Nineteenth Australasian Wind Engineering Society Workshop, April 4-6, 2018, Torquay, Victoria

A Methodology to Estimate Typhoon Wind Vulnerability for Insurance Loss Estimation

Navin Peiris[1], Mutahar Chalmers[2]
[1]Risk Management Solutions, London, United Kingdom. navin.peiris@rms.com
[2]Risk Management Solutions, London, United Kingdom. mutahar.chalmers@rms.com

ABSTRACT

Typhoons worldwide lead to billions of dollars of economic and insured losses annually. The insurance industry utilizes catastrophe models to produce views of typhoon risk for risk transfer mechanisms. The commonly adopted approach to modelling wind vulnerability is to use empirical relationships between claims ratio and peak gust to derive reference functions supplemented by engineering information where data is insufficient to cover all classes of buildings. It is most often the case that sufficient detailed empirical data is not available to derive the reference functions for a target country. This paper presents a methodology to estimate the wind vulnerability functions of a target country given the empirically derived reference functions in another country and engineering information. This paper will share the application of this approach to Taiwan and South Korea.

1. Introduction

The wind vulnerability of a building from an insurance perspective is driven by number of factors, which could be broadly divided as physical and economic, Peiris (2013). The physical drivers are hazard adaptation, legislation, architectural practices and deterioration. The economic factors that drive the wind vulnerability are, the relativity of repair cost to rebuilt cost, supply and demand of material and labour after an event and claims handling capacity of insurance companies. This paper presents a methodology to derive wind vulnerability functions of a target country, knowing the empirically derived wind vulnerability functions of a reference country (where both physical and economic factors are considered). It was assumed that the vulnerability relativity between the reference country and any target country is driven by the differences in the hazard adaptation measures and the relativity in the repair cost to rebuilt cost, where the other vulnerability factors remain similar. Hence a simplified wind damage model utilizing the wind loading recommendations in design codes was developed to explore the differences in hazard adaptation. The damage model also considered relativity of repair cost to rebuilt cost using construction cost data from respective countries. The wind damage model thus produces analytical vulnerability functions, which are used to scale the empirical vulnerability functions of a reference country to a target country. The proposed method complements the scaling approach of Khanduri and Morrow (2003) where the latter advises the direct use of reference country vulnerability functions in a target country for an empirically based calibration while preserving the vulnerability relativities. The proposed method here explores the target country vulnerability differences using engineering principles and affect the vulnerability relativities in addition to providing a first view of target country wind vulnerability, when very little empirical data is available for empirical calibration. Japan was chosen as the reference country with target countries being Taiwan and South Korea and only the building vulnerability is considered.

2. Wind Damage Modes in a Typhoon

The most common form of wind damage in a typhoon is damage to the roof cover as illustrated in Figure 1. In addition, structural damage to sections of the roof or the entire roof is possible where it may lead to the instability of the structural system owing to the loss of lateral stability. While roofing damage is common to most structural types, wall damage is possible e.g. gable end wall failures in bearing walls or wall cladding such as brick veneer and panels as shown in Figure 1. The main structural system is also susceptible to damage in the form of bearing wall collapse or the structural frame experiencing shear loads above the ultimate limit state of design. In addition to visible damage to exterior elements, interior elements also suffer damage where interior fittings could experience wind damage due to physical exterior element and structure damage and water ingress. While Figure 1 illustrates damage modes and damage to components of a building, a building experiences a particular damage state as a result of wind damage to a number of components to varying degrees. The severity of this damage state may depend on the multi-component failure, i.e. correlation of damage of multiple components. For example, damage to doors and windows, may lead to an increase in internal pressures within a building thus increasing the likelihood of roof uplift damage and the extent of the damaged roof.

Figure 1. Typical damage from cyclones and hurricanes to non-structural elements. Left – damage to tiled roof section including sheathing, typhoon Haiyan, Tacloban; Second Left – extensive damage to metal roofing panels, typhoon Haiyan, Tacloban; Third Left – wall cladding damage, hurricane Irma, Florida; Right – collapsed EIFS cladding panels, hurricane Irma, Florida. (RMS Photos)

3. Wind Damage Model

A typhoon will lead to a building experiencing a particular damage state ranging from no damage to complete collapse, where there will be multiple component failures with correlation of occurrences Pinelli et al. (2004). It would be difficult to model such complexities if there is insufficient data to define the properties of materials and connections to an extent that one could model the structural reliability of each driving component that contributes to wind damage. Hence a simplified approach based on component level failure is considered where the components are roof cladding, openings, wall cladding, internal fittings and base shear. It is assumed that once the resistance of each component to wind loading is overcome, the entire component is failed. For instance the wind resistance of the entire roof is assumed to be the same ignoring any variabilities that exist within the roof itself e.g. due to edge shielding, extra nailing along the vulnerable roof edges, etc. This further simplifies the modelling of roof failure in this example thus avoiding the need to determine the probabilities of a fraction of a roof getting damaged. For a given peak gust level, the probability of failure of each component was calculated using an analytical solution of the structural reliability model. These probabilities were combined together with their repair or replacement cost ratios to obtain the mean loss ratio or mean damage ratio (MDR) as a function of peak gust, thus forming the analytical vulnerability function.

Table 1. Properties of the residential building archetypes for the damage model.

Occupancy	No. of Stories	Height (m)	Roof Pitch	Constr. Class
SFD	2	8.0	30.0°	Timber/ Masonry

Although the study considered the common building types, this paper discusses the work done for single family dwellings (SFD) archetype for brevity whose properties are given in Table 1. The properties were chosen based on typical building profiles as one would expect to see in Japan, South

Korea and Taiwan. The wind resistance for roof cladding, openings and wall cladding components were calculated using the respective national building codes; Japan - AIJ (2004), South Korea – KBC (2005), Taiwan – TBC (2006). The basic design wind hazards were taken from each building code along with provisions for adjustment for upwind terrain and other properties to reflect the archetypes such as height and roof pitch. The wind resistance values were calculated for each location or centroid of administrative unit, defined at Ward (Japan), Dong (South Korea) and Postalcode (Taiwan) such that there are variabilities reflecting the design wind hazard as well as terrain variations. The terrain category was defined based on the physical built up density and height of buildings in each administrative unit derived from satellite imagery and census data.

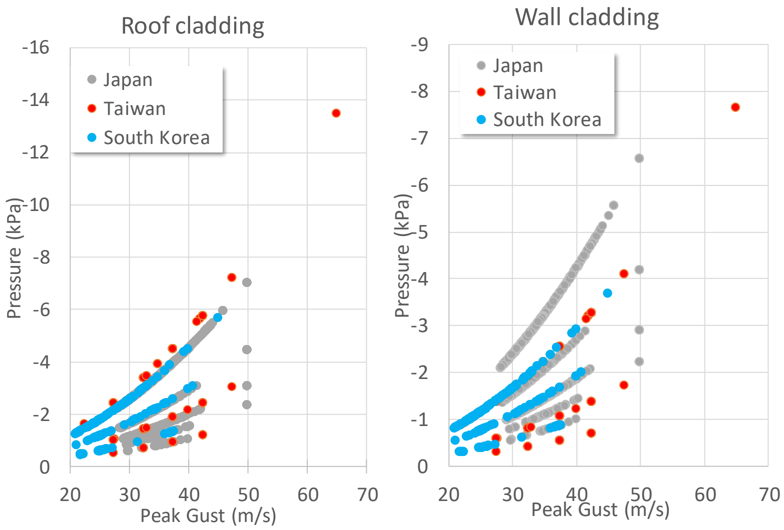

Figure 2. SFD and MFD roof and wall cladding pressures calculated for centroid of administrative unit chosen in each country (Japan, South Korea and Taiwan)

Figure 2 shows the roof and wall cladding pressures calculated for SFD archetype for the three countries. While Figure 2 shows the negative or suction pressures for wall cladding, the positive cladding pressures were considered for the openings. The base shear loads were taken to be the maximum of the wind and seismic basic shear given the practice of seismic design. The roof and wall cladding pressures show a non-linear increase with basic design wind speed reflecting the squared relationship with wind speed. The roof cladding pressures are generally higher in Taiwan than Japan, which are in turn higher than South Korea, consistent with the wind hazard variability and hence the hazard adaptability. It should be noted that the pressures calculated are an area weighted average of the peak pressures calculated for each pressure zone of a component (cladding or roofing) as defined by building codes. The pressures calculated for roof and wall were converted to resistance values using the limit state framework by applying partial safety factors as described in equation (1).

$$\frac{M_k}{\gamma_m} = \gamma_G G_k + \gamma_Q Q_k + \gamma_W W_k \quad (1)$$

Where M_k, G_k, Q_k, W_k are characteristic resistance, dead load, live load and wind load respectively. Where the partial safety factors, γ_m, γ_G, γ_Q, γ_W is for resistance, dead load, live load and wind load respectively. Given that the interest is to assess the vulnerability variability across administrative units leading to the inter-country comparisons, only wind loading from equation (1) was considered. Hence the partial safety factors γ_w and γ_m were used to convert wind pressures to resistance values for all components. Table 2 shows the partial safety factors used, where an assumption was made due to difficulty in finding γ_m in KBC (2005).

Table 2. Partial safety factors for resistance and wind loads.

Country	γ_m	γ_w
Japan	1.05	1.2
South Korea	1.05	1.3
Taiwan	1.10	1.3

The structural reliability model allows the determination of the probability of failure of a component when the applied wind load exceeds the resistance. The simplest structural reliability problem is the case of uncertain resistance, *R* and load effect, *S*. The limit state function for this case is given in equation (2) below.

$$g(R,S) = R - S \tag{2}$$

The probability of failure of such a system, P_f is given by equation (3) below.

$$P_f = P(g(R,S) \leq 0) = P(R - S \leq 0) \tag{3}$$

The general limit state function with arbitrary distributions and dependence structure usually requires a numerical solution (FORM/SORM or various MCS approaches). Analytical solutions however exist if *R* and *S* are considered as normal or lognormally distributed and independent. The choice of distributions for *R* and *S* is governed by two considerations; physical plausibility and computational simplicity. One can expect both the distributions of *R* and *S* is skewed positively. For instance, it is less likely that the resistance is higher than the expected value due to economic factors and below an acceptable minimum for safety considerations. Within the fabric of a building, only few areas have very high loads (eaves, edge cladding, etc.). The analytical closed form solutions are computationally efficient than numerical solutions. Given the above points, a lognormal-lognormal model was considered for the P_f determination given by equation (4) below. This is consistent with the model reported by Takada and Wang (2003), which itself refers AIJ (2004).

$$P_f = \Phi\left(-\frac{ln\left(\frac{\mu_R}{\mu_S}\left[(1+CV_S^2)/(1+CV_R^2)\right]^{1/2}\right)}{\left(ln\left[(1+CV_S^2)(1+CV_R^2)\right]\right)^{1/2}}\right) \tag{4}$$

Where μ_R, μ_S are mean resistance and loads, CV_R and CV_S are coefficient of variation of resistance and loads respectively. The values of CV_R and CV_S were taken as 0.2 and 0.4 respectively based on Cope et al., (2003). Equation (4) was used to determine P_f for roof cladding, openings, wall cladding, internal fittings and the base shear, which represents full structural failure. The applied wind loading for each component was determined using the peak gust values ranging from zero to 110m/s. The applied wind load considers the dynamic pressure and the area weighted pressure coefficients as defined in ASCE 7-10 (2010). The derivation of vulnerability functions requires a physical damage model deriving the probability of failure of components and a cost model to account for the repair cost to replacement cost relativity. The repair cost of roof claddings, openings, wall cladding and internal fittings together with replacement cost values for SFD archetype in Japan, South Korea and Taiwan were obtained from Davis Langdon (2010). The cost ratio for each component were obtained by normalizing the repair costs by the replacement cost of the whole building archetype. For base shear, it was assumed that a failure of the structural system would lead to a full replacement of the building. The analytical vulnerability function is defined as the mean loss or damage ratio (MDR) as a function of peak gust as shown in equation (5).

$$MDR_{ij} = \left(1 - P_{ij,base}\right)\left(P_{ij,opn}C_{opn} + P_{ij,wcln}C_{wcln} + P_{ij,rcln}C_{rcln} + P_{ij,fitt}C_{fitt}\left(\frac{v_i}{v_{max}}\right)^2\right) + P_{ij,base} \tag{5}$$

Where MDR_{ij}, is the mean damage ratio for i^{th} peak gust at j^{th} location; $P_{ij,base}$ is the probability of total failure due to base shear; $P_{ij,opn}$, $P_{ij,wcln}$, $P_{ij,rcln}$, $P_{ij,fitt}$ is the probability of failure of openings, wall cladding, roof cladding and internal fittings respectively. $P_{ij,fitt}$ was considered to be $P_{ij,rcln}$ for SFD since roofing damage is likely to lead to internal damage to SFD occupancies. The term *$(v_i/v_{max})^2$* was an attempt to give more weight to fittings at higher wind speeds where v_{max} was considered as 110m/s, the upper limit of the MDR function.

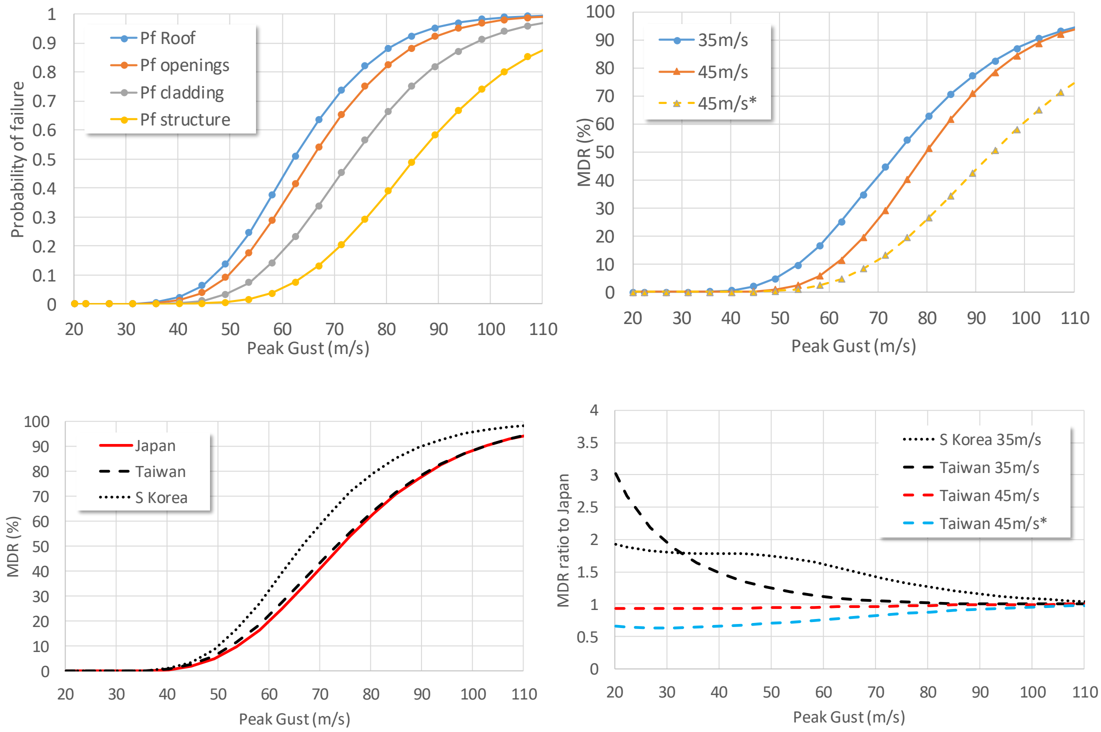

Figure 3. Top Left - Component failure probability functions as a function of peak gust for SFD archetype in Japan for a design wind speed of 35m/s; Top Right - Analytical vulnerability function for SFD archetype in Japan for a design wind speed of 35m/s and 45m/s; Bottom Left - Analytical vulnerability functions for Japan, Taiwan and South for SFD archetype from locations with design wind speeds of 35m/s; Bottom Right - Normalized analytical vulnerability functions to Japan for SFD archetype from locations with design wind speeds of 35m/s and 45m/s.

Figure 3 (top left) shows the component failure probability functions as a function of peak gust for SFD archetype in Japan where the design wind speeds are 35m/s. The functions show that roof failure is more likely followed by failure of openings and cladding. This is reflective of the absolute level of resistance of these components to wind loads and the margin of safety at a given peak gust level. Clearly the structural damage is less likely than damage to the envelope as expected from an engineering standpoint. Figure 3 (top right) shows the analytical vulnerability functions for the SFD archetype in Japan from locations where the design wind speeds are 35m/s and 45m/s. In this comparison, the base shear resistance was assumed to be the same at each location so that we see the effect of wind design resistance differences. The lower MDR for curve "45m/s" is reflective of lower component failure probabilities due to increased resistance. Figure 3 (top right) also shows the analytical vulnerability function at the 45m/s location where the location specific base shear resistance was applied (labelled "45m/s*"). The marked decrease is due to the increased base shear resistance at this location contributed by the seismic design requirements at the chosen location. It should be noted that the analytical vulnerability function is therefore sensitive to the seismic design provisions where the strength of the structural system is governed by seismic design requirements over wind design requirements.

4. Derivation of wind vulnerability functions for a target country

The first step in the derivation of empirical vulnerability functions in a target country is to derive the analytical vulnerability functions for the target as well as the reference country. The analytical vulnerability functions for the building archetypes could be derived using equation (5) for each administrative unit or location. For the analytical model to makes sense for wind vulnerability derivation there should be compatibilities in the wind climates between the locations in the reference country and the target country. This ensures that the wind design practices are compatible and hence the analytical functions address the differences in the code provisions for site effects and building properties of a given archetype building. Figure 3 (bottom left) compares the analytical vulnerability functions between Japan, Taiwan and South Korea for SFD archetype from locations where the design wind speed is 35m/s. Figure 3 (bottom right) shows the Taiwan and South Korea functions normalized by the Japan vulnerability functions. The second step is to scale the empirically derived vulnerability functions from Japan with the normalized analytical vulnerability functions for locations with the similar range of design wind speeds in the target country (climate compatibility). The normalized analytical vulnerability function varies with design wind speed as shown in Figure 3 (bottom right) also for 45m/s in Taiwan where it also shows the effect of using location specific base shear resistance. Hence it is important to use analytical functions for normalization where wind speeds are similar. Following the above approach, the empirical vulnerability functions for each administrative unit in Taiwan and South Korea could be derived for compatible design wind regions.

5. Conclusions

A methodology to derive wind vulnerability functions of a target country, knowing the empirically derived wind vulnerability functions of a reference country was discussed. The method utilized the structural reliability approach combined with a simplified damage model based on roof cladding, openings, wall cladding, internal fittings and base shear to estimate analytical wind vulnerability functions for building archetypes. The analytical vulnerability functions derived were used to scale empirical functions from a reference country to a target country for similar wind climates. This framework allows the derivation of wind vulnerability functions in countries with limited direct empirical data and could also provide a preliminary view of wind vulnerability considering the differences in building code provisions and repair cost relativity.

6. References

AIJ (2004). *Recommendations for loads on buildings*, Architectural Institute of Japan, 2004.

ASCE 7-10 (2010) *Minimum Design Loads for Buildings and other Structures*, Structural Engineering Institute, 2010.

Cope, A., Gurley, K., Pinelli, J., Hamid, S. (2003). A simulation model for wind damage prediction in Florida, *Proc. 11th Int. Conf. on Wind Eng.*, Texas Tech. Univ., Lubbock, Texas, 2003.

Davis Langdon (2010) *Spon's Asia-Pacific Construction Costs Handbook*, 4th Ed., CRC Press, 2010.

KBC (2005). *Government Guidelines of Korean Building Code*, 2005

Khanduri, A. C. & Morrow, G. C., (2003). Vulnerability of buildings to windstorms and insurance loss estimation, *J. Wind Eng. And Ind. Aero.* **91**, 2003, 455-467.

Peiris, N., (2013). Development of an engineering based residential wind vulnerability model for European extra-tropical cyclones, *12th Americas Conf. on Wind. Eng.*, 2013, Seattle, USA.

Pinelli J., Simiu, E., Gurley, K., Subramanian, C., Zhang, L., Cope, A., Filliben, J. J., Hamid, S., (2006). Hurricane Damage Prediction Model for Residential Structures, *J. of Struc. Eng.*, **130** (2004), No. 11, 1685-1691.

Takada, T., Wang, M. (2003). *Code calibration for measurement of limit state design in Japan*, JACOSSAR 2003, 969-974.

TBC (2006). *Specifications for building wind-resistant design*, Taiwan Building Code, 2006.