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Spectra of Wind Pressure Fluctuations on Structures

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Synopsis

The wind pressure fluctuations on structures are very complicated because wind is disturbed by structures and wind itself changes its direction and velocity, so it is not easy to know their nature clearly. In order to get information about the wind load on structures, wind pressure fluctuations on the walls and roofs of an actual house were measured, then the power spectrum of wind pressure fluctuations were computed from the test data. The measurements were carried out against the seasonal wind at Shionomisaki Wind Effect Laboratory of Kyoto University on Jan. 23 rd and Mar. 17 th 1963. The reference wind velocity was 5 m/sec to 18 m/sec at a point 10 m above ground level. There is an open field on the windward side of the house. The results show that the power spectrum on the windward walls were similar to that of a reference wind having no peak value at any period of pressure fluctuations. On the other hand it will be noted that the peak values were observed in the case of pressure fluctuations on roofs or eaves at the period of 0.2 sec to 0.3 sec, which shows that on roofs or eaves vortices break out periodically and that on pressure fluctuations they are affected more by the shape of the house than by the turbulence of a natural wind. The period of 0.2 sec to 0.3 sec at which the power spectra take peak values, is expected to be shorter when the reference wind speed becomes faster.

1. Introduction

The wind pressure on actual structures shows complicated fluctuations caused by the variations of wind direction, wind velocity and the shape of the structures. How these fluctuations in wind force should be considered in for the designing of structures will be important but we now have little available data on it. We conducted some experimental studies on this problem by measuring wind pressures at several points on the surfaces of structures, for instance, roofs and walls, and obtained the power spectra of wind pressure fluctuations. They are significant in relation to the natural frequency of the structure itself together with the components of the structure. These power spectra will be useful in determining the wind load on actual structures.

2. Experiments

The houses used in these experiments are House A and B which are shown in Figs. 1 (a) and 1 (b). Both houses have light-gage steel frame structures, but House A is larger than House B. Measured points and wind direction in the experiments are also shown in the same figures.

The wind pressures of two measuring points were conducted by vynil tube to the pressure tube type wind pressure gages. And those wind pressures were recorded simultaneously by a oscillograph.

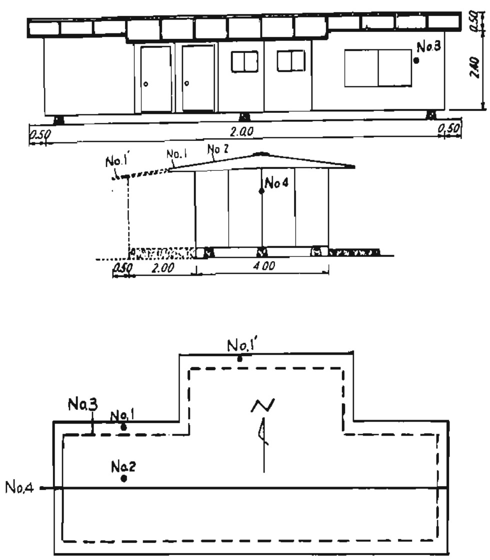

Fig. 1 (a) The dimension of actual House A and the position of wind pressure measuring points.

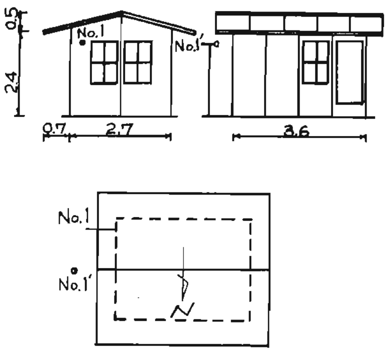

Fig. 1 (b) The dimension of actual House B and the position of pressure measuring points.

The natural frequency of the pressure gage is 20 cps and this gage could follow up about 10 cps of the wind pressure fluctuations. Photo. 3 shows a part of the record thus obtained. Photo. 1 shows the installations of pressure inlet plates.

This experiment was made in the seasonal wind at Shionomisaki, Wakayama prefecture in Japan on January 23 rd and March 17 th in 1963.

The windward area of the houses was an open field. 10 minute average wind velocities at the time of experiment were 5 m/sec to 18 m/sec by the aerovane

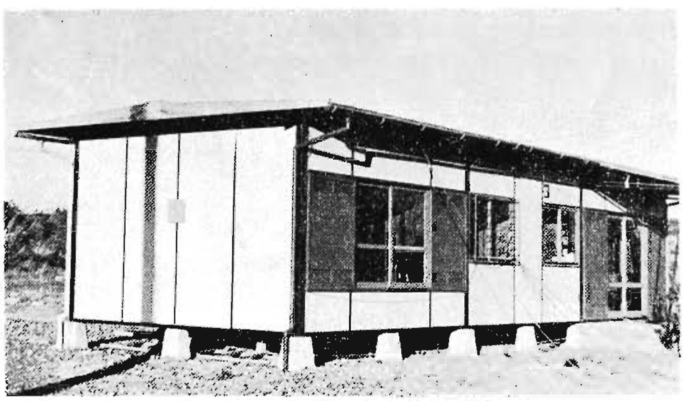

Photo. 1 View of the actual House B

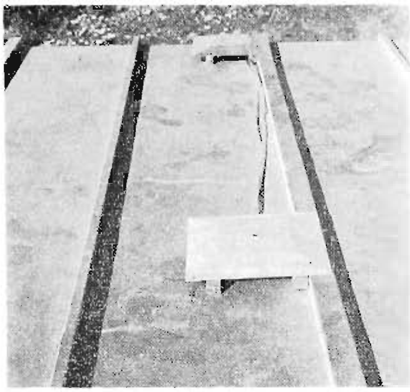

Photo. 2 The wind pressure inlet plates mounted on eaves and roof

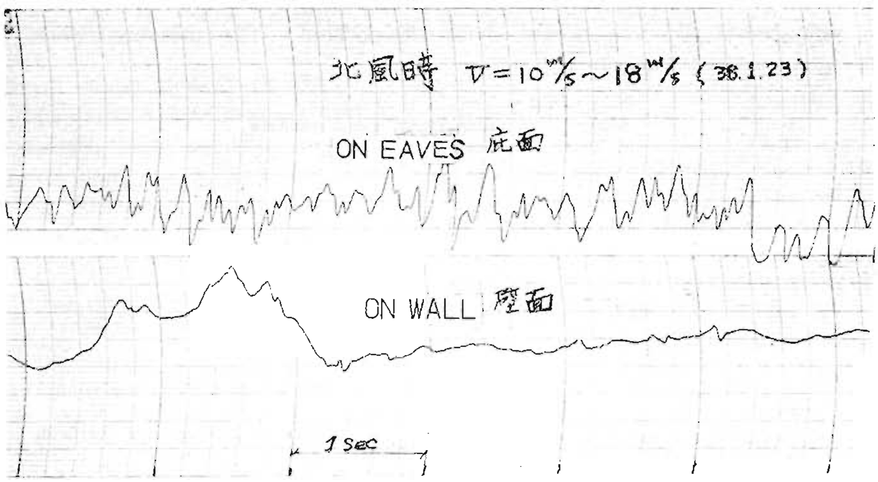

Photo. 3 (a) The records of measurement of wind pressure fluctuations on the actual house.

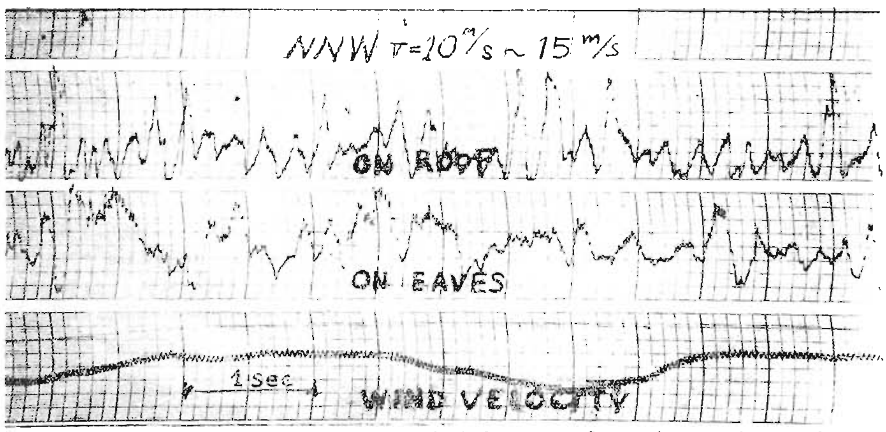

Photo. 3 (b) The records of measurement of wind pressure fluctuations on the actual house.

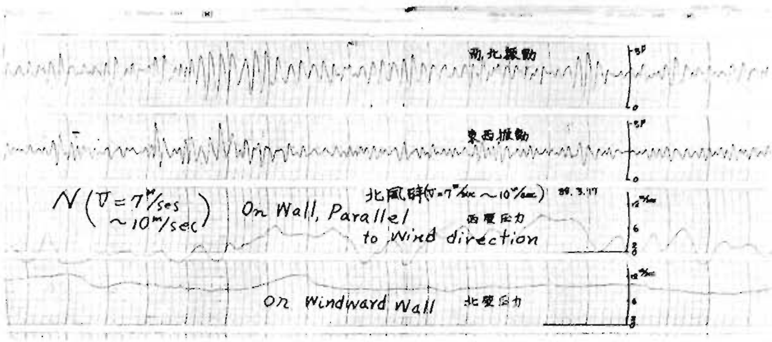

Photo. 3 (c) The records of measurement of wind pressure fluctuations on the actual house.

type anemometer at 10 m height above the ground. The measured point and condition in each run are as follows:

Table 1. Wind pressure measurements

Experiment No.	Wind direction	Velocity	Measured point
1	N	10～18 m/sec	House A, windward wall and windward eaves
2	NNW	10～15 m/sec	House A, windward eaves and windward roof
3	N	10～13 m/sec	House A, windward wall and the wall parallel to the wind
4	NW	5～12 m/sec	House A, 2 points on northside eaves
5	EEN	5～ 8 m/sec	House B, windward wall and a point 1.8 m above the ground near the wall

3. Power spectra of wind pressure fluctuations

As to the calculation of spectra, Tukey's method was adopted. There are several method other than this; however, Tukey's method is convenient for checking the significance of the peak and lowest value. Tukey had examined it by the degree of freedom. Table 2 shows clearly that to have a significant ratio of power density peak and lowest value should differ according to the degree of freedom value. Therefore, to obtain a spectrum of higher accuracy, it is necessary to apply a higher degree of freedom value.

Next, in the case where the peak value of the spectrum appears only on a single cycle band, the degree of freedom value is deemed as 1. And in such a case, the spectrum is considered not to have and real meaning. Therefore, to verify the existence of the peak and lowest value, at least four units of estimated

Table 2. Accurate to within 5%

Degree of freedom	Limit for ratio	
	Upper	Lower
1	161	0. 0062
2	19	0. 0526
4	6. 39	0. 156
6	4. 28	0. 234
8	3. 44	0. 291
10	2. 98	0. 336
15	2. 40	0. 417
20	2. 12	0. 472
30	1. 84	0. 543
50	1. 60	0. 625
100	1. 39	0. 719

values of power density should be in the subject cycle band.

Since these calculations are very troublesome, the use of an electronic computer is essential. The spectra, referred to in this paper had been obtained by the electronic computer KDC-1 of Kyoto University. The results are shown in Figs. 2, ~12. In these cases, the cycles are on the abscissa and the normalized power spectra densities are on the ordinate, both showed according to logarithmic scale. Each wind pressure fluctuation used in the calculations was taken from the 30 second recordings in a series of several continuous minutes. The periodical interval Δt for reading the value was made at 0.05 sec, after considering the response characteristic of the pressure gage, the number of measuring (n) was 600 and the division factor (m) was made at 25. Therefore the analytical maximum cycle

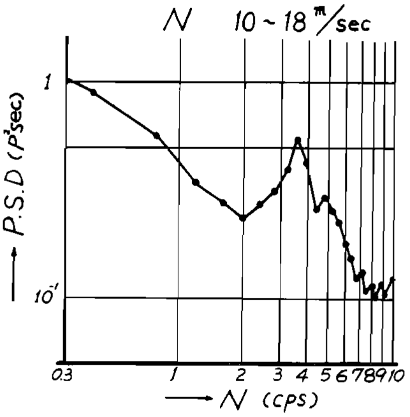

Fig. 2 Spectrum of the wind pressure fluctuation on eaves of House A.

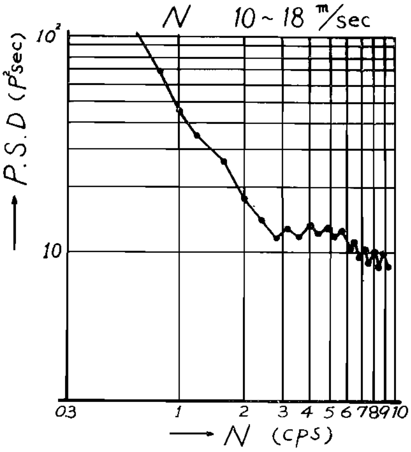

Fig. 3 Spectrum of the wind pressure fluctuation on windward wall of House A.

(1/2t=1/0.1) was at 10 cps and the degree of freedom value was about 50. From Table 1, in this instance, when the ratio of two power densities is bigger than 1.6, the calculated value is deemed to show a meaningful difference.

In these spectra diagrams, on the side of frequency zero, namely on the side of infinite cycles, very high value is observed, but this is not correct in the case of actual statues. Such a high value is merely an accidental error caused by the non-three-dimensional treatment of turbulent fluctuations. Accordingly, for correct analysis at such low frequency proper adjustments will be needed.

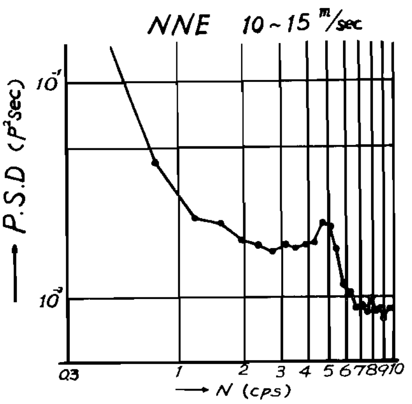

Fig. 4 Spectrum of the wind pressure fluctuation on roof of House A.

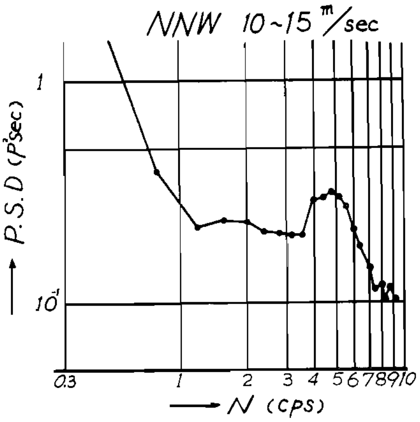

Fig. 5 Spectrum of the wind pressure fluctuation on windward eaves of House A.

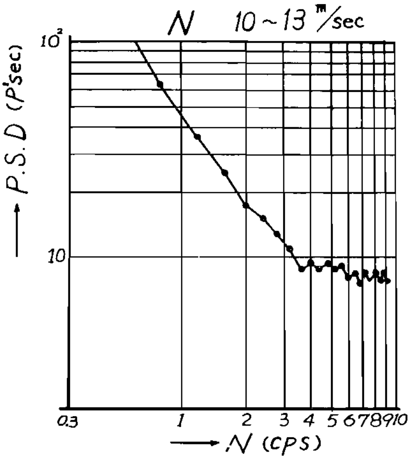

Fig. 6 Spectrum of the wind pressure fluctuation on windward wall of House A.

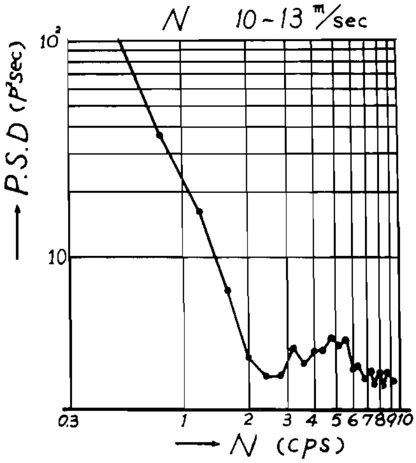

Fig. 7 Spectrum of the wind pressure fluctuation on wall, parallel to wind direction of House A.

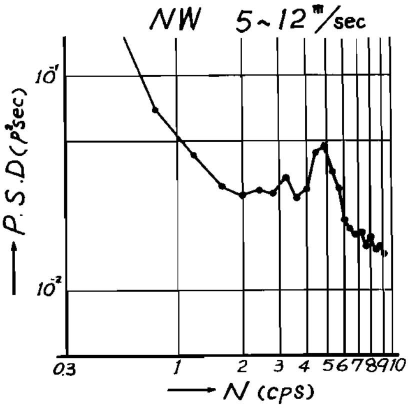

Fig. 8 Spectrum of the wind pressure fluctuation on north-side eaves of House A.

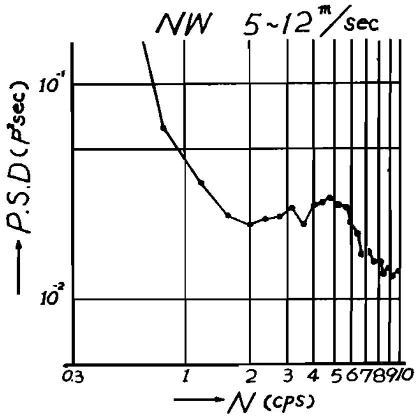

Fig. 9 Spectrum of the wind pressure fluctuation on north-side eaves of House A.

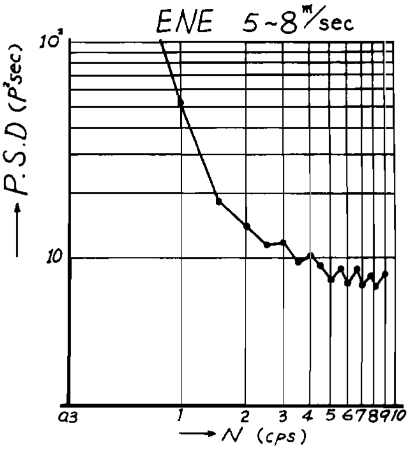

Fig. 10 Spectrum of the wind pressure fluctuation on windward wall of House B.

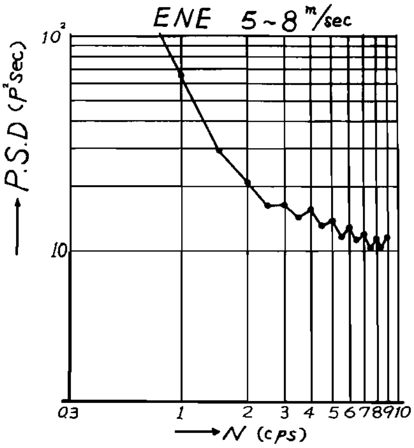

Fig. 11 Spectrum of the wind pressure fluctuation by free-direction pressure gage nearby House B.

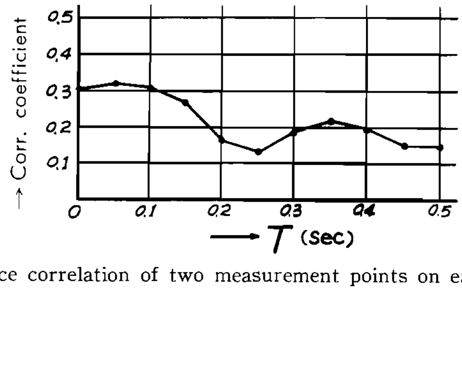

Fig. 12 Space correlation of two measurement points on eaves and roof.

4. Considerations on the computed results

1) *Spectra on the windward walls*

The spectra of Figs. 3, 6, 7 and 11 indicate pressure fluctuations on the windward walls. There is no peak showing the concentration of energy in any figure. This fact means that there is a predominant period in the wind pressure against the walls. Also in this case the ratio of wall areas of House A and House B is six, but there is no difference between the two spectra.

2) *Spectra on walls parallel to the wind*

The spectrum of Fig. 7 shows suction force measured on the westside wall under a north wind. In this figure, the significant peak of power densities is seen distinctly in the period band from 0.15 to 0.30 sec. Now the spectrum of Fig. 6 shows the wind pressure measured simultaneously on the windward wall. Nothing of the predominant period is observed on this spectrum. From these facts, the predominant period on the westside wall is deemed to be caused by wind vortices made on the corner of the house. That is, this predominant period does not indicate the fluctuations of the wind itself but shows the influence of wind vortices made by the house's structural shape.

3) *Spectra on roofs and eaves*

The spectrum of Fig. 1 shows the suction force measured on the eaves. On this spectrum, the predominant peak at 0.3 sec period indicates energy concentration. As the spectrum of wind pressure on the windward wall, measured simulaneously, gives no such indication from the above predominant peak strong periodical fluctuations on the eaves may be inferred. This periodical fluctuation is also deemed to be the result of the wind vortex made by the structural shape.

The spectra of Fig. 4 and Fig. 5, indicate the suction forces measured on eaves and roofs. On both of these spectram, predominant peaks are observed at a 0.2 sec period. These peaks also seem to be caused by wind vortices. Fig. 12 shows the space correlation of the above two suction forces on eaves and roofs. In between two points, a time lag of 0.3 of a sec is observed. This time lag is considered to be the travelling time of a vortex from the measuring point on the eaves to the measuring point on the roof. This time lag is equal to the travelling time of the vortex in a steady stream, obtained by wind tunnel experiments.

4) *Spectra on a windward wall and on a nearby free-direction pressure gage*

Spectra of Fig. 7 indicate the wind fluctuations on the windward wall, and the spectrum of Fig. 8 indicates the wind pressure fluctuations on the nearby free-direction pressure gage. These spectra are quite similar in general pattern, but they seem to indicate a rather lower power density at the point of high frequency on the spectrum of the wall.

Judging from the above data, i) On the windward walls as a whole no particularly predominant period of wind pressure fluctuation was observed at the wind velocities of 5 m/sec – 18 m/sec. And a power density was observed of a certain constant degree or of a decreasing degree, according to the decrease of the period, at the period bands of 0.1 sec to 0.3 sec. ii) Owing to the low pitch of the roof, of the subject house, a strong suction force caused by vortices on roofs and eaves was observed. In this experiment, the wind pressure fluctuations of 0.2 sec to 0.35 sec period were noted. In the case of higher wind velocity, such a period is assumed to have a shorter period of time, say about 0.1 sec or so.

Consequently, the above data imply the importance of the dynamic consideration of roofs and eaves. Also the fact that the suction force on eaves is as big as 1.5 to 2.2 in the wind pressure coefficient, indicates considerable wind vortex effects are caused by structural shape for more than by natural vortices of the wind itself.

5. Conclusion

The dynamic effects of wind pressure against structures are governed by the shape of the structures, excluding the walls perpendicular to the wind.

As a matter of course, the dynamic effects of wind pressure indicate different figures according to each working position on the structure. Therefore to avoid causing a large amplitude, structural components should be selected which have a natural frequency apart from that of the predominant period of pressure fluctuation.

In this paper, test data were for comparatively low wind velocity, and experiments in stronger winds will be carried out in the near future.

References

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