Extreme-value analysis for field measured peak pressure coefficients on a low-rise building

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ABSTRACT
A full-scale moveable instrumented low-rise building has been constructed and implemented to study wind velocity field and associated building surface pressures during typhoon landfalls. The major objective of the field study is to further understand typhoon-generated wind characteristics and wind effects on the low-rise building under extreme wind conditions. This paper presents extreme-value analysis of pressure data measured on a roof corner of the experimental building during a typhoon. The generalized extreme value (GEV) distributions are used to fit the peak suction pressure coefficients and it is found that the Type III Extreme Value distribution matches the data well. It is revealed that the predicted upper limits of the peak pressure coefficients are more than 20\% higher in magnitude than the highest values actually measured.

KEYWORDS: full-scale measurement; low-rise building; typhoon; peak pressure; extreme value analysis

1. Introduction

Strong typhoons frequently occur in the southeast coastal regions of China. Buildings and structures in these typhoon-prone regions, especially low-rise residential houses, may be damaged or destroyed when subjected to extreme wind actions. For example, Typhoon Saomai slammed into China’s southeastern coast in August 2006, killing at least 441 people, and destroying more than 50,000 houses, mostly low-rise residential buildings. Most of the casualties were caused by houses collapsing. Hence, there is an urgent need to understand the wind loads generated on low-rise buildings exposed to strong typhoon conditions and to improve building codes to address these design requirements.

In order to provide the measurements of wind effects on a low-rise building under extreme wind conditions, a full-scale moveable instrumented building has been constructed by the authors of this paper. The major objective of the field study is to further understand typhoon-generated wind characteristics and wind effects on low-rise buildings during typhoon landfalls. Although the effects of wind on low-rise buildings have received a great deal of attention over the past three decades [1-4], there was no attempt in the past to use a full-scale moveable instrumented building to monitor extreme wind effects during typhoon landfalls. This paper presents an investigation of extreme suction pressure coefficients measured on a roof corner...
of the moveable low-rise experimental building during a typhoon. The generalized extreme value distributions were adopted to fit the peak suction pressure coefficients obtained from the full-scale measurements and the Type III Extreme Value distribution was found to match the peak suction pressure coefficients well.

2. Full-scale measurements

2.1 The Experimental Building and Monitoring System

The moveable instrumented building consists of a 6.0×4.0×4.0m flat-roof building and a 10m meteorological tower (shown in Fig1). Setra 265 pressure sensors were used to measure surface pressures on the building. Wind velocity components were measured using two types of RM young anemometers: two propeller anemometers were installed at a height of 7.5 m and 10 m from ground, respectively and two ultrasonic anemometers were also mounted at the two levels. The anemometers were installed at a mast (meteorological tower) set up on the roof of the building. A CR-5 PC based central recording monitoring system which can simultaneously record field data from 60 channels was used to measure wind speed, wind direction and pressure data. Instrumentation details are given in Table 1. The moveable instrumented building has been placed in a coastal region of Guangdong Province, China since 2006 with an attempt to capture extreme wind events.

Table 1 Instrumentation specifications

<table>
<thead>
<tr>
<th>Instruments</th>
<th>Measurement</th>
<th>Accuracy /comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>RM YOUNG 81000</td>
<td>Wind speed Range 0~50m/s</td>
<td>±0.05(0~30m/s)</td>
</tr>
<tr>
<td>RM YOUNG 05106</td>
<td>Wind direction: Azimuth range 0<del>540° Elevation range -60°</del>+60°</td>
<td>±2°(1<del>30m/s) ±5°(30</del>50m/s)</td>
</tr>
<tr>
<td>Setra 265</td>
<td>Pressure Range ±1250Pa</td>
<td>±1%FS</td>
</tr>
<tr>
<td>CR-5</td>
<td>The data acquisition</td>
<td>60 channel</td>
</tr>
</tbody>
</table>

2.2 The wind characteristics

Three typhoons (Neoguri, Kammuri and Hagupit) were captured in the past three years and the field measurements of wind effects on the building were carried out during the typhoons.

Neoguri (0801) formed as a tropical depression over the South China Sea about 360km east of Nansha on 15 April, 2008. It moved generally west-northwestwards at first and intensified into a tropical storm that evening. Neoguri intensified into a severe tropical storm and turned onto a north-northwesterly track on the afternoon of 16 April. It intensified further into a typhoon that evening and turned to a northerly track on the evening of 18 April. After skirting the northeastern tip of Hainan on the early morning of 19 April, Neoguri weakened to a severe tropical storm and moved north-northeastwards. Neoguri weakened further into a tropical storm that morning and made landfall at Dongping Town, Yangdong County, Guangdong that afternoon.
Severe Tropical Storm Kammuri (0809) formed as a tropical depression over the northeastern part of the South China Sea on the morning of 4 August, 2008 and moved west-northwestwards. It intensified into a tropical storm the next morning. On the early hours of 6 August, Kammuri intensified into a severe tropical storm and moved northwesterly, it turned to move westwards later that afternoon and made landfall at Yangxi County in western Guangdong that evening.

Strong Typhoon Hagupit (0814) formed as a tropical depression over the western North Pacific about 2540 km east-southeast of Hong Kong on the morning of 19 September, 2008 and moved west-southwestwards. It intensified into a tropical storm on the early hours of 20 September, and into a severe tropical storm that afternoon. Hagupit moved northwesterly, and intensified further into a typhoon on 21 September. Moving west-northwesterly, Hagupit crossed the Balintang Channel on 22 September and entered the South China Sea that evening. Hagupit moved at a speed close to 30 km/h across the northern part of the South China Sea on 23 September and passed about 180 km south-southwest of Hong Kong from about 10 to 11 p.m. on 23 September. While crossing the northern part of the South China Sea, Hagupit attained an estimated maximum sustained surface wind speed of about 175 km/h near the centre. Hagupit made landfall near Dianbai in western Guangdong on the morning of 24 September.

Figure 2 shows the tracks of the three typhoons and the building location. Neguri and Kammuri did not pass the building site directly, while Hagupit made landfall very near the location of the building (the shortest straight distance between the eye of the typhoon and the building site was about 2.8 km). Table 2 provides the information on the wind speed measurements during the three typhoons.

<table>
<thead>
<tr>
<th>Typhoon Name</th>
<th>Wind Direction Range</th>
<th>Anemometer Height(m)</th>
<th>Max wind speed (3-sec)</th>
<th>Max wind speed (1-min)</th>
<th>Max wind speed (15-min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neoguri (0801)</td>
<td>100°-128°</td>
<td>10m</td>
<td>27.9m/s</td>
<td>21.4m/s</td>
<td>18.9m/s</td>
</tr>
<tr>
<td>Kammuri (0809)</td>
<td>148°-160°</td>
<td>10m</td>
<td>21.8 m/s</td>
<td>18.1m/s</td>
<td>17.6 m/s</td>
</tr>
<tr>
<td>Hagupit (0814)</td>
<td>160°-210°</td>
<td>7.5m</td>
<td>54.7 m/s</td>
<td>45.2 m/s</td>
<td>40.8 m/s</td>
</tr>
</tbody>
</table>

2.3 Pressure Tap Locations and Pressure Measurements
This paper presents analysis results of the pressure data measured on a roof corner shown in Fig. 3. These taps were distributed in grids of 3 columns and 3 rows with a spacing of 0.40m in both directions. The tap locations nearest the roof edges were 0.20m from the edges. Simultaneous measurements of the pressures were made at a sampling rate of 20 Hz together with recording of wind velocity data from the four anemometers. Peak (maximum or minimum) pressure coefficient is defined as follows:

\[ C_p = \frac{p - p_\infty}{1/2 \rho U_{3sec}^2} \]  

(1)

where \( p \) is the maximum or minimum pressure at a point of interest, \( p_\infty \) is the free stream static pressure or reference static pressure, \( \rho \) and \( U_{3sec} \) are the air density and the 3-s average value of wind speed at the roof height, respectively.

This paper focuses on the usage of the pressure data measured during Typhoon Neoguri to determine the minimum peak pressure coefficients on the roof corner of the building. 34 samples of records with 15min duration of the field data during the typhoon were selected for further analysis subjected to the selection criteria that the incident wind direction should be approximately a quartering wind approaching to the roof corner and the mean wind speed should be sufficiently high and stationary. These records contained the pressure data measured under approaching wind flows with directions around 120°. The mean wind direction of these records was 122.5° and the direction varying range was 118.6-126.0°, and the corresponding mean wind speed was 11.8m/s and its varying range was 8.2-18.9m/s.

3. Extreme-value analysis

3.1 Sampling of Extremes and Order Statistics

A 15min record contained 18,000 measured data, which was divided into 6 segments (sub-sets) with identical duration (\( T_{sample} = 2.5 \) minute). Then the minimum and maximum peak pressure coefficients for each segment were determined. The choice of \( T_{sample} \) was discussed in references [5-6]. The largest and smallest values were extracted from each segment for the determination of the minimum pressure coefficients. Only sampled peaks from runs with similar conditions were collected in the final ensemble [6].

3.2 Generalized Extreme-value Distributions

Type III and I extreme value distributions (EVD) were used to fit the roof corner peak pressure coefficients. These distributions are special cases of the generalized extreme value (GEV) distribution [7].

\[ F(x) = \exp \left\{ - \left[ 1 - k \left( \frac{x - \mu}{\sigma} \right) \right]^{1/k} \right\} \]  

(2)

The parameters of the distribution are \( k \) (shape), \( \mu \) (location), and \( \sigma \) (scale). When the shape parameter \( k \) is positive, the GEV is called the type III EVD. A positive value of shape factor is of particular significance, as the distribution can predict a theoretical upper limit of the variate, \( x \). This upper limit is given by

\[ x_{max} = \mu + \left[ \frac{\sigma}{k} \right] \]  

(3)

The method of probability weighted moments (PWMs) can be used to estimate these parameters [8]. The PWMs, \( \beta_c \), used in this method, are defined for a random variable, \( x \), by
\[ \beta_i = \int_0^1 x[F(x)]^i dF \quad (4) \]

where \( F(x) \) is the cumulative probability distribution function of \( x \).

Following the method of Ref. [8], a plotting parameter was formed as follows:

\[ p = (i - 0.35) / N, \quad \beta_{i,n} = \frac{1}{n} \sum_{j=1}^{n} p_{i,n} X_j \quad (5) \]

The PWMs of 0th, 1st and 2nd orders (i.e. \( \beta_0 \), \( \beta_1 \) and \( \beta_2 \)) were estimated by multiplying the recorded extreme pressure coefficients, ordered from smallest to largest, by \( p^0 \), \( p^1 \) and \( p^2 \); respectively, and averaging over the data set. These estimates were compared with the theoretical values of the PWMs for the GEV to estimate the parameters \( k \), \( \mu \) and \( \sigma \).

### 3.3. Results of the extreme-value analysis

The results of using the GEV to fit the peak suction pressure coefficients of tap11, tap12 and tap21 on the roof corner during Typhoon Neoguri are given in Fig.4-Fig.6. It is observed from the figures that the peak pressure coefficients were well fitted with a GEV distribution with a positive shape factor. The parameters obtained by the data fitting are listed in Table3. Figs.3 indicates that for tap11, the theoretical upper limit of the extreme pressure coefficient was -10.5, which was 26.4\% greater in magnitude than the lowest pressure coefficient of -8.3 actually measured during the record. Figs.4 and Fig.5 show that the theoretical upper limits for tap 12 and tap 21 were -12.3 and -11.9, respectively, which were 20.6\% and 27.6\% greater in magnitude than the measured lowest pressure coefficients of -10.2 and -9.3. Such large suction pressure coefficients on the roof corner were generated mainly due to the intermittent formation of conical vortices along the corner edges of the roof.

<table>
<thead>
<tr>
<th>Tap location</th>
<th>( \sigma )</th>
<th>( u )</th>
<th>( k )</th>
<th>Upper limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tap11</td>
<td>-1.06</td>
<td>-4.28</td>
<td>0.170</td>
<td>-10.5</td>
</tr>
<tr>
<td>Tap12</td>
<td>-1.42</td>
<td>-6.33</td>
<td>0.240</td>
<td>-12.3</td>
</tr>
<tr>
<td>Tap21</td>
<td>-1.85</td>
<td>-4.98</td>
<td>0.268</td>
<td>-11.9</td>
</tr>
</tbody>
</table>
4. Conclusions

The extreme value analysis of the pressure data recorded from the low-rise building during Typhoon Neoguri was conducted to determine the peak suction pressure coefficients on a roof corner. The generalized extreme value distributions were applied to fit to the peak suction pressure coefficients. It was found that the type III distribution fit the data well. The upper limits of the peak suction pressure coefficients determined by the extreme value analysis were more than 20% higher in magnitude than the measured lowest pressure coefficients.

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References