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CANADIAN BUILDING DIGEST

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CBD-34. Wind Pressures On Buildings

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Wind is one of the significant forces of nature that must be considered in the design of buildings. Structural loads applied by high winds are readily appreciated, even if the method of determining them is not so easily understood. Other effects that can be caused even by moderate breezes are commonly overlooked, however, because very often there is no obvious link between wind and the behaviour of a building.

Masonry walls may be displaced by ice accumulating in the wall as a result of moisture-laden air drawn out of a building under the action of wind suction. Rain leakage around flashings and through joints in curtain walls may be due to a pressure gradient across the wall, and the functioning of ventilating and heating systems may be affected by pressure distributions where ducts and openings are located.

Thus it is not only the structural engineer who must consider wind action but the architect and mechanical engineer as well. The latter are often concerned with average or day-to-day pressures, whereas the structural engineer is chiefly concerned with the maximum pressures that can reasonably be expected to occur during the useful life of the structure.

Conversion from Wind Speeds to Wind Pressures

Wind pressures exerted on a structure depend on the speed of the wind as well as the interaction between the air flow and the structure. Since wind is air in motion the pressures it can exert are related to its kinetic energy. If the full kinetic energy is transformed into pressure then the resulting increase is given by the expression

$$q = \frac{1}{2}\rho V^2$$

where ρ is the mass density and V the velocity of the air. This is called the "stagnation pressure" and is the maximum positive increase over ambient pressure that can be exerted on a building surface by wind of any given speed. It is the basic pressure to which all other pressures over the structure are referred.

The wind speed to be used in computing the design pressure depends on the particular component of the building being designed. For structural purposes the maximum value is required and will vary with the geographical location. Meteorological records of wind speed are analysed to yield the most probable maximum that will be equalled or exceeded, on the average, once during a given period of time comparable to the life of a structure. In the National Building Code of Canada 1960 the "return period," as it is called, has been set at 30 years.

Interaction of Wind and Structures

The distribution of pressures and suctions over a building depends largely on how it disturbs the air flow. In this discussion the datum from which all pressures and suctions are measured is the ambient pressure in the undisturbed air flow.

When wind strikes a simple structure such as a free standing wall, the streamlines in line with the wall are forced, to diverge and pass around the edges. The direction and magnitude of the original wind velocity are therefore altered by the encounter and cause changes in pressure.

Stagnation pressure is produced near the centre of the wall, but there is an increasingly steep pressure gradient towards the edges where the flow, diverted by the wall, regains its velocity in a direction parallel instead of perpendicular to it as before. Figure 1(a) is a plot of the pressures on the windward face.

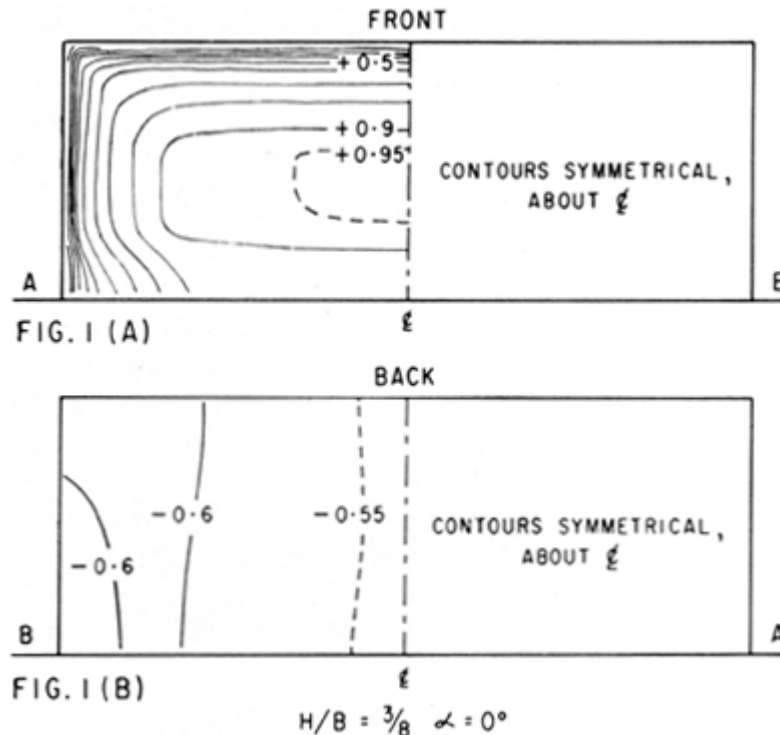


Figure 1. Pressure contours on a wall at right angles to wind direction (From: "Wind tunnel studies of pressure distribution on elementary building forms" by Chien et al. Iowa Institute of Hydraulic Research 1951).

Behind the wall a different situation prevails. The streamlines of flow are unable to come together immediately because of the inertia of the air and a wake is left where they are separated from the wall. Air from the wake region is "entrained" by the fast-moving flow lines, thus reducing the pressure below the ambient pressure of the undisturbed flow and creating "suction." Figure 1 (b) shows the pressure distribution for the rear of the wall. The numbers on the isobars (lines of equal pressure) are the factors by which the stagnation pressure is multiplied to give the pressure at the various points on the surface. These are the pressure coefficients (sometimes called shape factors) that relate the pressure and suctions on a structure to the basic design velocity pressure or stagnation pressure. Negative values indicate suction.

Pressure is not usually constant over a wall or roof surface; but to simplify design procedures an average coefficient is specified for a given surface; when multiplied by the area and the basic pressure it gives the total force on the surface. The net force on the free standing wall would of course be the result of both the pressure on the windward side and the suction on the leeward side. Correspondingly, for an exterior wall of a building the net pressure on the wall would be the difference in pressures outside and inside the building, the inside pressure being a function of openings, as is discussed later.

Flow Around a Building

Figure 2 illustrates a more complicated shape and the flow lines associated with it. For buildings with flat and low-sloped roofs the windward wall is the only surface subjected to pressure; all other surfaces are located in the wake where pressures are below the ambient.

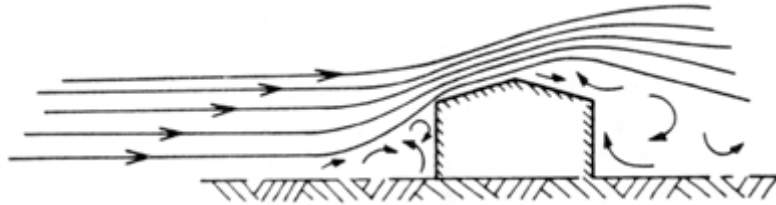


Figure 2. Flow lines around a simple building shape.

The reason for this is again that the flow lines deflected around the windward edges are unable to "cling" to the building surfaces as they pass around the sharp corners and a separation occurs between the wind and the building. Figure 3 is a cross-section of the pressure distribution on the building. It should be noted that the pressures are not uniform and that, in particular, certain small areas experience suction much higher than the average.

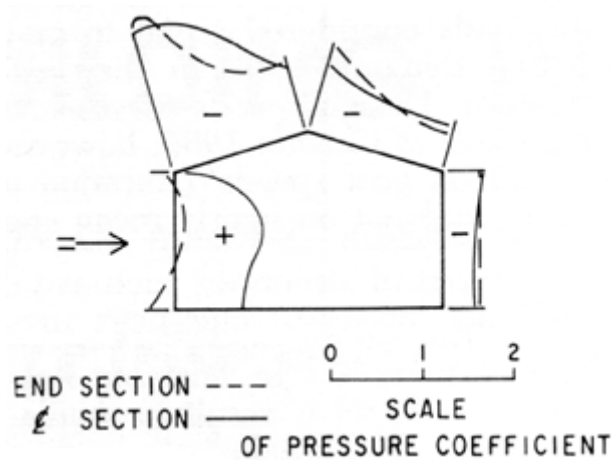


Figure 3. Distribution of pressures (+) and suction (-) on house with a low-sloped roof with wind perpendicular to eave.

Pressure Coefficients

Pressure coefficients used in practice have usually been obtained experimentally by testing models of different types of structures in wind tunnels. Commonly used coefficients refer to the average pressure or suction over a surface. Tangential forces are considered insignificant, so that the forces referred to act at right angles to the surfaces in question. Values for a fairly wide range of building shapes are catalogued in Supplement No. 3 to the 1960 edition of the *National Building Code of Canada*, "Handbook of Pressure Coefficients for Wind Loads 1961."

Variables Affecting Pressure Distributions

Building Shape. Pressures on certain parts of a structure are rather sensitive to changes in the shape of the building. The suction on the windward roof slope, for instance, vary considerably with the slope of the roof, the ratio of height to width, and the ratio of width to length of the building. Suctions on the leeward wall, on the other hand, are not greatly affected by such variables.

Sometimes shape details have an unexpectedly large effect on the wind pressure distribution. Parapet walls, large chimneys, silos and spires may have a considerable influence, and often the only way to assess such

effects is to test a scale model in a wind tunnel.

Openings. The size and location of openings such as windows and doors determine the internal pressure that must be considered in the calculation of net forces on walls and roofs. Internal pressures tend to take on the values appropriate to the exterior of the wall in which the openings predominate. If they are small and uniformly distributed, values of ± 0.2 are recommended, the more unfavourable of the two to be considered in each case.

Wind Direction. The orientation of a building to the wind has a marked effect on pressure distribution, particularly on suction maxima, which occur over a small area near the leading edges of roofs. The "Handbook of Pressure Coefficients for Wind Loads 1961" provides special local pressure coefficients for such areas that may be used in designing fastenings for roofing, building panels and similar details.

Increase of Wind Speed with Height. Since the wind speed and consequently the velocity pressure increase with height above the ground, a height factor is applied to the basic pressure (based on a height of 30 feet) in the design of buildings. For example, if a building is 90 feet high, the height factors that apply are 0.8 for the first 20 feet, 1.0 for next 20 feet, and 1.2 for the top 50 feet.

Shielding. Other buildings, trees and similar large objects in the immediate vicinity have a bearing on pressure distribution. The shielding provided is usually difficult to estimate, and model tests provide the most convenient means of determining design values. The assignment of reductions for shielding is complicated by the fact that conditions could change during the life of the structure. Shielding does not always have a beneficial effect, and in some cases suction coefficients should be increased because of the proximity of a neighbouring building.

Wind Pressures (On Various Parts of Buildings)

Roofs. The roof is usually the critical area in the wind design of low buildings, particularly residential structures. Where it is made up of light-weight components particular attention must be paid to anchorage details because of the suction condition prevailing over most, if not all, of it. A good example of such precautions is the time-honoured custom of weighting roofs in Alpine areas with large stones.

Critical Angle, Windward Slope. For every sloped roof there is a certain slope angle at which the suction coefficient over the windward slope reaches a numerical maximum. For low buildings this angle may be around 5 degrees; for average shapes such as the usual bungalow, from 5 to 15 degrees. For higher buildings with height to width ratios ranging up to 2: 1 the critical angle may be as high as 25 or 30 degrees. The average pressure coefficient for the critical angle is in the range -0.7 to -1.4.

Steep Roofs. As the roof slope increases beyond the critical angle the average pressure coefficient decreases numerically to zero; it then increases in a positive direction, indicating pressure, to a maximum of +0.8 or so for a slope angle of 90 degrees (i.e. in the plane of the windward wall). The angle at which the coefficient is zero varies from 20 to 45 degrees, increasing with the ratio of height to width of the building.

Leeward Slope. The effects of slope and building dimension ratios are much less pronounced on suctions on the leeward slope and for general purposes could probably be disregarded. Average values range from -0.5 to -0.8 for most building shapes and slopes.

Local Suctions. Local suctions are most serious for wind at an angle (usually about 45 degrees) to the side of the building. Local pressure coefficients of -2.0 are not unusual, and in certain model studies values down to -5.0 have been measured over very small areas near corners

projecting into the wind; this indicates the importance of proper fastening of roof coverings at such points.

Walls. For tall, slender structures the design of the walls and the frame, with regard to overturning moment, are likely to be critical. The trend toward high-rise buildings and curtain wall construction may lead to greater problems in limiting sway and in specifying the strength of fastenings for wall panels. Although average coefficients for leeward and side walls are only -0.5 to -0.7 high suctions occur just around the corners from the windward edges, and where stagnation pressures are high (near the top of tall buildings) these local suctions may be appreciable (possibly as high as -1.5).

Shielding. Model tests investigating the effects of building proximity have shown that where two buildings are close together rather high suctions may occur on the facing walls if the wind blows parallel to the "alley" between them. Average values of -1.0 have been measured, with local suctions along the windward edges as high as -2.0.

General Comments

Dynamic Nature of Wind. It is well known that wind is far from steady and that pressures on a building fluctuate widely both in time and in space. Design procedures to the present time have been based on the substitution of static loads considered equal to or greater than actual dynamic loads in their effect on the structure. Design speeds for the *National Building Code of Canada 1960*, however, have been based on gust speeds (duration of 3 or 4 seconds) and not on hourly mean speeds.

Certain types of structures such as tall slender buildings, masts or chimneys may react dynamically to a certain periodic gustiness. Other structures may cause an unstable flow pattern to be set up that will result in oscillatory forces. The possibility of dynamic loading of this nature necessitates the development of design procedures in which the dynamic structure of the wind and the dynamic response of the building are investigated. Research is being carried out along these lines at present.

Measurements on Full-scale Buildings. Perhaps the greatest need is for check measurements on full-scale structures in natural wind. The expense of instrumenting structures is high and the great variety of shapes and sizes precludes anything like an exhaustive study. Such checks are now being made, however, to give added confidence in the use of coefficients obtained from model tests.

Conclusion

Pressure coefficient tables now available are considerably more extensive and accurate than were those of previous simple approaches. Many more variables known to be significant have been taken into account and many new situations have been investigated.

Inevitably design procedures are becoming more complicated. In dealing with a phenomenon as complex as wind the prospect is for more involved load assumptions rather than the reverse. By recognizing the features that are actually significant, however, the designer will be able to, provide a more deliberate and balanced degree of safety and economy in his structures.

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