Aerodynamic database for low-rise buildings with varied eaves

1. Introduction

An aerodynamic database has been constructed by the Tokyo Polytechnic University as one part of the Wind Effects on Buildings and Urban Environment, the 21st Century Center of Excellence Program, 2003-2007, funded by the Ministry of Education, Culture, Sports, Science and Technology, Japan. Present work is the isolated low-rise building with varied eaves part of the aerodynamic database. Wind loads on low-rise buildings in codes and standards are mainly based on wind tunnel test results on simple models without eaves. Actually, low-rise buildings usually have various kinds of eaves for the sake of usage, which may have some effects on the wind flow around buildings.

To study the effects of varied eaves on wind loads on gable-roofed low-rise buildings, a series of wind pressure measurement wind tunnel test were taken for 3 kinds of eaves of gabled-roof buildings with slope of 26.7°, eave height of models varied in 60, 120, 180cm.

12 test cases are included in the following database, from which the local wind pressures, area averaged wind pressure coefficients and wind pressure coefficient time series on roof or wall surfaces and some more detail information can be queried.

The following paragraphs provide information on wind tunnel tests, processes of obtaining test data, usage of the data.

2. Wind Tunnel Test

Pressure measurement wind tunnel tests on low-rise buildings for this database were executed in the Boundary Layer Wind Tunnel, 2.2m wide by 1.8m high, in the Tokyo Polytechnic University, Japan.

The length scale was set at 1/100. As the velocity scale was assumed at 1/3, the time scale can be estimated at 3/100.

2.1 Wind field

Since a lot of low-rise buildings are located in suburban areas in Japan and some other countries, the suburban terrain corresponding to terrain category III in AIJ (2004)[1] was chose as the tested wind field. This category has a mean wind velocity profile exponent of 0.20 and a gradient height of 450m. It was simulated with turbulence-generating spires, roughness elements and a carpet on the upstream floor of the wind tunnel's test section. The wind velocity profile and turbulence intensity profile of the simulated wind field are shown in Fig. 1. The turbulence density at a height of 10cm was about 0.25. The test wind velocity at this height was about 7.8m/s, corresponding to about 23.4m/s at a height of 10m in full scale.

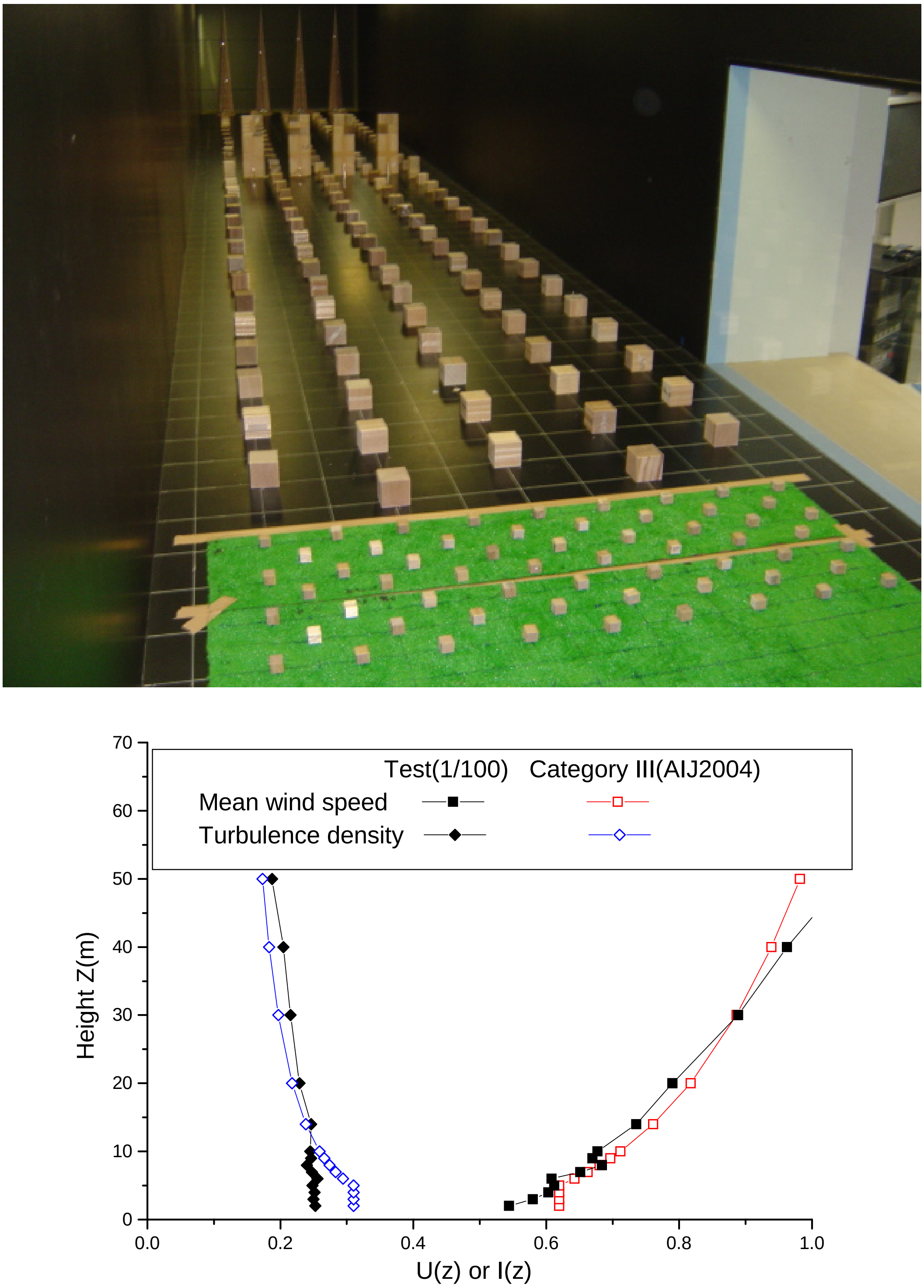
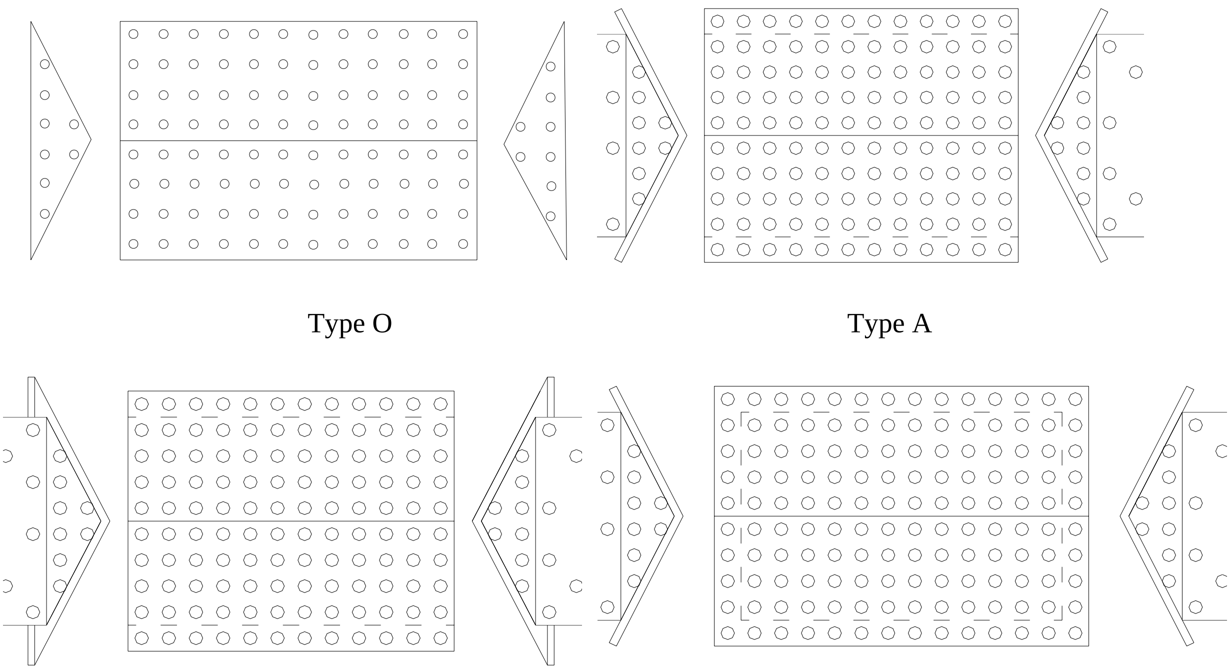


Figure 1. Simulated wind field of suburban terrain

2.2 Test models

The plan sizes of test gable-roofed low-rise building model are 24cm length, 16cm width, with roof pitch of 26.7^{o} (the slope are 1/2), and there are three model heights, 6cm, 12cm and 18cm. In order to study the effect of different kinds of eave, four types of gable roofs were included in the tests, Type O, Type A, Type B and Type C, as showing in Fig. 2, where Type O means without eave, Type

A has side eaves whose lower surfaces are parallel to the upper surfaces, Type B has side eaves whose lower surfaces are horizontal and Type C has both gable eaves and side eaves whose lower surfaces parallel to the upper surfaces.



Type O Type A

Type B Type C

Figure 2 Test models of low-rise buildings

2.3 Wind pressure measurement system

Wind pressure measurement taps were disposed uniformly over the surfaces of the tested models. Basic spaces among the taps were 20mm corresponding to 2m in full scale. Since the wind pressure measurement scanivalve couldn't measure a large number of taps synchronously, some inner points in wall surfaces where the pressures changed smoothly were not measured, which are shown in dashed circle in Fig. 3. Synthetic resin tubes 80cm long and 1.2mm in internal diameter connected each tap with a pressure measurement scanivalve, which can measure the fluctuating wind pressures at 384 points nearly synchronously.

In this test, the sampling frequency was 781.25Hz and the sampling period was 18 seconds for each sample, corresponding to 23.4Hz and 10 minutes in full scale. Each test case was sampled 10 times. The test data were then low-pass filtered at 300Hz.

All cases involved in this wind tunnel test are list in Table 1.

Table 1. Test model cases

Case number	Roof Type	*H0*(mm)	β (°)	Eave type	*Wind direction* θ (°)
1-3	Gable	60,120,180	26.7	Type O	0:22.5:90
4-6	Gable	60,120,180	26.7	Type A	0:22.5:90
7-9	Gable	60,120,180	26.7	Type B	0:22.5:90
10-12	Gable	60,120,180	26.7	Type C	0:22.5:90

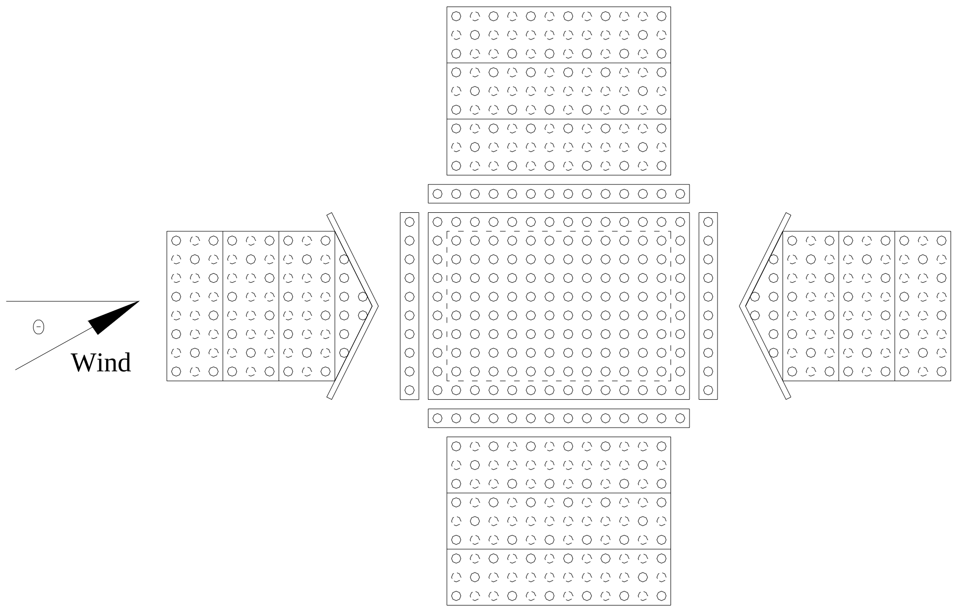


Figure 3. Arrangement of wind pressure measurement taps

3 Test Data Process

The measured voltage signals were translated into time series of wind pressure with the calibrating data of the pressure sensors at first. After that, the effect of the tube system on the measured wind pressure was eliminated by dividing the transfer function from the power spectra of the raw wind pressure. The transfer function of the tube system shown in Fig. 4 was identified with a frequency sweep technique.

The time series of wind pressure coefficients is calculated as:

$$C_{p\_ori}(i,t) = p(i,t) / p_H \tag{1}$$

where $C_{p\_ori}(i,t)$ is original wind pressure coefficients at measured tap i at time t; $p(i,t)$ is measured wind pressure at tap i at time t; p_H is the reference wind pressure of the approaching wind velocity at the average roof height, $0.5\rho V_H^2$, V_H the mean longitudinal wind speed at the reference height (average height of the roofs) H; ρ the air density.

In order to make the wind pressure coefficients correspond to some duration, the time series of wind pressure coefficients were moving averaged as:

$$C_p(i,t) = \overline{C_{p\_ori}(i, t - \Delta t/2 \sim t + \Delta t/2)} \tag{2}$$

where Δt is the duration of the wind pressure coefficients. In this test, the time series data were all moving averaged every 0.0064s, corresponding to 0.2s in full scale. According to an expedient formula by Lawson [2], the corresponding general size is roughly estimated at 1m for this duration at the design wind velocity of 23.4m/s. To design cladding or components with a size smaller than 1m, one can calculate its extreme wind loads based on the original time series of point wind pressure coefficients given in the database for the corresponding duration.

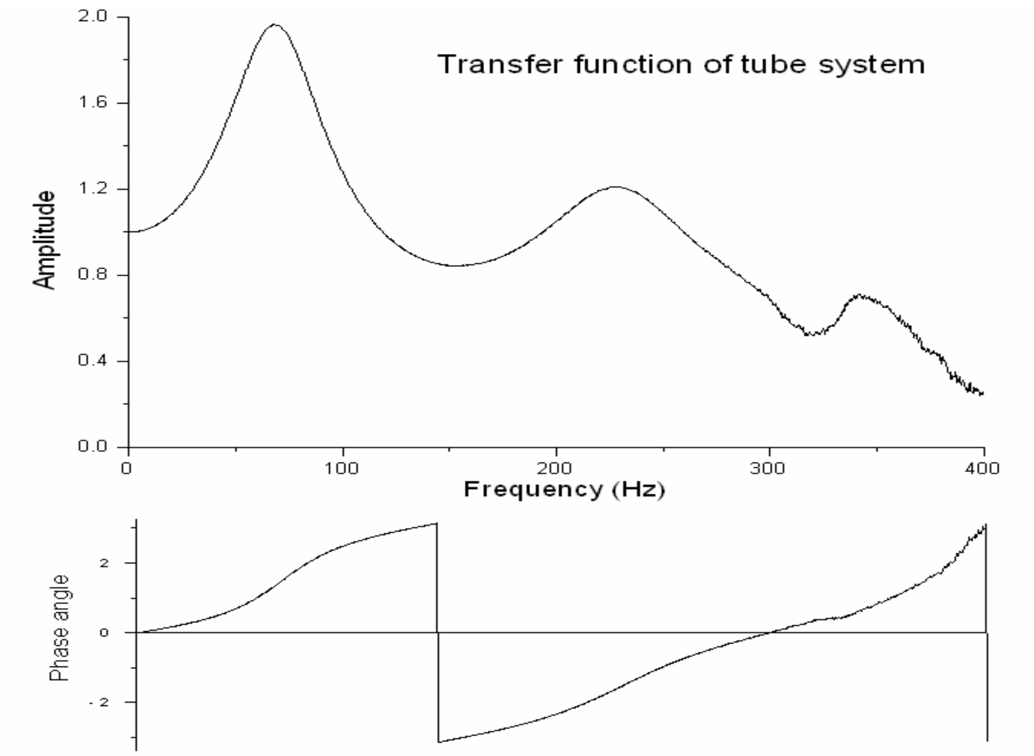


Figure 4. Transfer function of tube system

4 Database system

The statistical values of local wind pressure coefficients are expressed as contours in the database system. Time series of point wind pressure coefficients are stored in MATLAB data format.

4.1 Statistical values of local wind pressure coefficients

Contours of the statistical values of local wind pressure coefficients calculated from Equation (2) with duration of 0.2s in full scale were drawn. There were four types of statistical values shown: mean, RMS, positive extreme and negative extreme.

The mean and RMS values were the averaged values of ten samples:

$$\overline{C_p} = \frac{1}{10}\sum_{n=1}^{10}\overline{C_p}(n) \tag{3}$$

$$\tilde{C}_p = \frac{1}{10}\sum_{n=1}^{10}\tilde{C}_p(n) \tag{4}$$

where, $\overline{C_p}(n)$ and $\tilde{C}_p(n)$ are the mean and RMS values of the time series of the *n*th sample.

The extreme values were calculated by the Cook & Mayne method [3], where the extreme distribution of wind pressure coefficients was assumed as a Fisher-Tippett Type 1 (FT1) distribution:

$$\hat{C}_p = U_{\hat{C}p} + 1.4 / a_{\hat{C}p} \tag{5}$$

where, $U_{\hat{C}p}$ *and* $1/a_{\hat{C}p}$ are the mode and dispersion of the Fisher-Tippett Type 1, respectively, which can be calculated by the Best Linear Unbiased Estimators (BLUE) [4] as：

$$U_{\hat{C}p} = \sum_{i=1}^{10} a_i X_i \tag{6}$$

$$1/a_{\hat{C}p} = \sum_{i=1}^{10} b_i X_i \tag{7}$$

where, X_i is the ith value of the ascending array of maximum values of 10 samples and a_i and b_i are given by Table 2.

Table 2, coefficients of BLUE for FT 1 distribution (for 10 samples)

i	1	2	3	4	5	6	7	8	9	10
a_i	0. 22	0. 16	0. 13	0. 11	0. 096	0. 081	0. 067	0. 054	0. 042	0. 029
b_i	−0. 35	−0. 091	−0. 019	0. 022	0. 049	0. 066	0. 077	0. 083	0. 084	0. 078

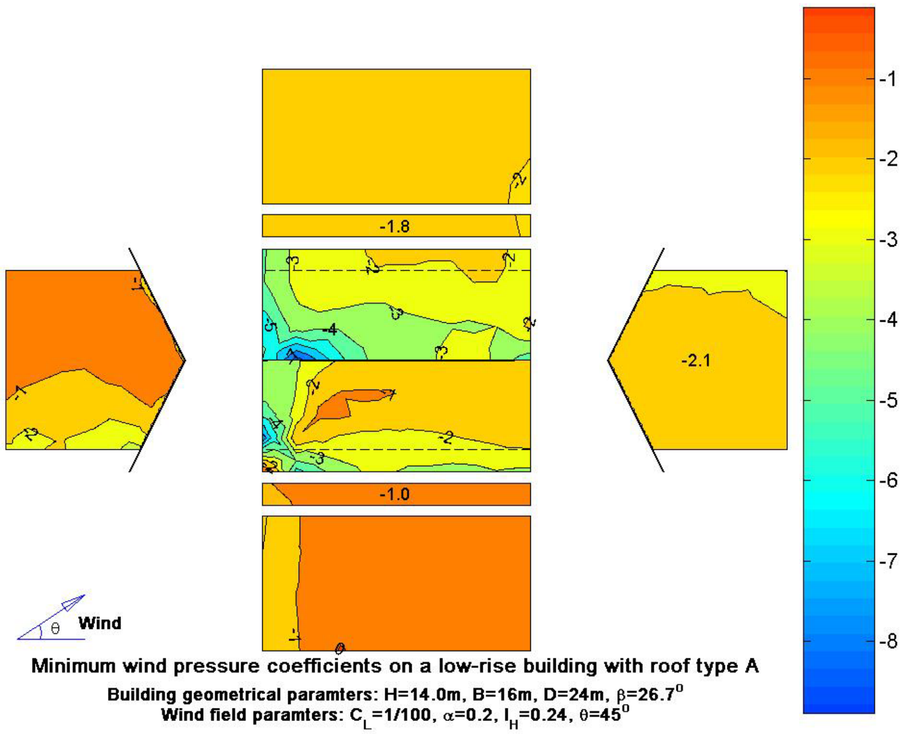


Figure 5. An example of contours of statistical values of local wind pressure coefficients

Equation (5) expresses positive extreme values, and it can also be used to calculate negative extreme values. The probability of exceedence of the extreme values calculated from Equation (5) is 22%.

Fig. 5 shows an example of the contours of statistical values of local wind pressure coefficients. Values not at the measured points shown in Fig. 3 were interpolated from measured values.

4.2 Statistical values of area averaged wind pressure coefficients

The contours in Section 4.1 are based on statistical values of wind pressure coefficients at measured points. Mean wind force coefficients of wind force on a wall or roof surface can be calculated from mean values of point wind pressure coefficients. However, the RMS and extreme values of wind force cannot be evaluated in this way because of the correlation among point wind pressures.

For convenience, the statistical values of area averaged wind pressure coefficients on each roof or wall surface were shown in this database too.

The area averaged wind pressure coefficients on a roof or wall surface were calculated from:

$$C_F(j,t) = \sum_{i=1}^{N_j} \left(C_p(i,t).A_i \right) / \sum_{i=1}^{N_j} A_i \tag{8}$$

where, $C_F(j,t)$ is the area averaged wind pressure coefficient on Surface j at time t; $C_p(i,t)$ is the wind pressure coefficient at point i at time t, obtained from Equation (2) with a duration of 0.2s in full scale; A_i is the effective area of wind pressure measured at point i; and N_j is the number of measured points on Surface j. The number of surface, j, was defined in the webpage of each case.

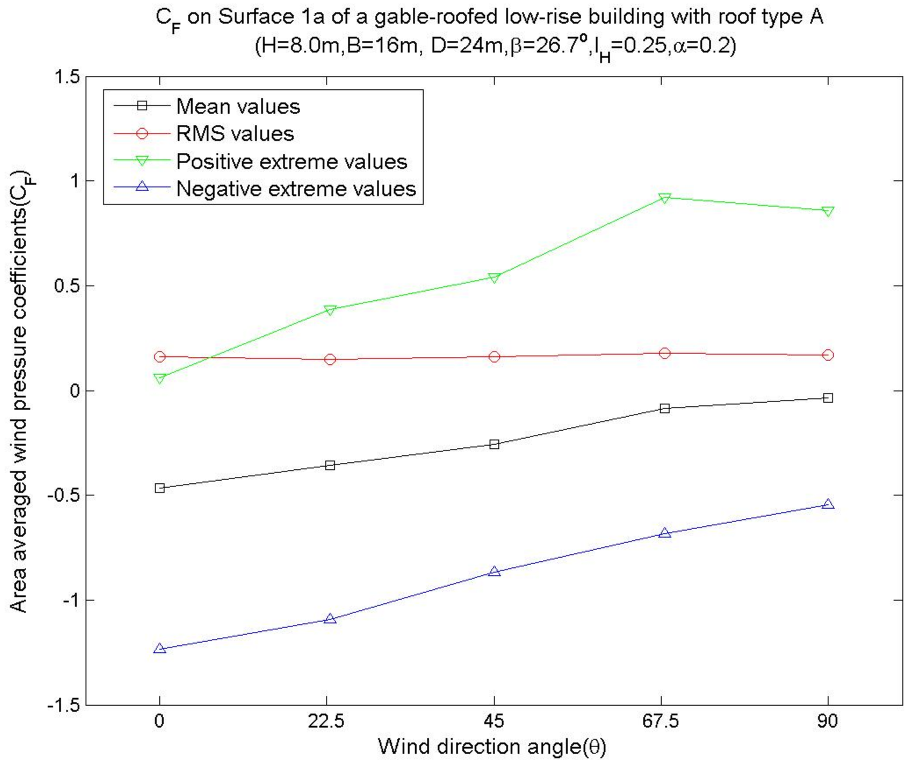


Figure 6. An example of the statistical values of area averaged wind pressure coefficients

The mean, RMS, positive extreme and negative extreme values of area averaged wind pressure coefficients on each roof or wall surface were calculated from $C_F(j,t)$ by the methods used in Section 4.1. The graphs of those values versus wind direction angle are shown on the website as Fig.6.

4.3 Time series of point wind pressure coefficients

One of the ten samples of time series of synchronous-measured point wind pressure coefficients at each measurement point for each test case calculated from Equation (2) with a duration of 0.2s in full scale, which can be used to analyze the dynamic responses of the low-rise buildings, are shown in this database.

The data are saved in MATLAB data format, as shown in Fig. 7. There are 11 values saved in each data file, including the information of model geometrical parameters, locations of measured points, sampling information and time series of wind pressure coefficients. There is also a character constant nominated README, in which the detail of the wind tunnel test and the test data is included.

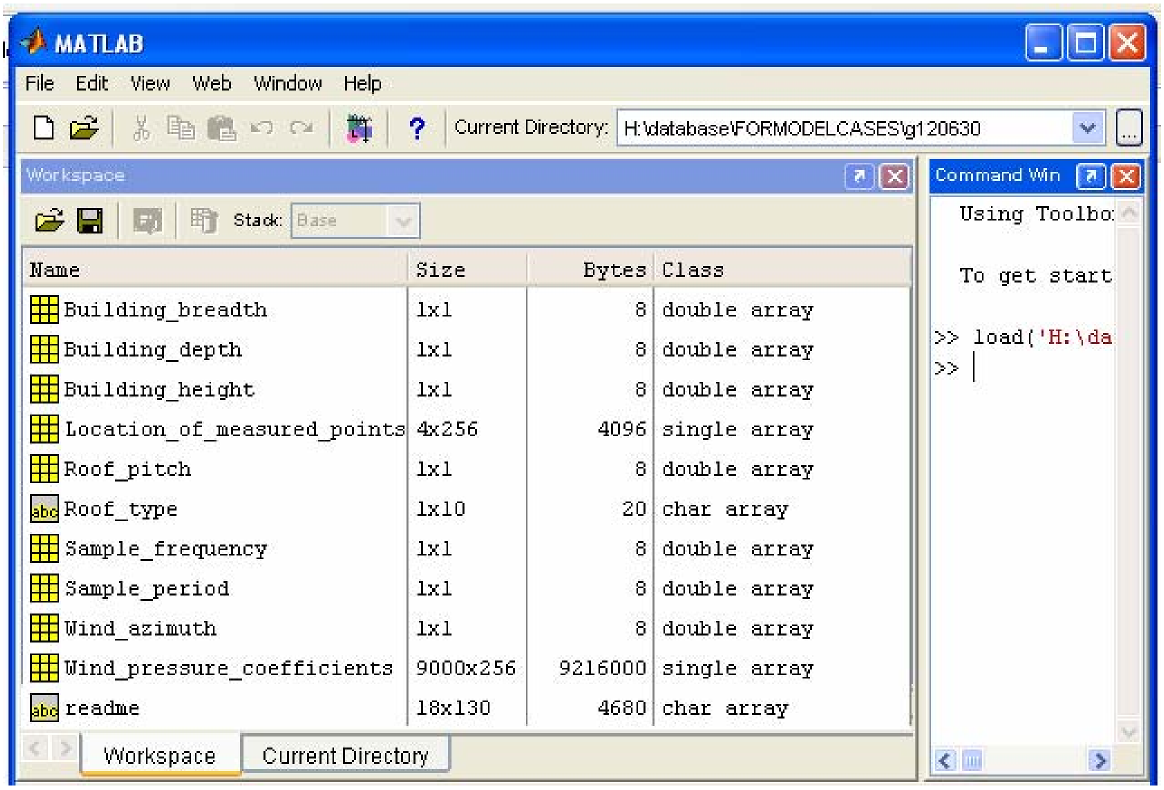


Figure 7. Format of time series of point wind pressure coefficients

5. Usage of data

The time series data of point wind pressure coefficients can be used to analyze the dynamic responses of low-rise buildings.

The statistical values of local wind pressure coefficients are useful for the design of main structural frames such as girders and pillars and cladding and components such as window panes, furring strips, purlins, and so on.

The statistical values of area averaged wind pressure coefficients on a surface can be used to design structural frames such as girders and pillars.

References

[1] AIJ Recommendations for Loads on Buildings (in Japanese), Architectural Institute of Japan, 2004

[2] T. V. Lawson, , Wind effects on buildings, Volume 1: Design application, London, Applied Science Publishers, 1980

[3] N. J. Cook, J. R. Mayne, A refined working approach to the assessment of wind loads for equivalent static design, J. of Wind Eng. & Ind. Aerody., 6(1980)125-137

[4]. J. Lieblein, Efficient methods of extreme-value methodology, Natl. Bur. Stand. (U.S.) Rep. NBSIR 74-602 (1974).