Wind pressure and spectrum measurement for three square prismatic buildings arranged in L shape

B.S. Shiau, L.H. Chiu
Department of Harbor and River Engineering, National Taiwan Ocean University – e-mail: bsshiau@gate.sinica.edu.tw – 2 Pei-Ning Road, Keelung 202, Taiwan

Department of Harbor and River Engineering, National Taiwan Ocean University – e-mail: b0085@mail.ntou.edu.tw – 2 Pei-Ning Road, Keelung 202, Taiwan

Keywords: wind pressure, pressure spectrum, turbulent boundary layer.

ABSTRACT

This study is to measure in wind tunnel on the surface wind pressure characteristics and pressure spectrum of three square prismatic buildings arranged in L shape which were attacked under different wind angles in the turbulent boundary layer flow. The variations of surface mean wind pressure coefficient, root mean square of wind pressure fluctuation coefficient, and surface wind pressure spectrum at the height of $z/H=0.888$ for three buildings under different wind attack angles are investigated.

1. INTRODUCTION

It has been frequently suffered typhoon’s serious attacks during summer and autumn seasons in Taiwan. Strong wind of typhoon caused severe damage on building cladding. Also, variation of surface wind pressure distribution affected the building natural ventilation. For such purposes, it is necessary to study the building surface wind pressure characteristics which can provide more accurate and detail information for the building wall curtain cladding and natural ventilation designs.

Melbourne (1980) had conducted experiments for studying the surface wind pressure and pressure spectrum of a cubic structure. Tieleman et al. (1997) studied the importance of turbulence for the prediction of surface pressure on low-rise structures. Wacker (1995) reported that the pressure fluctuations measured on the front face of the high-rise building is close to a Gaussian distribution, while the probability density distribution of the pressure fluctuations on the front face of the low-rise building is skewed. Kareem and Cermak (1984) investigated power spectral densities of the fluctuating pressure field acting on the side faces of a square prism immersed in boundary layer flows, and they observed the wind pressure spectra peak occurred around a reduced frequency of 0.1,
which corresponds to the Strouhal frequency. Wacker (1995) also indicated that the pressure spectral peak on the front surface of building is close to the reduced frequency of 0.1. In additions, pressure spectral peak on the rear side of the building is also around the reduced frequency of 0.1. Uematsu and Isyumov (1998, 1999) studied the wind pressure of the low-rise building and peak gust pressure on the roof of the building. Hout et al. (1986) had studied on one building.

In urban city, two buildings of side by side arrangement are commonly encountered (Shiau & Lai (2005)). In some cases, three buildings arranged in L shape had been existed in urban city. The wind attack angle on the buildings also often changed in time. Therefore the objective of present study is to measure in wind tunnel on the surface wind pressure characteristics and pressure spectrum of three square prismatic buildings arranged in L shape which were attacked under different wind angles in the turbulent boundary layer flow.

2. EXPERIMENTAL SET-UP

The experiments were conducted in the Environmental Wind Tunnel of National Taiwan Ocean University. The test section of the wind tunnel had a cross section of 2 m by 1.4 m with 12.5 m long. The wind tunnel was an open suction type and it contracted to the test section with an area ratio of 4:1. The turbulence intensity of the empty wind tunnel is less than 0.5% at the free stream velocity of 5 m/s.

The X-type hot-wire incorporating with the TSI IFA-300 constant temperature anemometer was used to measure the turbulent flow signals. Output of the analog signals for turbulent flow was digitized at a rate of 2 kHz each channel through the 12 bit Analog-to-Digital converter. Since none of the analog signals containing significant energy or noise above 1 kHz, with the Nyquist criteria, a digitizing rate of 2 kHz was sufficient. The low pass frequency for the analog signals is set as 1 kHz in all runs of the experiments.

Four spires and roughness elements are arranged on the entrance of test section to simulate a neutral atmospheric boundary layer flow in urban region as the approaching flow. Three square models are arranged in L shape (see Fig. 1). The wind tunnel model is at a geometric scale of 1 to 500. Each square prismatic building model is 10 cm by 10 cm, and 25 cm high. Fig. 1 is the schematic diagram of the arrangement of three buildings models in the wind tunnel.

![Schematic diagram of the arrangement of three buildings](image)

Figure 1: Schematic diagram of the arrangement of three buildings

The surface wind pressure was measured by using the HyScan-2000 scanning system of the Scanivalve Corporation. The system included a pressure calibration module SPC-3000, and a control pressure module CPM-3000. Pressure was measured by using the ZOC-23B pressure transducer that has 32 channels. The CSM-2000 unit receives many address information from the IFM2000 module and distributes it to the cable-serviced ZOC-23B modules, then routes the addressed analog signals back to the IFM2000 module. The IFM2000 module is the interface unit for ZOC-23B. The DAQ2000 is the self-contained high speed data acquisition and processing system. The HyScan-2000
system incorporating with the DAQ2000 can sample 16–32 channels of the pressure transducer analog data. In the present study, we sampled 24 channels almost simultaneously at the sampling rate of 2000 Hz and took the sampling time 32.468 seconds for each run.

3. RESULTS

Turbulent boundary layer flow and the mean wind pressure coefficient, $C_p$, and root mean square of wind pressure coefficient, $C_{prms}$, under different wind attack angles are measured and analyzed. The fluctuating wind pressure spectrum was also investigated. As indicated by Walker (1195), and Shiau & Lai (2005), that the maximum mean wind pressure occurred close to the location $z/H=0.888$ for front face of building. So the following analysis of wind pressure characteristics focused on such location.

3.1 Approaching flow.

The neutral atmospheric turbulent boundary layer flow of urban area terrain type was simulated as the approaching flow. The mean velocity profile of the simulated turbulent boundary layer flow is shown in Fig.2. The mean velocity profile is approximated by the power law equation. The turbulent boundary layer thickness is of about $Z_{ref} \approx 100$ cm, and the free stream velocity is of $U_{ref} \approx 12.6$ m/s. The present simulated turbulent boundary layer flow is with a power exponent, $n$ is 0.279. Counihan (1975) indicated the power index range 0.23–0.40 for urban area. The present simulation of approaching flow fit to the power index range for terrain type of urban area as indication of Counihan (1975).

![Figure 2: Mean velocity profile of approaching flow](image)

The simulated turbulence intensity profile is shown in Fig.3. It is seen that the simulated longitudinal turbulence intensity increases with decreasing the height. As the height close to the ground, the longitudinal turbulence intensity exceeds 20%. Counihan (1975) summarized that the longitudinal turbulence intensity for heights 2–30 m above ground level for urban area fell in the range of 0.2 to 0.35. It is reasonable to estimate that the longitudinal turbulence intensity at the height 2–30 m above the ground in the terrain type of urban area is greater than 20%.

Fig.4 shows the comparison of the present simulated longitudinal turbulent velocity spectrum at $Z/Z_{ref}=0.202$ with as appeared the Karman power spectrum equation. Maeda and Makino (1988) rewrote the Karman power spectrum equation and it was expressed as following form:

\[
U(Z)/U_{ref} = \left(\frac{Z}{Z_{ref}}\right)^n
\]
The spectrum density, $S_u(n)$ and frequency, $n$ are normalized, and they are denoted by $US_u(n)/u' L^u_x$ and $nL^u_x/U$, respectively. Here $u'$ denotes the mean square of longitudinal velocity fluctuation, $u^2$; $c$ is coefficient of 4.2065; $L^u_x$ is the integral length scale of longitudinal velocity in x direction; $U$ is the longitudinal mean velocity at the height of $z$. The integral length scale is obtained by multiplying the integral time scale, $T_E$ with the longitudinal mean velocity, $U$. The integral time scale, $T_E$ is computed by integrating the longitudinal velocity autocorrelation coefficient function, $R_u(\tau)$. It is found that a satisfactory agreement is achieved for the turbulent approaching flow structure simulation.

Figure 3: Longitudinal turbulence intensity profile of approaching flow

Figure 4: Longitudinal turbulence intensity of approaching flow at $Z/Z_{ref}=0.202$
3.2 Mean wind pressure coefficient variations under different wind attack angles.

The mean velocity of upstream of building at the building model height for the present study is $U_h = 8.5$ m/s. And the mean wind pressure coefficient in the present study is defined as:

$$C_p = \frac{p - p_o}{0.5 \rho U_h^2}$$

where $p$ is the building surface mean wind pressure, $p_o$ is the reference pressure at the upstream of building model for the height above boundary layer thickness, and $\rho$ is the air density.

The mean wind pressure coefficient as functions of wind attack angle for front faces (at $z/H = 0.888$, $y/W = 0.38$ and -0.38) of three buildings are shown in Fig.5. When the wind flow along the $x$ downstream direction (i.e. attack angle is 0 degree), the mean wind pressure coefficient is the largest for side building (building 1). Due to building 2 is located behind the building 3, the mean wind pressure coefficient alters to negative value for building 2. For side building (building 1), surface mean wind pressure coefficient decreases as increasing the wind attack angle. Increase of wind attack angle up to 135 degree, the surface mean wind pressure coefficient reaches the smallest or the largest value of negative pressure. And as wind attack angle increases again to 360 degree, the value of surface mean wind pressure coefficient increases accordingly.

![Figure 5: Mean wind pressure coefficient as functions of wind attack angle for front faces of three buildings at location $z/H = 0.888$, and $y/W = 0.38$ and -0.38](image)

3.3 Root mean square of surface wind pressure.

The root mean square of surface wind pressure fluctuation coefficient is defined as:

$$C_{prms} = \left[ \frac{(p - p_o)^2}{0.5 \rho U_h^2} \right]^{1/2}$$

The root mean square of wind pressure fluctuation coefficient, $C_{prms}$ as the function of wind attack angle for front faces (at $z/H = 0.888$, $y/W = 0.38$ and -0.38) of three buildings is shown as Fig. 6. It is interesting to notice that $C_{prms}$ of building 1 alters abruptly at attack angle of 45 degree. Since for this wind attack angle, buildings 2 and 3 is just located before buildings 1. Buildings 2 and 3 obstruct the wind flow and make the flow turbulence increases largely behind them. Therefore $C_{prms}$ increases significantly.
3.4 Surface wind pressure spectrum.

The wind spectrum variation at $z/H=0.888$ for different downstream distances on the inner side of building 1 under wind attack angle 0 degree is shown in Fig.7. The frequency, $f$ is normalized by the width of the building, $W$ and the mean velocity of upstream of building at the building model height, $U_h$. The power density, $S_p(f)$ is scaled with standard deviation of pressure fluctuation, $\sigma_p$. The spectra show that peaks of power density occur at $fW/U_h=0.20$. It implies that the vortex shedding frequency in this region of building 1 is shown with Strouhal number of $St=fW/U_h=0.20$.

![Figure 6: Root mean square of wind pressure coefficient as functions of wind attack angle for front faces of three buildings at location $z/H=0.888$, and $y/W=0.38$ and -0.38](image)

![Figure 7: Wind pressure spectrum variations along downstream distance for inner face of building 1 at $z/H=0.888$](image)

Fig.8 is the wind spectrum variation at $z/H=0.888$ for different downstream distances on the inner side of building 2 under wind attack angle 0 degree. The Strouhal number is $St=0.18$ which is smaller than that of building 1. Since building 2 is just located behind the building 3, the Strouhal number is...
4. CONCLUSION

This study is to measure in wind tunnel on the surface wind pressure characteristics and pressure spectrum of three square prismatic buildings arranged in L shape which were attacked under different wind angles in the turbulent boundary layer flow. Measurement and analysis for the height $z/H=0.888$ of three buildings are performed.

Results show that when wind flows along the $x$ downstream direction (i.e. attack angle is 0 degree), the surface mean wind pressure coefficient is the largest for side building (building 1). For side building (building 1), the surface mean wind pressure coefficient decreases as increasing the wind attack angle. Increase of wind attack angle up to 135 degree, the surface mean wind pressure coefficient reaches the smallest or the largest value of negative pressure. And as wind attack angle increases again to 360 degree, the value of mean wind pressure coefficient increases accordingly.

For wind attack angle 0 degree, the peak of power density occurs at $fW/U_h=0.20$. The vortex shedding frequency in the inner face of side building (building 1) is shown with Strouhal number of $St=fW/U_h=0.20$. The Strouhal number of the inner face of building 2 (beside building 1) is $St=0.18$ which is found smaller than that of building 1.

REFERENCES


