*, where aspect ratio is defined as building width divided by building length. The building orientation and