건물에서의 바람에 기인한 압력차의 예측

Prediction of Wind - induced Pressure Difference in Buildings

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요 약

바람은 건물 외벽에서의 압력차의 주요인의 하나이다. 바람에 의한 압력차를 정확히 예측할 수 있다는 것은 외벽에 있어서의 풍하중, 건물내로 투입되는 공기양의 설계치 결정, 그리고 건물을 사용하는 거주인의 병리학적 면에서 보다 중요한 것이다. 단열재로 잘 설계된 건물에서는 투입되는 공기에 의한 열부하가 전체 열부하의 30 ~ 50%도 될 수 있으며, 화재시 화염과 연기의 확산에도 중요한 문제이다.

20층 아파트를 사용해서 실물실험을 한 후 측정된 여러가지 값을 예측할 수 있는 방법을 고찰했으며 본 연구에서는 건물에서 바람에 기인되는 압력차를 예측하는 modeling과 Simulation에 있어서의 고찰할 여러가지 재원을 제시했다. 또한 Model을 이용한 실험결과는 Simulation에 있어서 적합한 조건을 충족시키면 풍동을 사용하여 바람에 기인하는 압력차를 예측할 수 있다는 것이 증명되었다.

1. INTRODUCTION

Wind is the major cause of the pressure difference produced across building external envelopes. The prediction of this pressure difference with good accuracy is an important step for the design wind load of cladding and the calculation of air leakage through building envelope and for the determination of the physiological aspects of the building ventilation for the occupants.

The heat loss due to air filtration for insulated buildings of good construction may be from 30 to 50% of total heating requirements [1]. The safety regarding spread of fire and smoke in buildings also has significant relation to this topic [2].

Following the full-scale measurement of pressure differences at a twenty-storey apartment building by the author and his coworkers [3], an attempt was made to verify and simulate wind-induced pressure component of measured data to establish this prediction.

For the prediction of air in- and ex-fil-

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tration and exact evaluation of working pressure on a building, it is necessary to find out the pressure difference across building enclosure induced by wind, temperature difference and mechanical ventilation operation. i.e.,

$$\triangle p = (\triangle p)_W + (\triangle p)_S + (\triangle p)_M \qquad (1)$$

A full-scale measurement of pressure differences across the external walls of a twenty-storey apartment building carried out by the author and his coworkers [3] was followed by attempts to simulate both wind and thermal effects to verify the results and establish the prediction of them. In this paper, the attempt to verify and simulate wind-induced pressure component of measured data to establish this prediction is presented and the background philosophy of modelling and simulation employed in the study is described.

The modelling of wind effects is a straightforward wind tunnel test. In this paper, the required similitude for testing and conversion of measured external pressure to differential pressure across building walls for the full-scale comparison are discussed.

2. SIMILITUDE REQUIREMENTS

For the determination of the wind-induced structural response, the wind tunnel has been considered to be a generally acceptable tool, provided that the modelling requirements are carefully taken into accounts.

In ordinary testing of wind-induced pressure measurement, the following similitude requirements should be considered:

1) Geometrical and mechanical characteristics of the building;

The geometrical similitude has to be satisfied in order to reproduce the simulated pressure pattern and the flow pattern around the building. The similitude of dynamic characteristics is negligible unless there is significant dynamic amplification of pressure due to building motion.

2) Reynolds and Froude numbers;

Reynolds and Froude similitudes are required so as to have the consistent equations of fluid motion between the model and the prototype.

Since Froude number is essentially given as the relative importance of inertia force to vertical force due to gravity and/or buoyancy, this requirement can be simply relaxed in most of the pressure measurements, unless there are significant temperature effect involved.

In most of wind tunnel testing, it is impractical to satisfy Reynolds number similitude. However, the consequence of this distortion can be sometimes significant:

a) When the structure has a smoothly curved surface geometry, the flow pattern around it is very sensitive to the change of Reynolds number because of the shift of flow separation points. There is a corresponding change of the wake width and the drag force as well as the frequency of vortex formation. It should be also noted that the critical Reynolds number also depends upon the surface roughness of the solid boundary and the turbulence level in the approaching flow [4].

b) When the structure has sharp corners, the separation points do not move from there and the flow pattern is consequently less sensitive to the Reynolds number. However, the wake after separation from the upstream corner may reattach to the body surface. The flow reattachment results a reduction of drag force and increase of Strouhal number in general. The critical aspect ratio of the body at which this change of flow pattern occurs also depends on Reynolds number as well as the corner radius and the air stream turbulence level [5].

c) For the problems involving effects of wind turbulence as a major concern, it is essential to simulate the velocity spectra correctly. It has been pointed out [6] that the structures of turbulent flows are very similar for all Reynolds numbers as long as the shear flow turbulence is well developed. This is a significant "gospel" for the "wind tunnelers" who employ the turbulent boundary layer flow as a simulated natural wind, since achieving the strict Reynolds similitude is impractical anyway. However, it should be remembered that the Reynolds number does play a part in the existence of the inertia subrange of the energy spectrum. Very low Reynolds number can result inaccurate simulation of turbulence structure due to narrower than required inertia subrange [7].

3) Similarity of shear flow characteristics;

The similitude requirement of the wind flow characteristics has been established since its importance was first pointed out by Jensen [8]. An artificially developed turbulent boundarry layer in wind tunnels has been known to give a good simulation of natural wind in both mean speed profile and spectral quantities of turbulence. The length scale of modelling should be chosen in accordance with the produced scale of turbulence. The topographical feature of the immediate surroundings of the building should be also provided for the near field simulation.

3. EXPERIMENTS

The wind-tunnel used is an open-circuit wind tunnel with a test section of 0.91 x 0.61 m and approximately 4.5 m long. The tunnel has a maximum mean speed of 45 m s^{-1} in the test section with less than 1.5% wind speed deviation in the middle 85% of the tunnel width. For the present study, a set of three triangular spires and a 2.5 m long plate with 13-19 mm high roughness cubes were installed on the wind tunnel floor to develop a simulated atmospheric boundary layer flow. The model

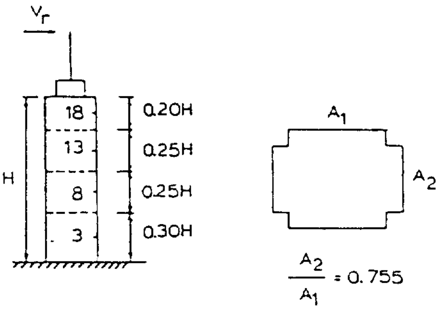

Fig. 1. Building model

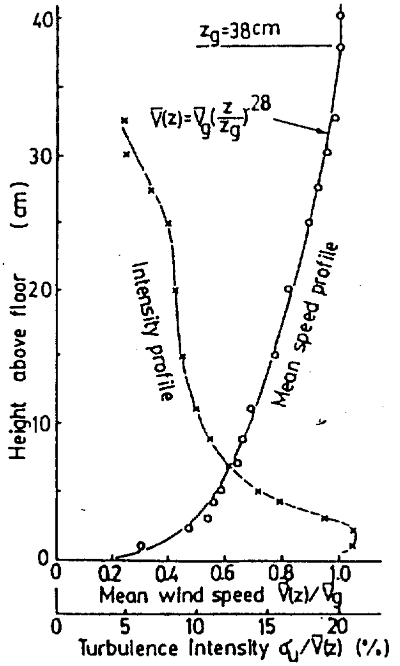

Fig. 2. Profiles of mean windspeed and longitudinal turbulence intensity

building is shown in Fig. 1.

The vertical profiles of mean wind speed as well as the intensity of the along-wind turbulence component at the model location are summerized in Fig. 2. The power law exponent for the mean speed profile at the test section was found to be 0.28, which was comparable to the full scale observation. The shear flow at the test section was approximately 0.38 m deep. The spectrum of the along-wind velocity component at the building top elevation agreed well with the well-known von Karman's spectrum as seen in Fig. 3 and the linear scaling factor was chosen to be 1:1000 from the measured peak of it. The topographical feature of the immediate surroundings of the building was also scaled to the same ratio to provide the near field simulation.

4. CONVERSION TO THE PRESSURE DIFFERENCE

The model building is rigid and air-tight, equipped with pressure taps and a pneumatic averaging system as the prototype. No attempt was made to simulate the actual air filtration through the building envelope. These results, therefore, need to be converted to the differential pressure for the full-scale comparison. Calculation of the wind-induced pressure differential across the building walls was carried out using the following information:

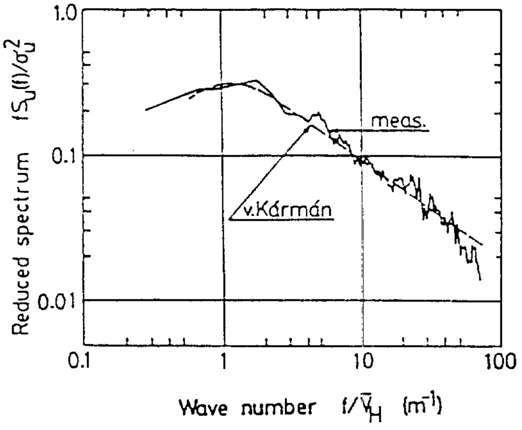

Fig. 3. Dimensionless spectral density of the longitudinal component of turbulence

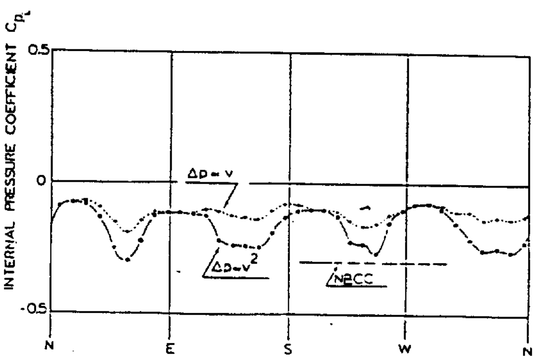

Fig. 4. Calculated internal pressure cofficients for linear and quadratic assumptions

1) The distribution of crack and openings of the building envelopes;
2) The distribution of external pressure induced by wind;
3) The spatially constant building internal pressure;
4) The air flow velocity V through crevices related to the corresponding pressure drop $\triangle p$ by;

$$\triangle P = a_1 V + a_2 V^2 \tag{2}$$

in which the two constants a_1 and a_2 largely depend upon the shape and dimensions of the openings. These terms correspond to the standard friction loss and other losses, respectively. A simple mass balance quation can thus decide the building internal pressure and consequently the pressure difference across each wall. For comparison, two cases of $\triangle p = a_1 V$ and $\triangle p = a_2 V^2$ are given in Fig. 4 and the pressure differentials across the building envelop at four different elevations are summerized in Fig. 5.

The full-scale seems to suggest that the coefficient a_1 has more significant role than

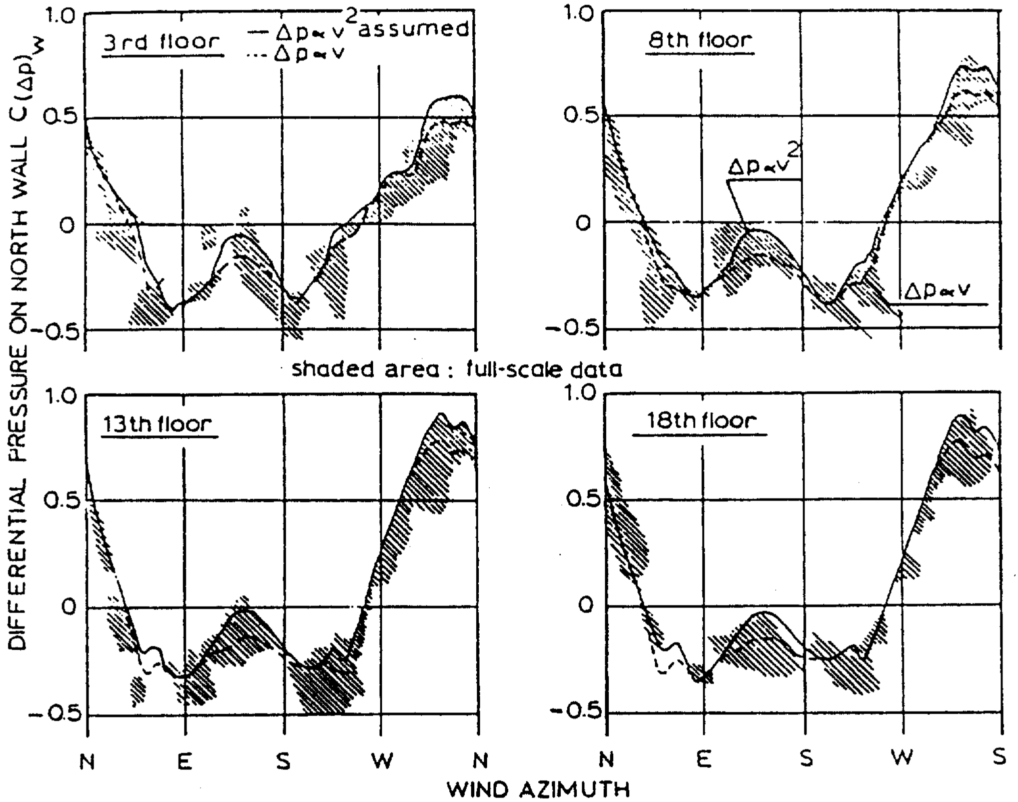

Fig. 5. Comparison of model and full-scale differential pressures of the north wall

the second term of Eq.(2).

5. CONCLUDING REMARKS

The study leads to the following conclusions:

A. With the careful consideration of similitude requirements, the wind tunnel test was able to verify the wind-induced component of measured pressure differentials.

B. The calculation of the pressure differentials from the measured external pressure distribution gave reasonably accurate results assuming the standard friction losses across openings.

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