Wind Pressures on Multi-Storey Buildings

Experiments in a wind tunnel on a model of a tall building of rectangular plan show the effects of variation in wind velocity with height. The effect of radiusing the corners is also discussed.

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The trend towards the construction of buildings which are taller in proportion to their base dimensions increases the relative importance of wind loading in their design. At the same time, the trend adds to the uncertainty of the adequacy of existing standard specifications as a basis for assessing these wind loads. The naturally occurring variation of wind velocity with height above ground gives rise to an increasing range of wind pressures as building heights increase. This difference in pressure from top to base causes vertical components of flow which, in turn, modify the pressure distribution around the building, so that the shape factor (which is derived from integration of the pressures at a given height) varies up the building.

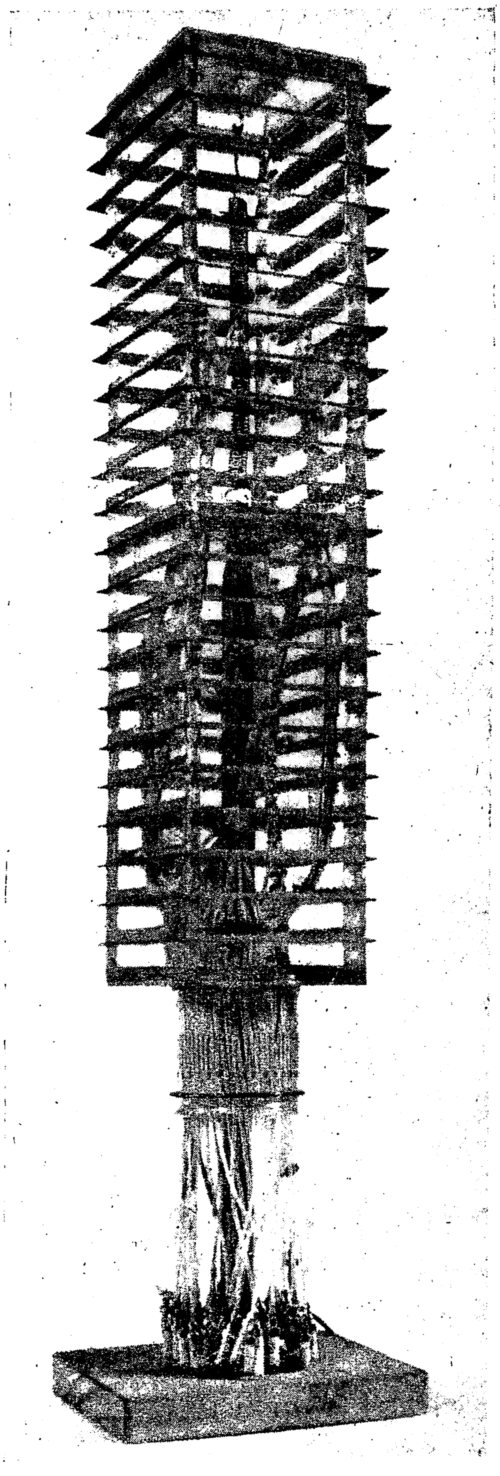

Fig. 1 Tall building model showing the pressure tappings.

Wind tunnel tests carried out at the School of Engineering, University of Auckland, on a model of a building of approximately square planform with a height 4·5 times the base dimension, enable an assessment to be made of the importance of these effects. The model, Fig. 1, to a scale of 12 ft to 1 in, was of a proposed 23 storey block 207 ft high with a uniform section 45 ft by 46 ft. The floors are cantilevered out from a central reinforced concrete stalk. A permanent sunshade in the form of a continuous strip 3 ft wide sloping downwards at 30° and mitred at the corners is fitted to each storey.

Wind Tunnel Arrangements

In the wind tunnel tests, a grid of wires was placed upstream of the model, producing a velocity gradient as given in BS: CP3, "Buildings: Loadings" (Chap. V, Table III), which closely approximates to a power law of the form $V \propto Z^{1/6}$ between heights (Z) of 30 and 200 ft. According to Davenport this curve gives a good representation of the gradient if the surrounding buildings are relatively low and scattered. The hollow model was pivoted at its mid-height to the top of a strut which passed up inside it from a load balance mounted below the tunnel, enabling drag and overturning moment to be measured. In addition, one face of the model was provided with pressure tapping holes, one at the mid-face of each storey and a further 24 spaced over the face of the 16th storey in three rows from corner to corner. These tappings can be discerned in the photograph of the model, Fig. 1. In use, the base of the square portion of the model comes down on to the floor of the wind tunnel (except for a small working clearance) and the cylindrical portion projects out of the tunnel. The spring shown inside the model is merely to hold the roof on.

Taking the shape of the pressure distribution curves for this storey, shown in Fig. 2, as generally applicable, and the actual pressures as proportional to the mid-face pressures, the measured mid-face pressures up the building, Fig. 3, enable the shape factor or drag coefficient for each storey to be found. The total drag and overturning moment calculated from pressure summation was compared with that measured directly. Side force and twisting moment were also calculated.

As an extension to this work, the effects of rounding the corners on drag and overturning moment were measured, using a plain model without shades, starting with sharp corners which were progressively radiused. No pressure distributions were measured.

In all cases the measured forces were corrected for tunnel blockage, the amount of correction being estimated from a survey of the pressure distribution on the top and bottom walls of the tunnel, both with and without the model in place. This was done because standard corrections for blockage were not considered reliable in the presence of a forced transverse velocity gradient due to the grid.

Scale effect was considered to be negligible for the sharp-corned model. With radiused corners, trip wires were used to induce transition to turbulence in the boundary layer at the radii and so reduce the scale effect.

The pressure distribution, Figs. 2 and 3, is the result of three types of flow which occur according to the wind angle, Fig. 3. The shaded area represents the wake, which embraces either two or three sides of the building, and is characterized by a substantially uniform pressure at all heights and face angles from 80 to 180° to the wind. The highest suction is within the bubble of separation on the face at 60 to 75° to the wind, when flow re-attachment occurs further along the face (Fig. 4b).

The variation of measured drag with wind direction is shown in Fig. 5. Pressure integrations at 0 and 45° wind show good agreement with the drag of the plain (unshaded) model, which appears to justify the assumption made earlier of constant pressure distribution shape at all heights for a given face angle.

The overturning moments enabled the height of the resultant wind force to be found. This varied over a narrow range from 0·55 of the total height at 0° wind angle to 0·53 at 45° wind. The side forces, though sufficient to deflect the resultant wind load as much as 30° from the wind direction (at 15° wind angle) are of little design importance as they do not increase the load at the critical case which occurs with a wind angle of 45°. The twisting moments are too small to be significant.

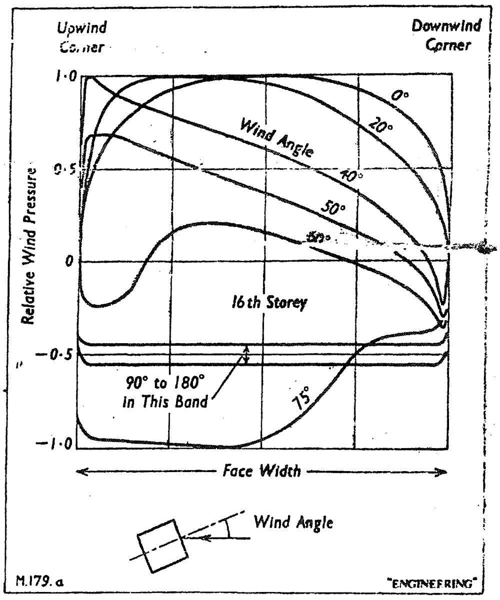

Fig. 2 Local wind pressures relative to the mid-face pressure due to a 0° wind.

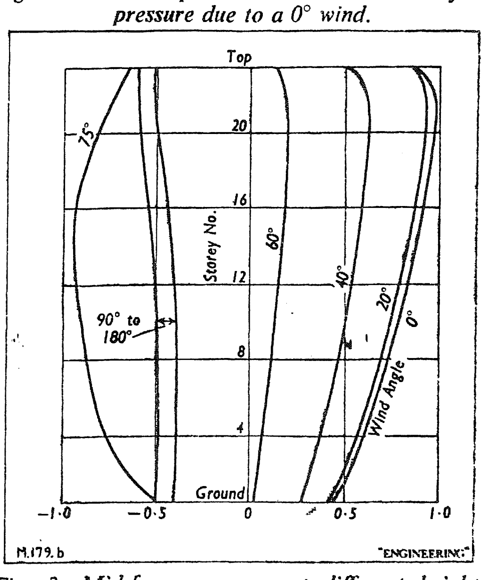

Fig. 3 Mid-face pressures at different heights relative to pressure at the top of the building.

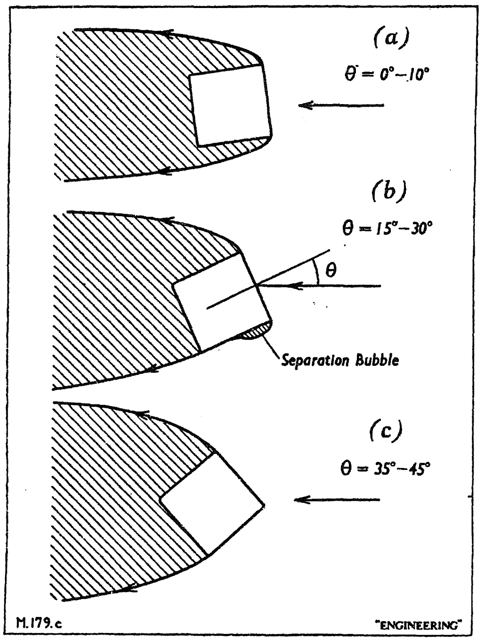

Fig. 4 Types of flow found with different wind angles.

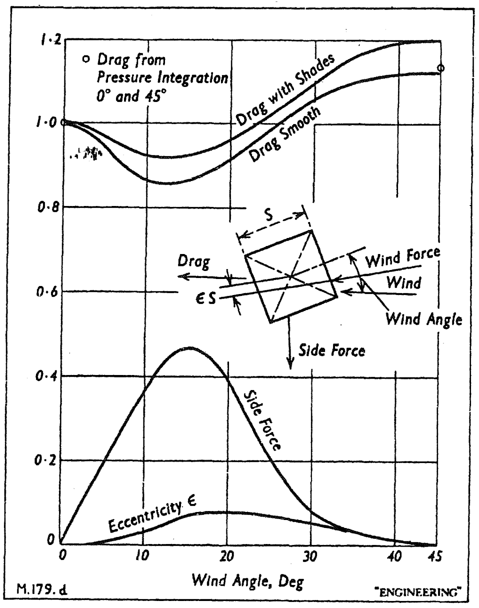

Fig. 5 Variation with wind angle of drag and side force (relative to drag at 0° wind angle) and eccentricity of wind force.

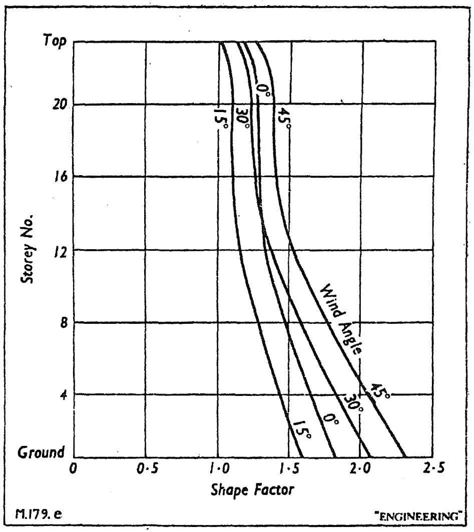

Fig. 6 Variation of shape factor with wind angle and height.

At the design stage, the wind load on a building is generally calculated from a shape factor and a design wind velocity. The latter may take into account variation with height from the ground, but it is unlikely that the use of a varying shape factor also would be acceptable. Such variation does occur, as can be seen from Fig. 6, which is based on pressure integrations. The shape factor is the drag coefficient based on the local wind pressure at each height, and on the width of one face, not on the projected width normal to the wind. The increased shape factors near the ground arise from the *relatively* larger suctions in the wake as compared with the wind pressures, the effect being greater for a 45° wind than for a 0° wind. The same effect has been shown by Masch and Moore[2] in the case of a circular section cylinder.

Results Compared

The increased shape factor tends to counteract the reduced wind pressures at small heights. A comparison has been made of the actual drag and overturning moments with those obtained by two simplified calculation procedures, namely:—

(*a*) Taking a constant shape factor and a constant wind pressure equal to that at the top of the building (as present BS practice).

(*b*) Taking a constant shape factor but varying the wind pressure according to the BS gradient.

The shape factor taken is that for the 16th storey which is away from end effects due to the top of the building and yet little affected by the velocity gradient. On this basis, comparative figures are obtained (Table I).

It therefore appears that the effect of the approximately uniform pressure in the wake reduces the apparent error, due to neglect of the wind velocity gradient by at least 50 per cent for this shape and height of building. Analysis of some of Masch and Moore's tests show an equivalent reduction of 33 per cent for a circular section cylinder with a height to diameter ratio of 9·6 and a velocity gradient similar to that of the present experiments.

TABLE I

		0° wind	45° wind
Drag	Actual	100	100
	Method (*a*)	120	108
	Method (*b*)	85	77
Overturning moment	Actual	100	100
	Method (*a*)	109	103
	Method (*b*)	90	84

Table II

Radius	Reduction, 0° wind, per cent.	Reduction, 45° wind, per cent.
3 ft.	21	5
6 ft	68	21

Radiusing Corners

Tests with a range of corner radii showed that substantial reductions in drag at zero wind angle could be obtained with relatively small radii (obtainable by using curved glass corner windows), but that the critical design drag with 45° wind angle is not so markedly affected. The results for two selected radii are given in Table II.

These results are of the same order as those reported by Polhamus[3] for two-dimensional uniform velocity conditions.

REFERENCES

[1] Davenport, A. G. "Rationale for Determining Design Wind Velocities." *Proc. ASCE*, Vol. 86, No ST5, May, 1960.

[2] Masch, F. D. and Moore, W. L. "Drag Forces in Velocity Gradient Flow." *Proc. ASCE*, Vol 86, No HY7, July, 1960.

[3] Polhamus, E. C. "Effect of Flow Incidence and Reynolds Number on the Low-Speed Aerodynamic Characteristics of Non-Circular Cylinders." *NASA TR R*-29, 1959.

More Civil Engineering Research Started

In addition to the research which the Civil Engineering Research Council already has in hand in respect of the design of Arch Dams and Deep Bored Cylinder Foundations (ENGNG., 30 Mar. '62, p. 432), the Council has now initiated the following work.

A sum of £5,000 per annum has been allocated for a two year research programme into the pressure of concrete on formwork. This investigation is to be undertaken in conjunction with the Cement and Concrete Association.

There is considerable doubt regarding the reliability of the experimental data on the pressure of concrete on formwork, particularly for extreme conditions of temperature and rates of placing. The main object of the research is to make a comprehensive study of the pressures due to green concrete. It is anticipated that valuable information will also be obtained regarding the controversial matter of striking times for formwork. Much of the experimental work will be carried out on construction sites.

The construction of earthworks is to be investigated at the Road Research Laboratory and the Council has set aside a further sum of £5,000 per annum for the work, which is also expected to take two years.

The object of this research is to make a comprehensive study of the number of working days for earthwork construction that may be expected in different parts of Britain, having regard to such factors as rainfall, temperature, humidity, soil conditions and type of plant. Although this information will not prevent or reduce delays in earthwork construction, it should assist in the preparation of realistic estimates for this type of work. It is hoped that methods of facilitating earthwork construction in wet weather may also emerge from this investigation.

A sum of £2,000 has been allocated to the British Welding Research Association to investigate the fatigue resistance of welded steel plate girders. A further sum of £2,000 will be considered at a later date. The DSIR Fatigue of Engineering Structures Committee has indicated the need for more data on large welded plate girders used on bridge construction and in cranes and gantries.

Maximum priority is to be given to investigations into problems that are found on construction sites and a sum of £1,000 has been set aside for use on this work during the remainder of 1962. Anyone wishing to draw on this fund for work in this category is asked to get in touch with the Research Director, Civil Engineering Research Council, at the Institution of Civil Engineers, Great George Street, London SW1.

It has always been the intention that the work of the Research Council should be published in a form that will assist in its ready use by practising engineers. To this end, the Council are advertising for an assistant who will be able to prepare reports on the research work that the Council has in hand.

The Council's application to the Department of Scientific and Industrial Research for grant aid for the period 1962-66 will be considered by the Industrial Grants Committee of the department at the end of July next.