

## Field Measurements at Maishima Wind Resistant Laboratory

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### Synopsis

For the estimation of wind loads applied to structures, field measurements have been carrying out at Maishima Wind Resistant Laboratory of Osaka City University. Three kinds of models are employed to the field measurements. These models are used for the individual purpose respectively. This paper presents the purposes and outlines of each field measurement.

**KEYWORDS:** field measurement, natural wind, unsteady wind force, conical vortex, internal pressure

### 1 Introduction

Generally wind tunnel experiments are employed for the estimation of wind loads applied to structures. However, it is doubtful to apply these results directly to the actual structures because of the use of the small-reduced model and/or the unsteady characteristics of the natural wind. On the other hand, it is very difficult to perform the field measurement by using of the actual structures. Therefore, the field measurements with small models of prototype have been carrying out at "Maishima Wind Resistant Laboratory of Osaka City University". This paper presents the purposes, outlines and parts of the results of each field measurement. The results obtained by these field measurements are thought to be available to estimate the experimental results and to apply these results to the design of the actual structures.

### 2 Test Site

The field measurements have been carrying out at a test site on reclaimed land called "Maishima" located at Osaka North Port area. At the test site, three models, a reference tower and an investigation house have been arranged as shown in Figure 1.

The reference tower is 10m high. A propeller anemometer is set on the top of the reference tower. An ultrasonic anemometer is set at the height of 2.5m of the tower, and three-cup anemometers are set at the

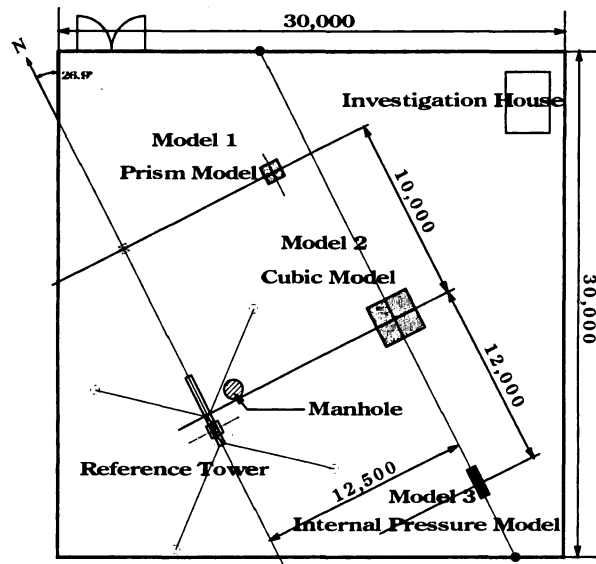
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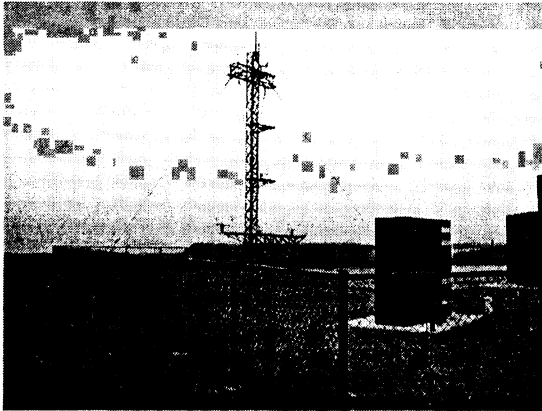
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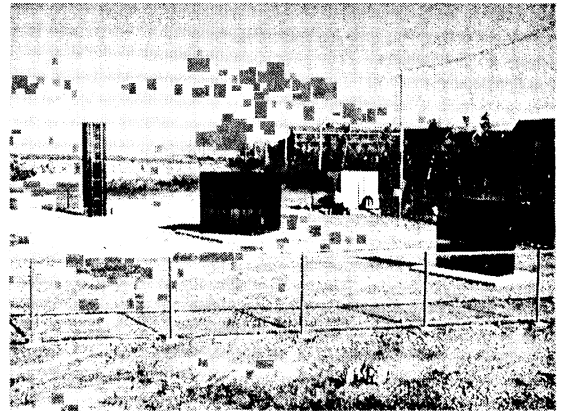
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**Figure 1 Test Site of Field Measurement**



**Photo 1 Reference Tower**



**Photo 2 Test Site**

height of 7.5m, 5m, 2.5m and 1.25m respectively.

Three models are in the test site. Model 1 is a elastic prism model used for the estimation of the unsteady wind forces, Model 2 is a cubic model for the investigation of the wind pressures applied to the roof and wall of the model and Model 3 is used for the study of the internal pressures of the structures. These models are arranged parallel to the north-south axis, because the predominant wind direction in Osaka is west.

### **3 Measurement System**

The measurement system is shown in Figure 2. It is possible to measure 128 items simultaneously as maximum for each model. The combinations of measurement items for each model are different respectively. Wind velocity and direction have been measured by anemometers and wind vanes. The wind pressures applied to the model and inner pressure were measured against the static pressure at the manhole near the base of the reference tower. These pressures, displacements, accelerations, temperature, wind velocity and wind direction were measured simultaneously. The time history data was recorded at 50Hz.

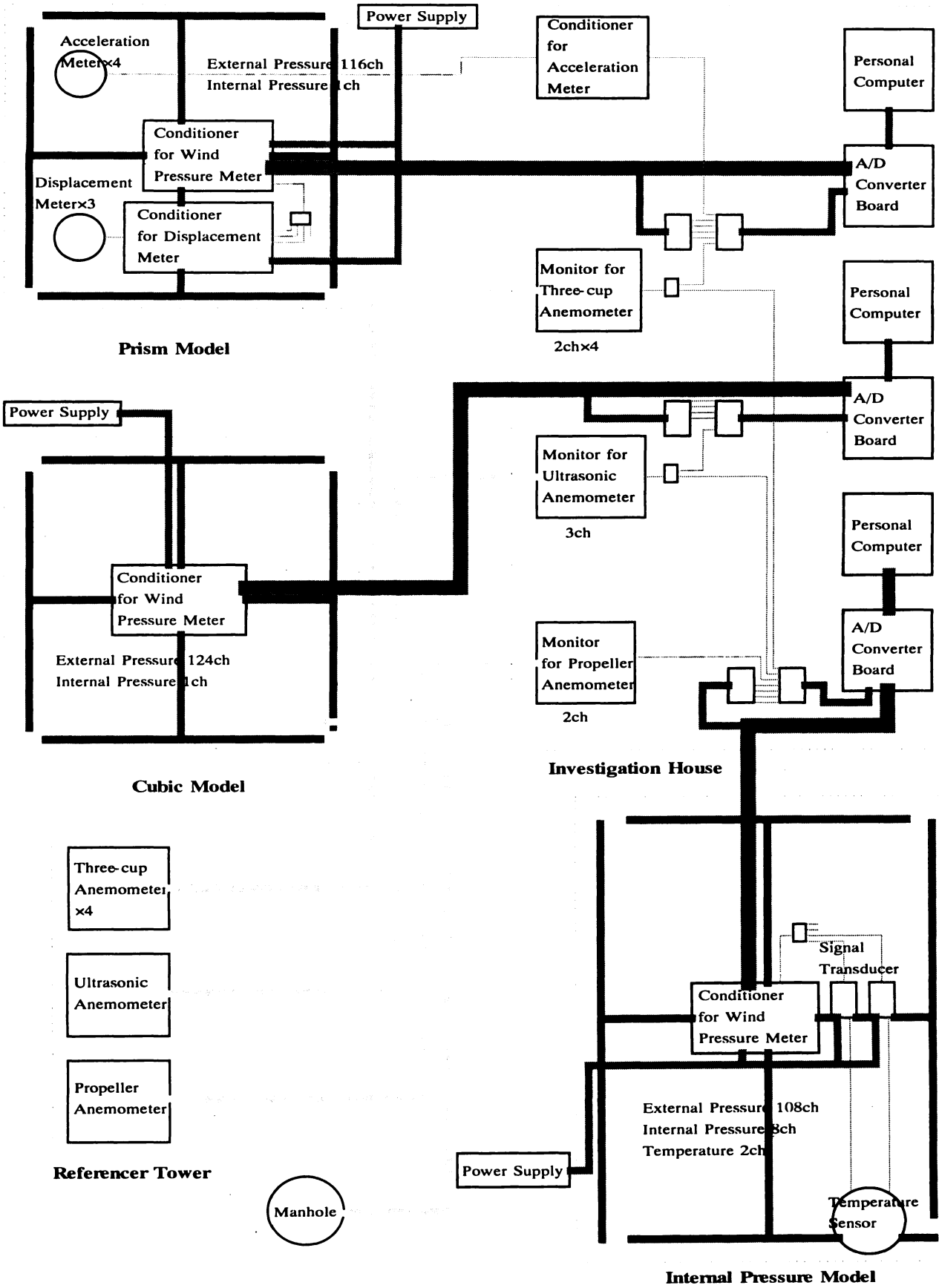


Figure 2 Measurement System

## 4 Nature of Natural Wind

### 4.1 Measurement Data

When field measurements are carried out, it is very important to grasp the characteristics of natural wind. In this section, we considered about its nature by using the data obtained from the three-cup anemometer and wind vane mounted at a height of 5m of the reference tower. The data analyzed in this section was recorded on from the 21st of December 1998 to 2nd of April 1999. The averaging time of which was 60 seconds.

### 4.2 Results and Considerations

The relation between wind direction and wind velocity is shown in Figure 3. As for wind direction, north wind direction is  $0^\circ$  and turning clockwise direction is positive. The data shown here was obtained in winter season, and strong wind is recorded in the case that wind direction is WNW and NNE. Maximum of the mean velocity was 13.8m/sec.

The relation between wind direction and turbulence intensity is shown in Figure 4. When the wind direction is NNE, turbulence intensity is larger than in case of WNW. It suggests that north wind comes from city area whereas west wind comes from marine area.

The relation between wind direction and turbulence scale is shown in Figure 5. These turbulence scales are analyzed in 40.96 seconds. The ensemble average of turbulence scales is about 20m, but in case that wind direction is WNW, these values are larger than in case of NNE. It is due to difference of routes (roughness) as well as the relation between wind direction and turbulence intensity.

The relation between wind velocity and turbulence intensity is shown in Figure 6. As the wind velocity is larger, turbulence intensity decreases and reduces to about 10%.

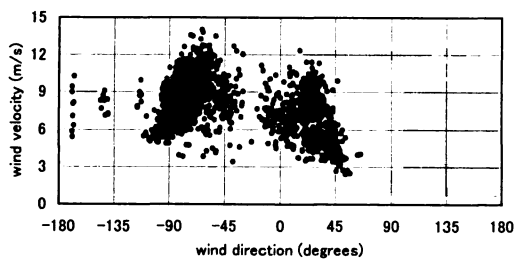


Figure 3 Mean Wind Velocity

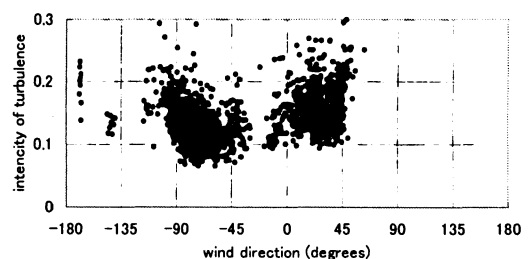


Figure 4 Turbulence Intensity and Wind Direction

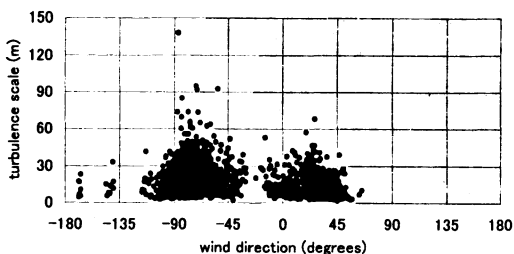


Figure 5 Turbulence Scale

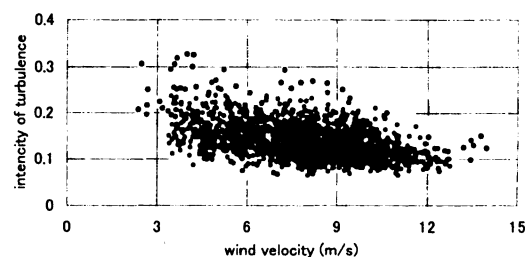


Figure 6 Turbulence Intensity and Wind Velocity

## 5 Prism Model

### 5.1 Model

The model section was square with sides of 1m and the height of it was 5m (aspect ratio=5). The mass of it is about 700 kg. The density of it was about  $140\text{kg/m}^3$ . The wall, which is made of polycarbonate, is independent of stiffness of the model. The details of the objective model were shown in Figure 7.

The model contained a total of 116 pressure taps on the wall, and the position of which is shown in Figure 7. Three displacement meters were mounted on the top of the inner column, which is independent of the model. Two acceleration meters were fixed on the beams of level 3 and level 4.

### 5.2 Results and Considerations

#### (i) Oscillation Characteristics

The analytical oscillation characteristics of the model are shown in Figure 8 and Table 1. The natural frequency of the first lateral mode is about 2Hz.

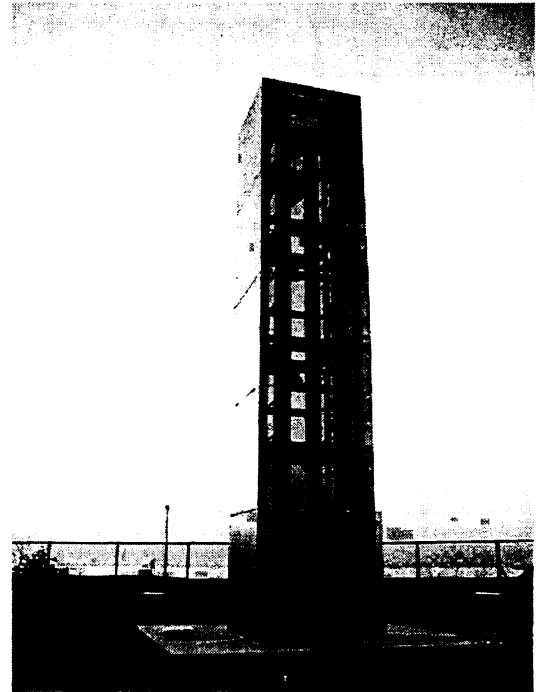


Photo 3 Prism Model

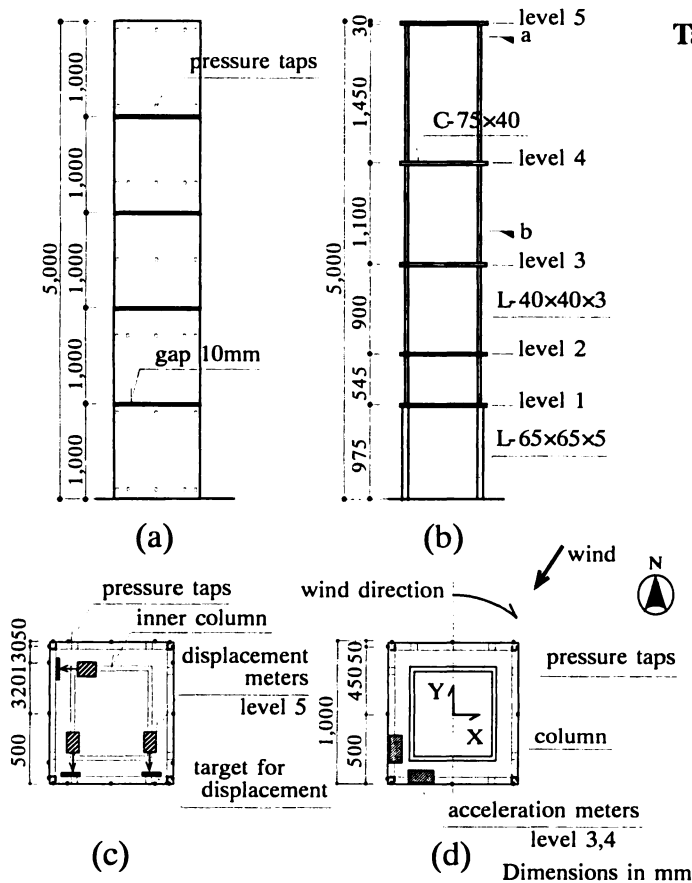


Figure 7 Experimental Model

Table 1 Analytical Oscillation Characteristics

mode	Lateral oscillation		Torsional oscillation	
	Frequency	Generalized mass	Frequency	Inertia
1st	2.119Hz	259.6kg	2.714Hz	$79.3\text{kg}\cdot\text{m}^2$
2nd	4.838Hz	472.9kg	6.272Hz	$116.4\text{kg}\cdot\text{m}^2$
3rd	8.266Hz	248.4kg	10.876Hz	$76.2\text{kg}\cdot\text{m}^2$
4th	13.310Hz	208.6kg	17.871Hz	$63.9\text{kg}\cdot\text{m}^2$
5th	30.317Hz	252.6kg	41.189Hz	$77.7\text{kg}\cdot\text{m}^2$

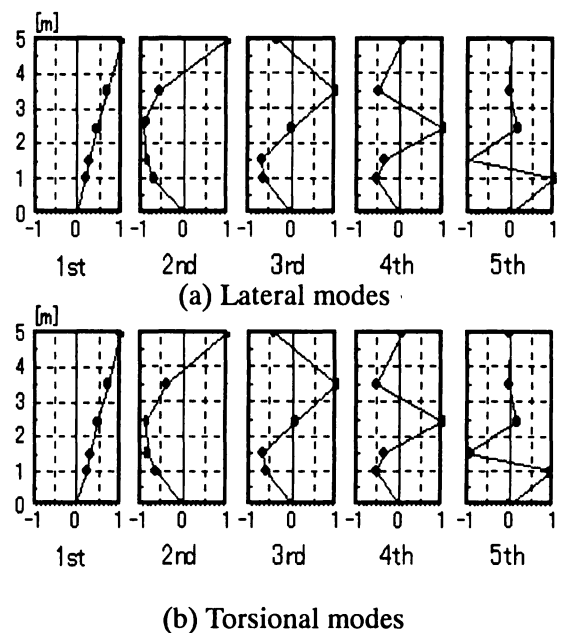


Figure 8 Analytical Modal Shape

The oscillation characteristics by free vibration test of the 1st lateral mode are shown in Table 2.

(ii) Mean and Fluctuation Property of the Wind Force and Response

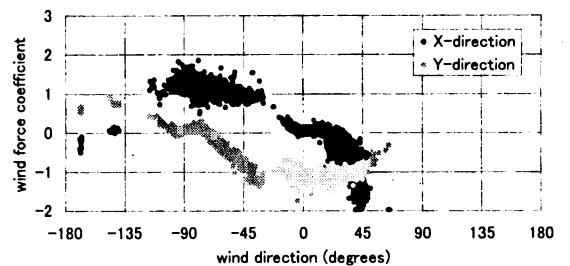
Mean wind force coefficients of X and Y-direction are shown in Figure 9. Sine and cosine wave are lined to grasp its tendency. The coefficients of X-direction, coefficient values are generally 0 when wind direction is 0° (N). When wind direction becomes larger, coefficient values are a little increasing and indicate that the wind force of X-direction becomes large to eastern side. It is the reason that strong vortex is formed at the windward side (eastern side in this case), and lift force acts in an opposite against wind direction. And then in Y-direction, the absolute value of wind force is getting a little smaller. Because the vortex formed in a wake moves backward and drag force decreases.

Mean and fluctuating rms displacement ratios, which were calculated from the displacement of the top of the model, are shown in Figure 10 and 11. The lateral axis is the reduced velocity.

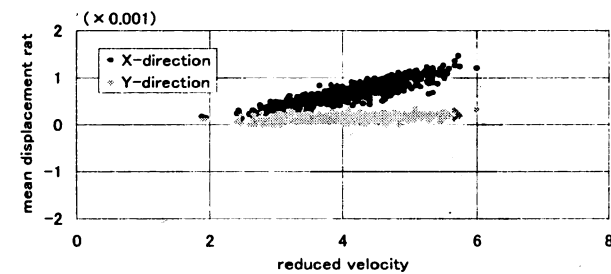
In Figures 10 and 11, the mean value of wind direction means the direction range of ±11.25°. In case that the wind direction is W, mean displacement ratio of X-direction increases with the reduced velocity, but that of Y-direction has little change. Fluctuating rms displacement ratio in X-direction increases with reduced velocity, and the ratio in Y-direction increases larger than X-direction. Concerning on fluctuating rms displacement ratio, in the case that wind direction is NW, these values are similar each other in the both of X- and Y-direction.

**Table 2 Experimental Oscillation**

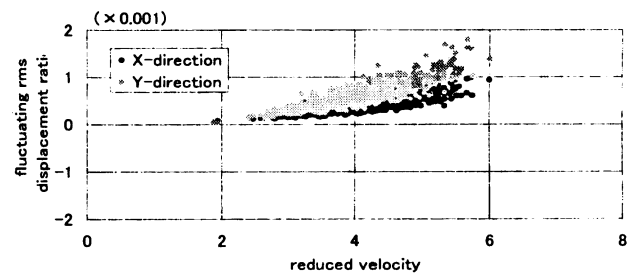
mode	X-direction		Y-direction	
	Frequency	Damping ratio	Frequency	Damping ratio
1st	2.002Hz	0.52%	1.953Hz	0.54%



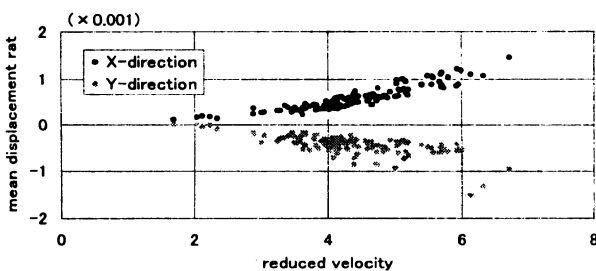
**Figure 9 Mean Wind Force Coefficient**



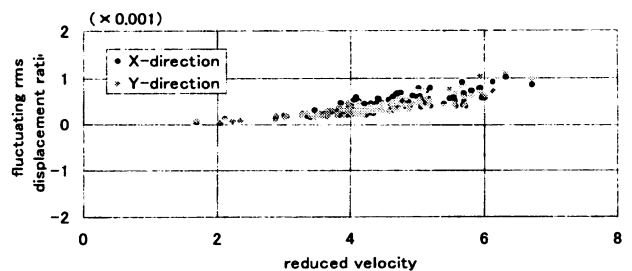
(a) Wind direction W



(a) Wind direction W



(b) Wind direction NW



(b) Wind direction NW

**Figure 10 Mean Displacement Ratio**

**Figure 11 Fluctuating rms Displacement Ratio**

### 6 Cubic Model

When the building with a flat roof is exposed by the wind from the diagonal direction, it is well known that the conical vortex is formed on the roof surface. Some property as the conical vortex shows the phenomenon called the switching is made clear by the wind pressure measurement and flow visualization. In this time, the field measurement about the wind pressure using the cubic model to assume about one several tenth scale of the actual building is carried out for the purpose to verify these phenomena under the natural wind. In this section, the outline of the field measurement is shown, and these results are compared with the results of the wind tunnel experiment about the distribution of the mean wind pressure coefficients and the fluctuation wind pressure coefficients. And the property of the unsteady wind pressure in the natural wind is considered.

#### 6.1 Model

The model used in this field measurement is a cube with sides of 2.4m and situated at the center in the test site. In order to measure the wind pressure change by the conical vortex formed on the roof surface, the wheels are installed under the pillars of the model to be turned so that the wind blows from the diagonal direction (Figure 12). On the surface of the model, 170 pressure taps are equipped as shown in Figure 13. As for the arrangement of the pressure taps, they are equipped densely in the part of the corner of the windward side.

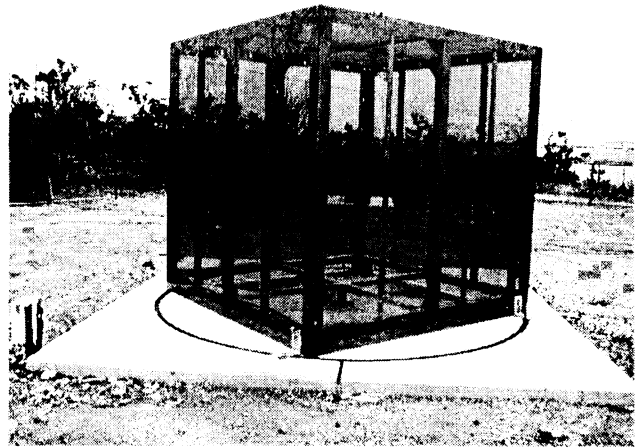


Photo 4 Cubic Model

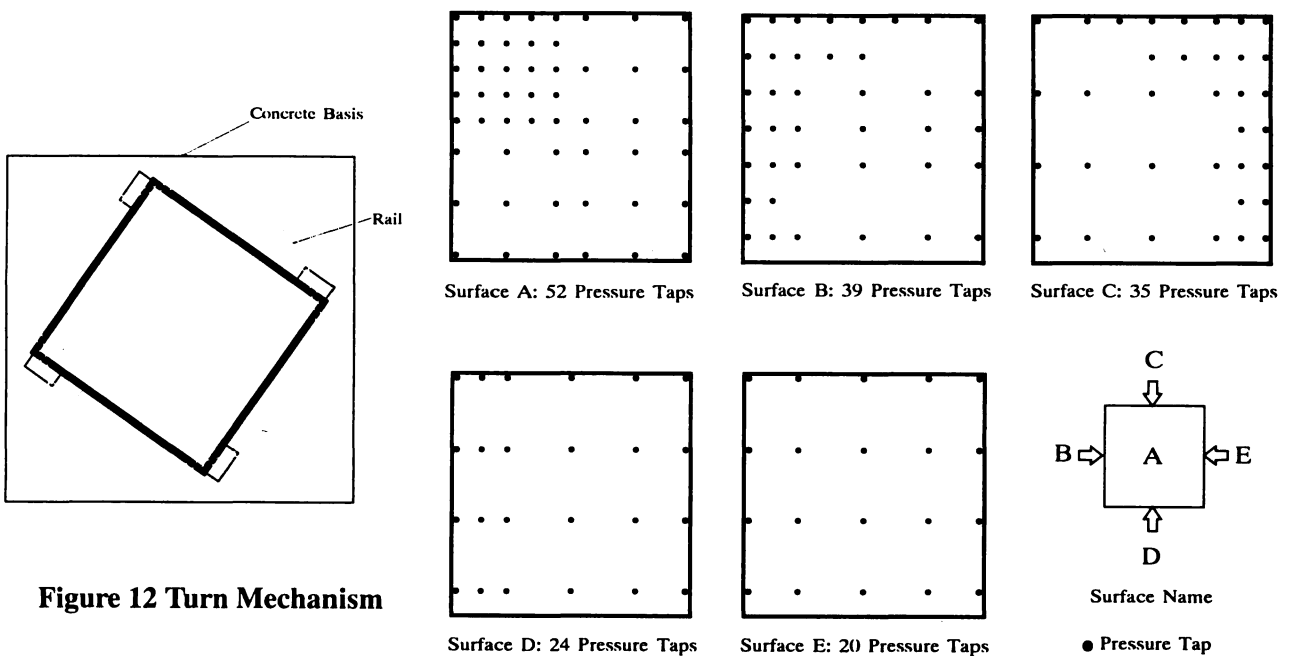


Figure 12 Turn Mechanism

Figure 13 Arrangement of Pressure Taps

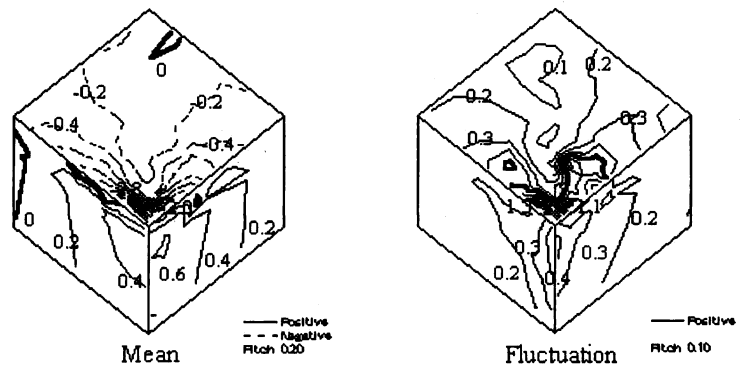
**6.2 Measurement Data**

In this measurement, the wind direction (1ch), the wind velocity (1ch), the external pressure (124ch), the internal pressure (1ch) and the atmospheric pressure (1ch), in amount 128ch are measured simultaneously. The wind direction and velocity are measured with the ultrasonic anemometer set at the height of 2.5m equivalent to the height of the top of model on the reference tower situated about 11m away to the western side. Also, as for the external pressure, 124 pressure taps are selected out of 170. The sampling frequency is 50Hz and the measurement time is about 11min. per one measurement.

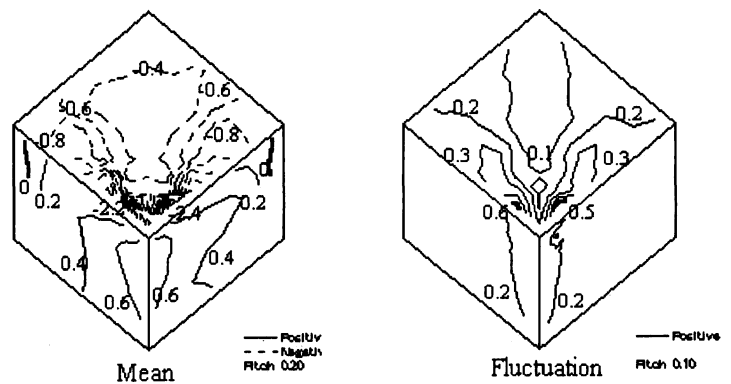
**6.3 Results and Considerations**

In this section, the results of the field measurement for 80 seconds while the wind from diagonal angle of the model is stable roughly are shown. The distribution of the mean and fluctuating wind pressure coefficient in this time are shown in Figure 14. Seeing the distribution of the mean wind pressure coefficient, the large negative pressure acts near the corner of the roof surface of the windward side, the area of the negative pressure spreads in all direction with decreasing its value for the leeward side from there. Considering the past experiments, it is thought that this is caused by the conical vortex occurs with the separation of the flow near the ridge of the windward side on the roof surface. The distribution of the mean and fluctuating wind pressure coefficient in the wind tunnel experiment are shown in Figure 15. Comparing the results of the field

measurement and wind tunnel experiment about the distribution of the mean wind pressure coefficient, the situation of the distribution on the roof surface is similar well. The mean wind pressure coefficient of the field measurement and wind tunnel experiment results is approximately equivalent about both the surface of the roof and side. However, as for the fluctuating wind pressure coefficient, the field measurement results become about twice value of the wind tunnel experiment results. One of the causes is thought that the wind direction and velocity are approximately constant in the wind tunnel experiment but in the field measurement the fluctuation of them are more remarkable.



**Figure 14 Field Measurement Results**



**Figure 15 Wind Tunnel Experiment Results**



### 7. Internal Pressure Model

When designing the wind load of the exterior material of the building, the internal pressure is the influential element, and it is very important to evaluate this correctly. However, because of the various difficult reasons in the past study there are little reports about the internal pressure, then many obscure points are left. In this study, the model assuming the apartment building is arranged at the test site and the external and internal pressure are measured in the natural wind. In this field measurement, especially, the influence of the distribution of the external pressure and the opening ratio is examined.

#### 7.1 Model

The model used in this field measurement is modeled the 15th floor apartment building and made in about 1/25 scale. The 108 external pressure taps are installed on the wall to become dense in the part of the corner (Figure 16). As for the internal pressure, the measurement chamber for the internal pressure made of acrylic fiber board (Figure 17) is set in 4 hatching parts (N1-N8, 8 rooms in amount) in Figure 16. This chamber is separated into 2 rooms in the airtight condition as shown in Figure 17. In the part which faces the outside of this chamber, some small holes assuming the crack of the opening are arranged as in Figure 17, and the opening area is made to be able to be adjusted. The internal pressure of these rooms changes by in/out air flow in this crack. Therefore, the indoor temperature is mesasured by the signal transducer to consider the change of the flow volume coefficint for the temperature correct.



Photo 5 Internal Pressure Model

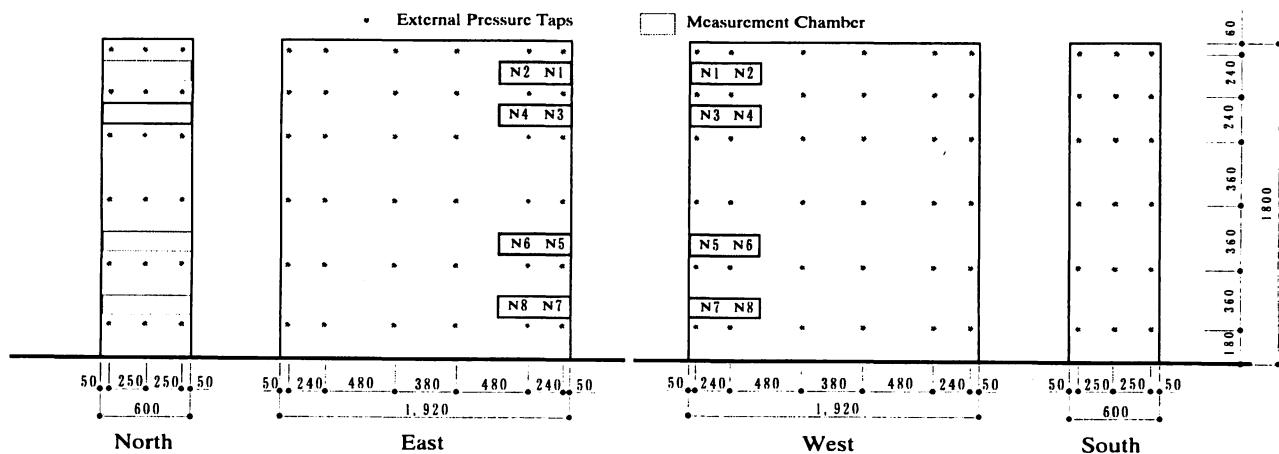
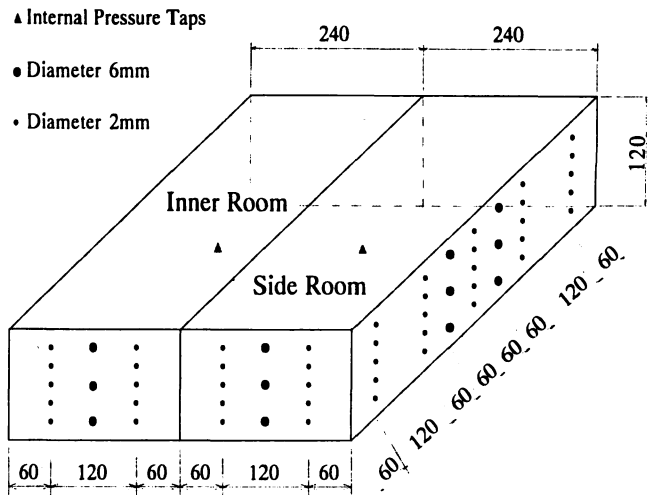


Figure 16 Elevation of Internal Pressure Model

**7.2 Measurement Data**

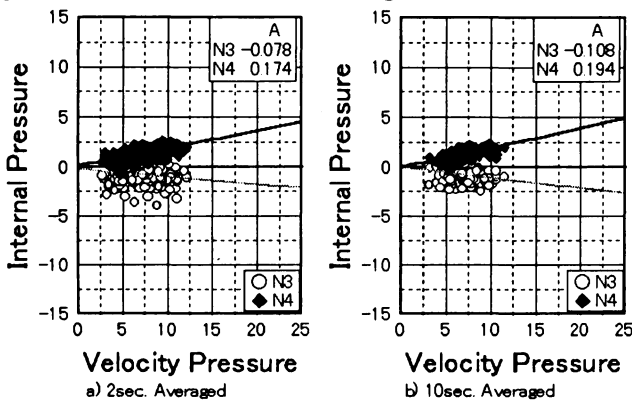
In this field measurement, the wind direction (3ch), wind velocity (4ch), external pressure (108ch), internal pressure in the chamber (8ch), internal pressure in the model (1ch), atmospheric pressure in the manhole (1ch), the temperature in the chamber (2ch) and atmospheric temperature(1ch) in amount 128ch are measured simultaneously. The wind direction and velocity to use as the reference in the data disposal are decided to use the records by the three-cup anemometer set at the height of 2.5m on the reference tower. The sampling frequency is 50Hz.



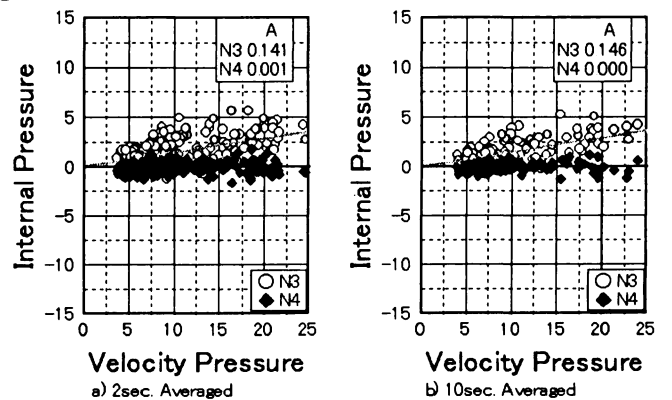
**Figure 17 Internal Pressure Chamber**

**7.3 Results and Considerations**

The relations between the velocity pressure and the internal pressure computed from the data of the three-cup anemometer are shown in Figure 18 and Figure 19 respectively. The data of the west wind is used in Figure 18, the northwest wind is in Figure 19. Also, the averaged time of a) is computed in 2sec. and b) is in 10sec. In case of Figure 18, because the external pressure of the short side wall becomes negative, the internal pressure of the side room shows the negative value. However the internal pressure shows the positive value in the inner room because the positive external pressure of the wall surface blown directly is larger than the opposite wall surface. On the other hand, as shown in Figure 19, the internal pressure becomes positive in the side room because the pressures acting on the two wall surfaces show positive. Also, in the case the averaged time is more than 2sec. for example 10sec. averaged time, there is no large change about the internal pressure coefficient. However, in the partial data, when computing the averaged time in 1sec., the coefficient changes greatly. Also, the tendency is seen that the absolute value of the internal pressure coefficient becomes larger a little with the height.



**Figure 18 West Wind**



**Figure 19 Northwest Wind**

## 8. Conclusions

- 1) The characteristics of natural wind (mean wind velocity, turbulence scale, turbulence intensity and mean wind force coefficient) at "Maishima Wind Resistant Laboratory" are investigated. It is found that turbulence intensity and turbulence scale indicate different values by the wind direction.
- 2) Concerning on Prism Model, the analytical oscillation characteristics of the model, and mean and fluctuation property of the model responses by unsteady wind force are considered. It is found that the lift force acted opposite direction against the wind direction as well as the past results of wind tunnel experiments when the wind direction was a little inclined from the facade, and that gust factors of the wind force and displacement of X-direction indicate nearly constant values in extent of  $\pm 45^\circ$ .
- 3) On Cubic Model, the pressure distribution is formed as same as the wind tunnel experimental model. The mean wind pressure coefficient by the field measurement and by the wind tunnel experiment are approximately similar, but about the fluctuating wind pressure coefficient, the values by the field measurement become twice of them by the wind tunnel experiment. This is caused by the difference of the fluctuation of the wind direction and velocity.
- 4) Each room of the apartment building, the mean internal pressure is different with depending on every room position. Also, by giving the opening condition, it is possible to estimate roughly the mean internal pressure from the distribution of the external pressure.

As mentioned, the study of the field measurement using the model in the natural wind which our research institute carries out since last year is introduced. These studies are going to be continued and examined about the detail relations using the wind tunnel experiments in the future.

## Acknowledgement

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