WIND PRESSURE COEFFICIENTS ON EXTERIOR WALL ELEMENTS OF TALL BUILDING

COEFFICIENTS DE PRESSION DU VENT SUR MUR EXTERIEUR DE BÂTIMENT ÉLEVÉ

by
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Summary

Measurements of wind pressure distributions on a model of tall building were made in a turbulent wind tunnel with a velocity profile. The wind pressure distributions in a constant uniform velocity field were also measured, and the differences in the patterns of pressure distributions due to the effects of velocity profile were observed at lower part of the model.

This paper also describes the measurements of the natural wind pressures and glass strains on the exterior wall elements at Kasumigaseki Building.

The data were analysed to estimate the power spectral densities and gust factors in order to investigate the dynamic response of glass panels installed at high rise building against the natural wind pressure.

1. Introduction

The wind pressure coefficients acting on cladding elements of the tall buildings are often measured by modelling the building in a wind tunnel with a constant uniform velocity field. The design wind pressure is the product of the wind velocity pressure multiplied by a correction factor to allow for gusts and a pressure coefficient obtained by usual wind tunnel test. But, as well known, the natural wind is a turbulent air flow and its speed increases with the height, it is very important to simulate the profile and turbulence of the natural wind in the wind tunnel. Besides, the maximum gust speed will increase with decrease of the length of averaging periods and the local pressures by the gusts of a few seconds may arise on the cladding elements. Then it is necessary to consider what period should be used for the design wind pressure on the cladding elements and estimate the values of correction factors for the short gusts. Therefore, for investigating the effects of short duration local pressures, it is very important to measure the variations of wind pressure on the exterior wall element of actual tall building under the natural wind.

2. Wind Tunnel Test in a Turbulent Flow

2-1 Wind tunnel and model

The 1/300 sealed model is shown in Fig. 1. The full scale of this 47-storey tall building having a rectangular plan with two reentrant corners is about 160 m high, 80 m long and 25 m wide.

The wind tunnel has a working section of about 10 m long, 1.5 m wide and 1.5 m high. The wind speed is continuously adjustable up to the maximum 20 m/s. The model is set at 2.5 m from the nozzle for the test in the constant uniform velocity flow. In the case of testing in a turbulent flow with a velocity profile the model is set at 7 m from the nozzle.

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2-2 Wind profile and turbulence in the wind tunnel

On the roughness plate showed in Fig. 2 there are various sizes of wooden blocks. The wind profile and turbulence are obtained by changing the arrangement of the unit roughness plates or the size of wooden blocks on the plates sketched in Fig. 3.

The profile of mean velocity pressures at the test section measured with the Pitot tube and Betz type manometer is plotted in Fig. 4.

The turbulence measured by a hot wire anemometer in Fig. 5 indicates that the turbulence is nearly 25 % in the lower parts of the wind tunnel.

Fig. 4 suggests that the wind velocity pressure is almost proportional to the root of the height in the wind tunnel, namely the mean wind velocity profile is supposed to agree with the 1/4 power law approximately.

2-3 Wind pressure distributions on the model

Wind pressure coefficients are calculated from the pressure distributions on the model in a constant, uniform velocity field. The patterns of the design wind pressures on the building are obtained by the product of the pressure coefficients by the design velocity pressure having the 1/2 power law.

In this case, the design wind velocity pressure is taken to be 1.0 at the same height in a free wind as the top of the tall building.

The patterns of the pressure distributions on the model in a turbulent flow with the velocity profile having the 1/4 power law approximately are estimated to divide the pressure distributions measured at all points of interest by the velocity pressure measured in front of model at the same height as the top of the model.

If the shape factors in a turbulent flow with a velocity gradient are estimated in the same way as the evaluating the wind pressure coefficients in a constant uniform velocity field, it is disagreeable that those values are often greater than 1.0.

To compare the contours of above mentioned patterns of pressure by the test in the presence of the velocity profile with those in the constant uniform flow test, Fig. 6, Fig. 7 and Fig. 8 are represented in the case of the wind ward face, side face and leeward face on the building respectively.

Judging from these patterns, difference due to the effects of velocity profile and turbulence in wind tunnel are observed mainly at the lower parts of the model.

So it is supposed that the natural wind pressures are not necessarily small at the lower parts of the high rise buildings.

3. The Gust Wind Pressure on the Claddings of Actual Tall Building

3-1 Test building and instruments

The test building, known as Kasumigaseki Building, is a 36-storey office building having a rectangular plan with relatively smooth facades and its dimension is about 147 m high, 84 m long and 43 m wide. The sketch of Kasumigaseki Building and its surroundings in Fig. 9 shows that the wind are relatively unobstructed because of no tall building close to it.

For measurement of wind pressure a Newberry type wind pressure transducer is fixed at the circular hole drilled in a glass plate near the centre of each side of the 36th and 11th floors; east face, south face and west face.

The strains on the inner surface of glass panels are also measured at proper positions showed in Fig. 10.

The data of wind pressures and glass strains stored in magnetic tape recorders or electromagnetic oscillographs are analysed with a real time correlator and a digital computer to estimate the correlation functions, power spectral densities and gust factors.

3-2 Power spectra of wind pressure and glass strains

Fig. 11 shows a part of records of wind pressure and glass strains at the 36th floor in Aug. 29, 1968 Typhoon No. 10. The power spectral densities in Fig. 12 illustrate that a sharp peak in each spectra exists at the frequency near 10 Hz This sharp peak is considered to be caused by the natural flexural vibration of the glass plate because this frequency coincides with the calculated natural frequency which is a little lower than 10 Hz. And in Fig. 12 general agreement of the spectra for the wind pressure and the glass strains can be seen in the range of the frequency below the natural frequency of flexural vibration of glass plate. In the same frequency range the power spectra of wind pressures are proportional approximately to the -5/3 power law.

3-3 The maximum values of wind pressures and wind velocities

The records in Fig. 13 are the data of the wind pressures at the 36th floor in Typhoon No. 9, Aug. 23 in 1969. The power spectra plotted in Fig. 14 indicate that the spectrum of wind pressure on the east face is a little larger than those of other faces in the region of high frequency of about $10^{-1} \sim 1$ Hz.

There are two anemometers, the one is an aerovane type anemometer at the top of Kasumigaseki Building 187 m high, the other three-cup anemometer on the roof of Tokyo Club Building 36 m high adjacent to Kasumigaseki Building.

Fig. 15 shows the gust factor of wind pressures and velocities estimated from their power spectral densities. It is proved that the gust factor of the wind pressure on the front face, the south face in this figure, is nearly given by the square of the gust factor of the wind speed measured at the height of 187 m. The maximum values statistically expected of the instantaneous wind pressures and velocities are shown with the gust factors in Tab. 1. Judging from these results the correction factors for the effects of short duration local pressures on the cladding elements should be taken as 1.3 at front face and 1.5 at rear or side face.

Fig. 15 also indicates that it is sufficient to consider the gusts within the range of gust periods up to the shortest 1 sec for estimating the design wind pressures on the cladding elements of the windward face, but it will be necessary to regard for the gusts with the periods shorter than 1 sec on the side and rear face. It is interesting that the instantaneous wind pressure on the rear and side face is considerably large, though the mean value of wind pressure is comparatively small, then very large correction factor to the wind pressure coefficient is often necessary to evaluate the design pressure regarding for the short duration gust.

Fig. 16 and Tab. 2 give the data of the gust factors of wind pressure measured at the 36th and 11th floor in Typhoon No. 10, Aug. 22, 1970. It shows that there is no wide difference between the gust factors at the 36th floor and those at the 11th floor with regard to the short gusts within the region of gust period of about $10 \sim 0.1$ second.

4. Final Remark

(1) From the results of the wind tunnel tests in a turbulent flow with a velocity profile it is concluded that the wind pressures are not necessarily small at the lower parts of tall building and in estimating the wind pressure coefficients the velocity pressure in a free wind at the same height as the top of the building is preferable.

(2) The resonances of glass panels with short gusts are found, but the amplitude of the oscillation of glass strains by this resonance is supposed to be relatively small.

Good agreement of the spectra between the wind pressures and the glass strains are observed, so it is considered to be able to estimate the strength of glass against the gusts by static pressure tests within a region of frequency below the natural frequency of flexural vibration of glass plate.

(3) For determining the wind pressure on the exterior wall elements, it is sufficient to investigate the maximum value of the wind pressure on the windward face of the building in a range of gust periods longer than about 1 second.

The 1-second gust factor relative to 10-second mean wind pressure is 1.3 approximately.

(4) Owing to the turbulence of the flow around the building on the rear and side face there are considerably large pressure fluctuations of short gusts though the average pressures are small and reduce often to approximately zero. Then, the gust pressure factors on the rear and side face are found to be unusually large. Therefore for accurate evaluation of local wind pressures, the wind pressure coefficient should be considered dynamically, and for instance, be defined as a function of gust pressure duration time.

Acknowledgements

The authors would like to thank the members of Kasumigaseki Building Office in Mitsui Real Estate Development Co. Ltd. and Fujikura Cable Works Ltd. for their very willing help with this observation. They also wishes to thank Dr. Soma for offering the records of wind speeds at Kasumigaseki Building.

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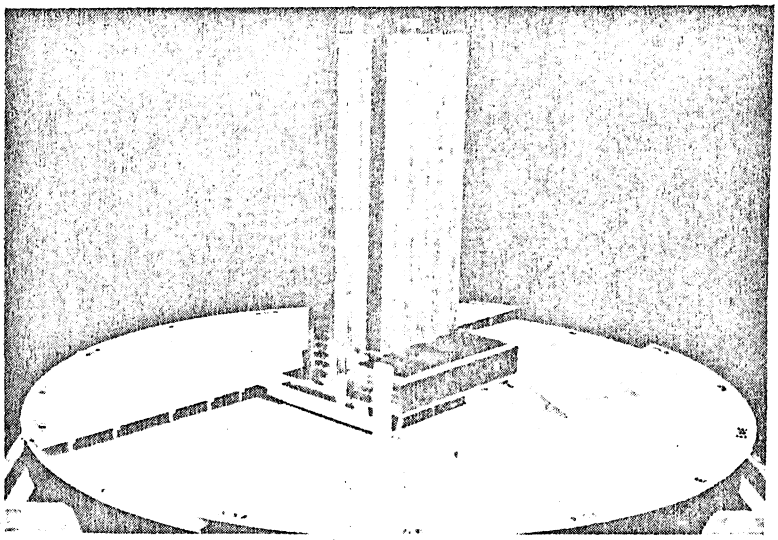

Fig. 1 1/300 Scaled Model

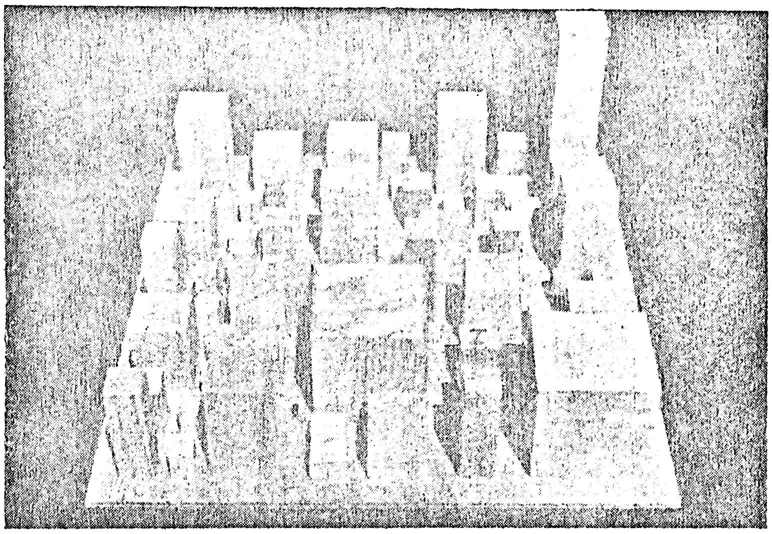

Fig. 2 Roughness Plate

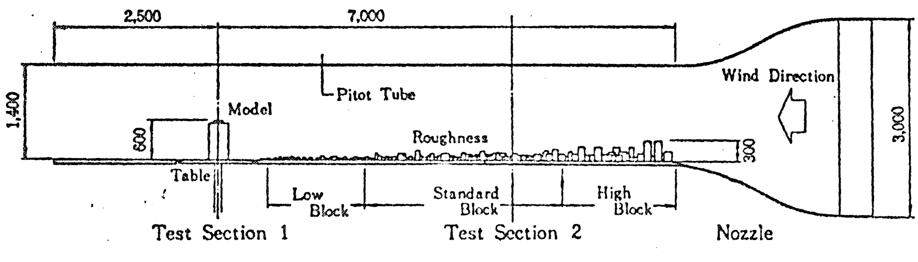

Fig. 3 Section of Wind Tunnel

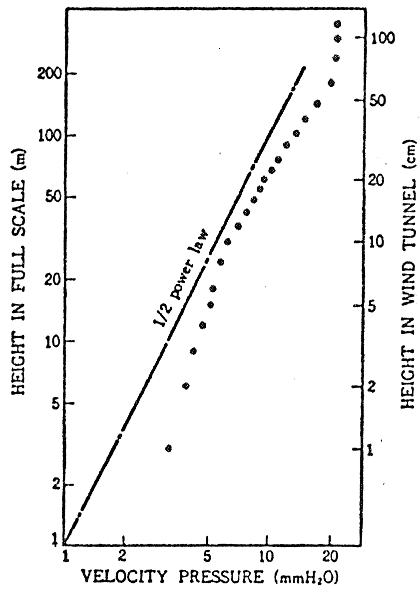

Fig. 4 Profile of Mean Velocity Pressure.

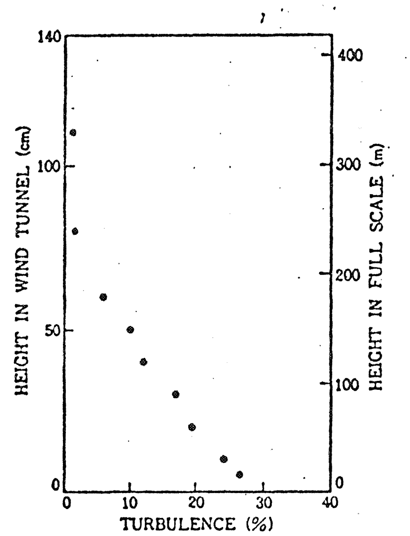

Fig. 5 Intensity of Turbulence

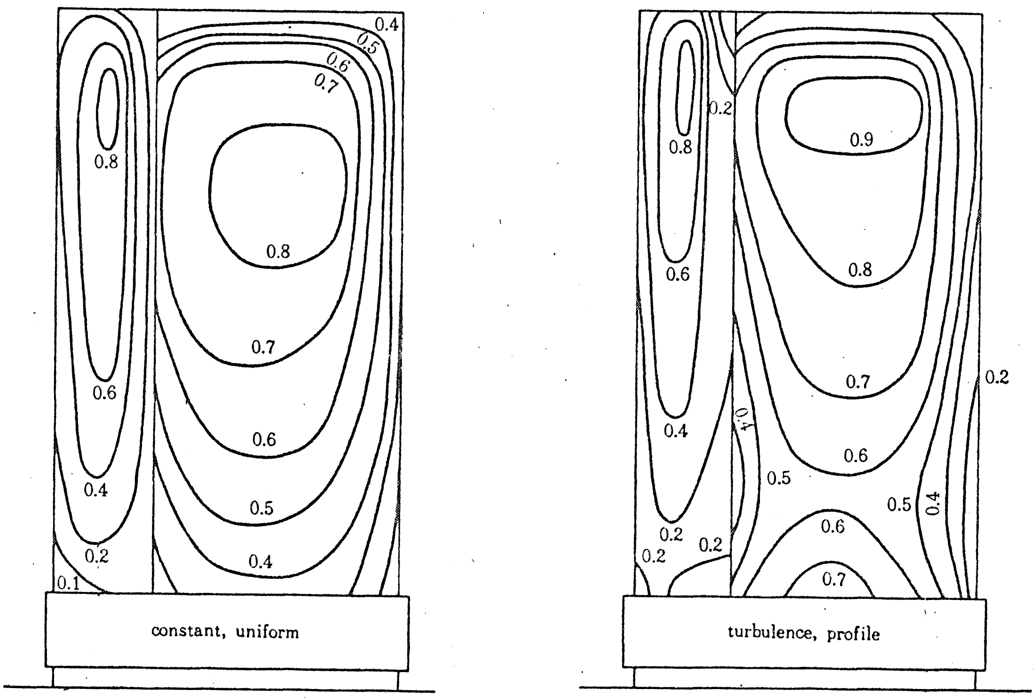

Fig. 6 Patterns of Wind Pressure Distributions under 1/4 Power Law Profile Wind (Front).

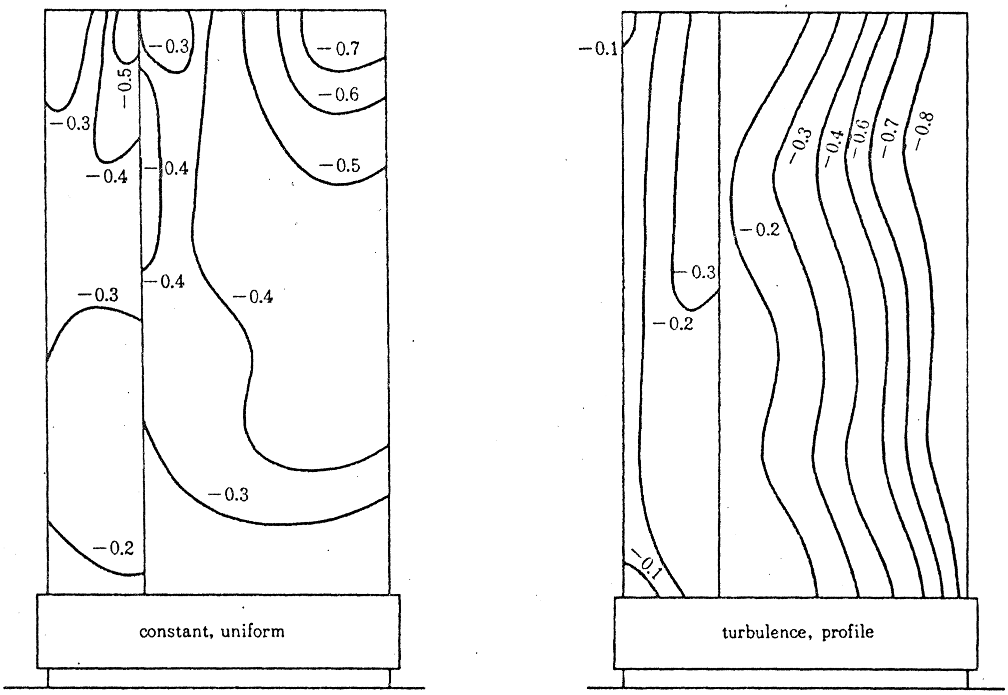

Fig. 7 Patterns of Wind Pressure Distributions under 1/4 Power Law Profile Wind (Side).

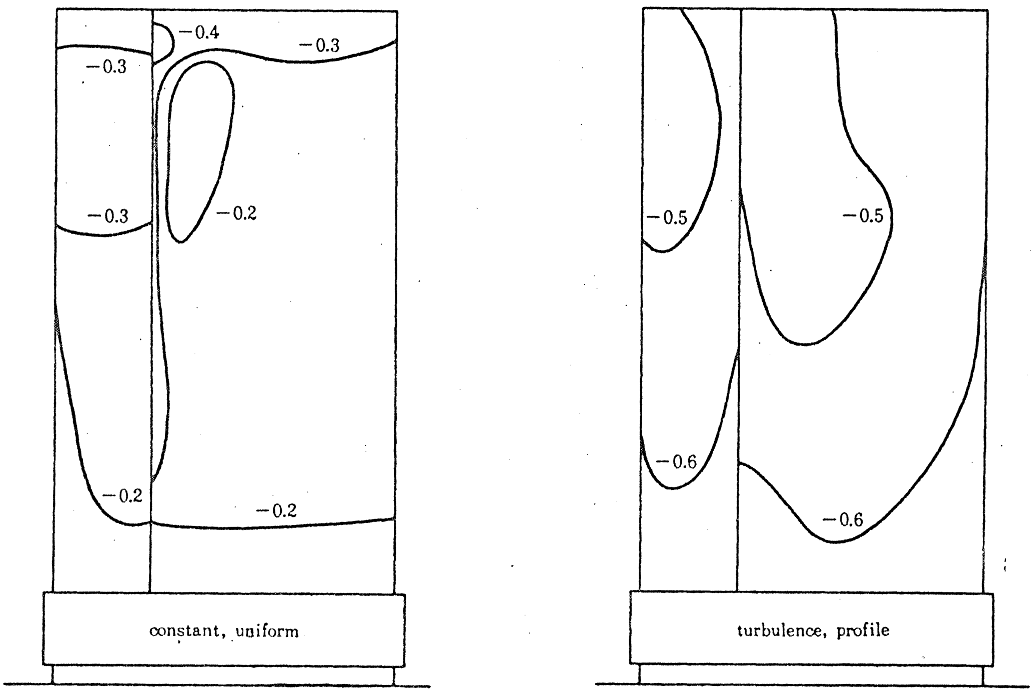

Fig. 8 Patterns of Wind Pressure Distributions under 1/4 Power Law Profile Wind (Back).

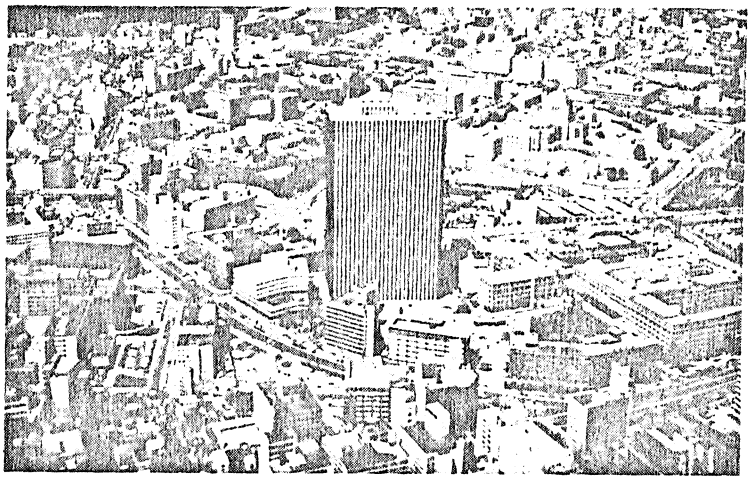

Fig. 9 Kasumigaseki Building and its Environments.

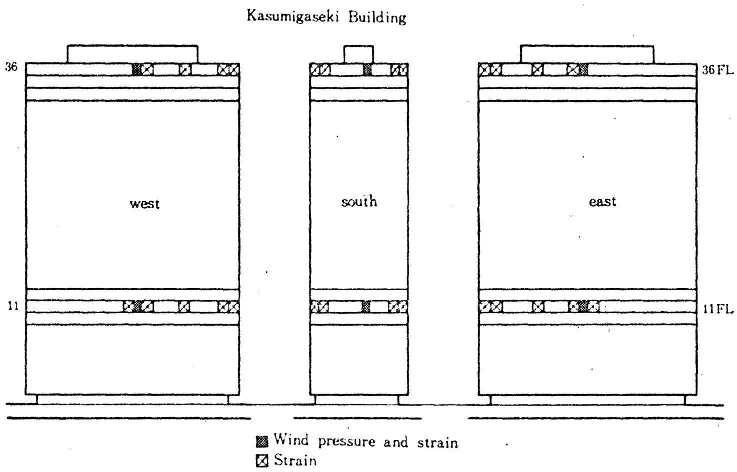

Fig. 10 Gage Positions for Observations.

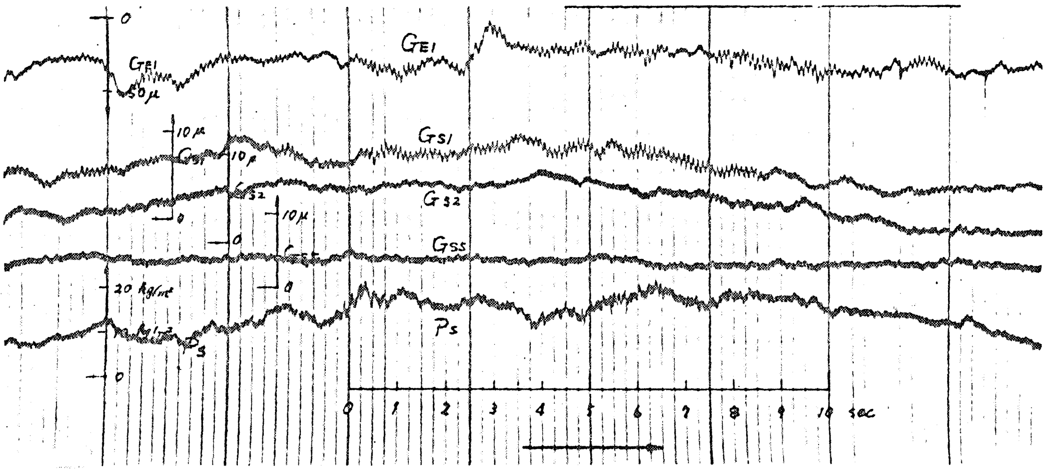

Fig. 11 A Part of Record of Wind Pressure and Strains (T6810).

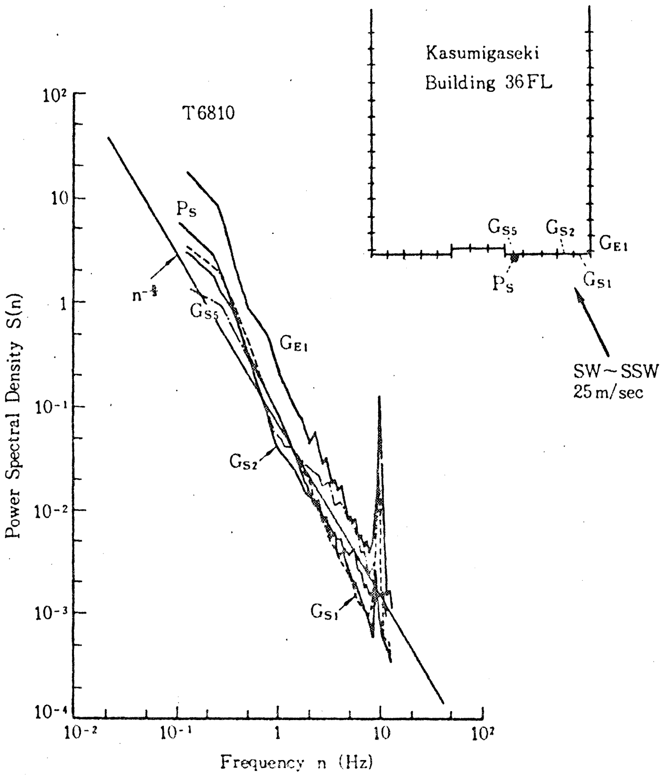

Fig. 12 Power Spectral Densities at the 36th Floor (T6810).

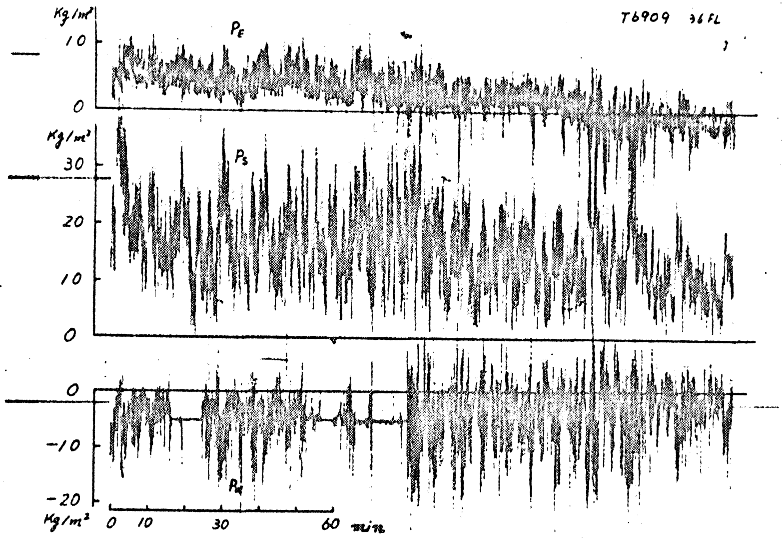

Fig. 13 Record of Wind Pressures (T6909)

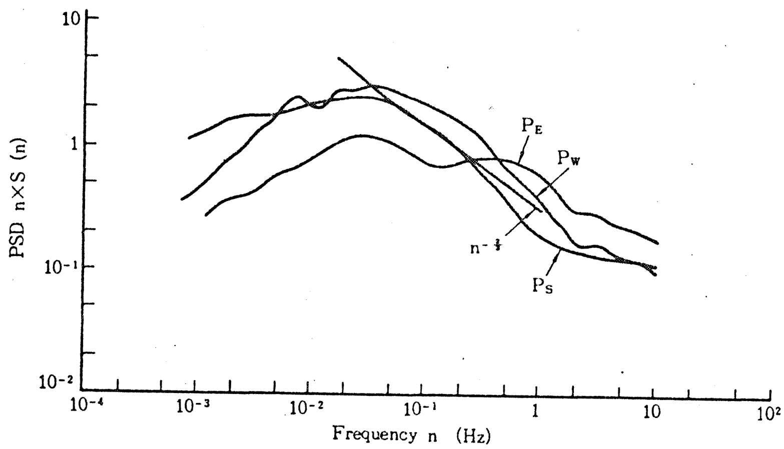

Fig. 14 Power Spectra of Wind Pressures at the 36th Floor (T6909).

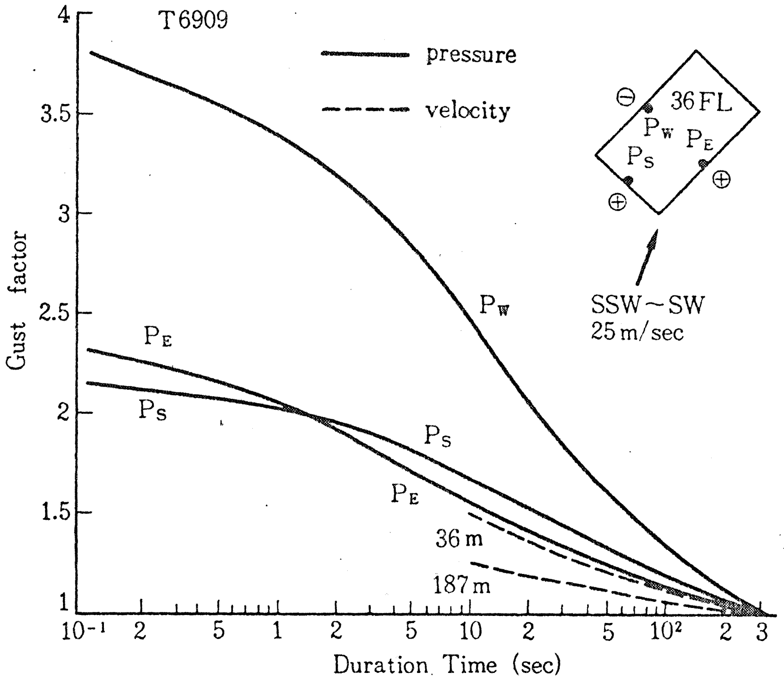

Fig. 15 Gust Factors of Wind Pressures and Velocities (T6909)

	$P_{0.1}$	$P_{0.1}/P_{10}$	P_{10}	P_{10}/P_{300}	P_{300}
P_E	22.4	(1.51)	14.8	(1.52)	9.7 kg/m²
P_S	37.7	(1.28)	29.4	(1.65)	17.8 kg/m²
P_W	−15.3	(1.54)	− 9.9	(2.47)	− 4.0 kg/m²
H = 187 m			V_{10}	V_{10}/V_{300}	V_{300}
			27.5	(1.25)	22.0 m/sec
				$(1.25)^2 = 1.56$	

Table 1 Maximum Wind Pressures and Velocity (T6909)

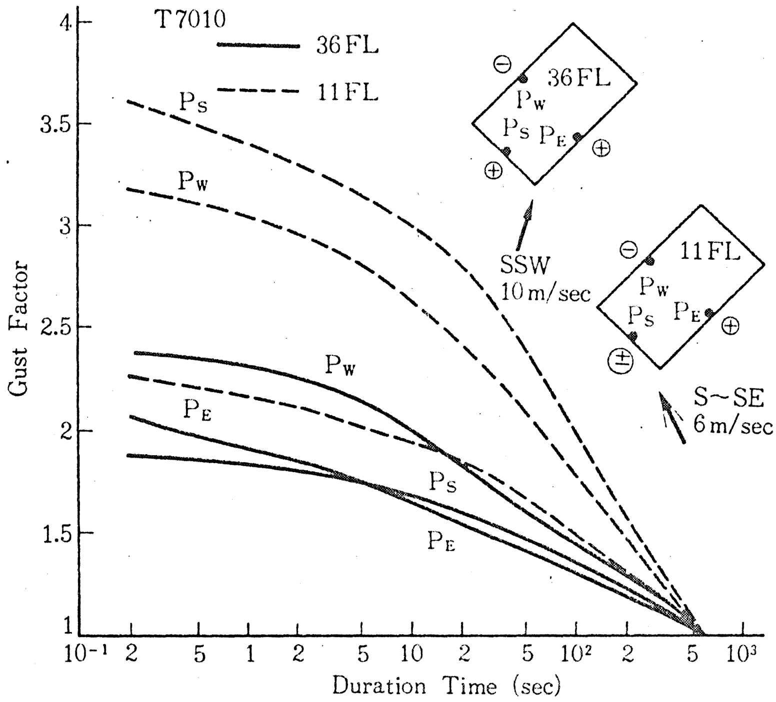

Fig. 16 Gust Factors of Wind Pressures at the 36th Floor and the 11th Floor (T7010).

		$P_{0.1}$	$P_{0.1}/P_{10}$	P_{10}	P_{10}/P_{600}	P_{600}
36 *FL*	P_E	7.2	(1.25)	5.7	(1.64)	3.5 kg/m²
	P_S	10.2	(1.12)	9.1	(1.67)	5.5 kg/m²
	P_W	− 5.3	(1.20)	−4.4	(1.98)	−2.2 kg/m²
11 *FL*	P_E	7.0	(1.17)	6.0	(1.94)	3.1 kg/m²
	P_S	7.0	(1.20)	5.8	(2.98)	1.9 kg/m²
	P_W	− 4.9	(1.22)	−4.0	(2.59)	−1.5 kg/m²

Table 2 Maximum Wind Pressures (T7010).