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CANADIAN BUILDING DIGEST

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CANADA

Wind Pressures and Suctions on Roofs

by W. A. Dalglish and W. R. Schriever

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Although the dangers of damage to roofs from hurricane winds are vaguely appreciated by most people, the nature and distribution of wind forces are not generally understood. The subject is complicated and some understanding of air flow around buildings is required as a basis for sound roof design. It is the purpose of this Digest to assist the reader in acquiring this understanding.

By looking at the most striking effects of wind on roofs — damage caused by very high winds — three lessons can be learned.

1. Entire roofs are often lifted off a building: wind must exert strong lifting forces rather than pressures on roofs.
2. Damage is frequently confined to small sections near corners and ridges: the distribution of wind forces must be non-uniform, with extremes in certain areas.
3. Damage is sometimes limited to the roof covering proper — shingles or built-up roofing — rather than to the roof assembly as a whole: a pressure differential must exist across the roofing membrane alone rather than across the assembly.

Positive wind pressure, in the sense of a downward roof load, is almost never the cause of a failure. Even if there are occasional downward wind loads, roofs in Canada are normally well designed to carry downward loads from snow.

Structural damage from very strong (and fortunately relatively rare) winds is the most obvious effect of wind on roofs, but even moderate winds are important in the over-all picture. The movement of air through roof spaces must also be considered. The same wind-induced pressure distributions that cause structural loading also cause air to flow, even at moderate wind speeds, from regions of higher to regions of lower pressure if openings exist either intentionally or accidentally. The wind factor must, therefore, be taken into account in planning the size and location of ventilation openings. A difference may be, of course, that at low wind speeds building pressurization by mechanical equipment and, in winter, chimney effect can cause pressure differentials of the same order of magnitude as those produced by wind. In principle, however, it is best to put exhausts in areas of continuous suction (independent of wind direction).

Pressure Distribution on Roofs

It should be noted that although the *magnitudes* of the pressures and suctions are proportional to the square of the wind speed, the *distribution* of pressures and suctions does *not* change with speed for most "sharp-edged" structures and buildings. The pressure distributions can readily be expressed independent of wind speed by dividing the wind-induced pressures by the "stagnation pressure", $\frac{1}{2} \rho v^2$, where ρ is the air density and v is the wind speed.

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The stagnation pressure represents the total kinetic energy of the wind and is used as the basic design pressure. It is the pressure obtained on a surface perpendicular to the wind that makes the wind "stagnate" completely. To obtain the actual wind pressures or suction on a surface the stagnation pressure is multiplied by pressure coefficients or shape factors appropriate to any given building surface. Pressures and suction are measured relative to the barometric pressure of the undisturbed flow, which is given the value zero. Although the pressure distribution is far from uniform, average pressure coefficients for entire roof and wall surfaces are used to simplify the design problem.

Pressure coefficients for particular building shapes such as those contained in Supplement No. 3 to the National Building Code have been derived from wind tunnel tests on small-scale models. Meteorological data are naturally also required to supply the necessary design wind speeds for a specific geographical location. Finally, site investigations are sometimes desirable to allow an assessment of the probable sheltering or funnelling effects of neighbouring structures on the building to be designed.

Roof design for wind effects, then, appears to be a formidable task requiring the collaboration of three different specialists. Although it is true that the designer would be poorly equipped without the help of technical data, he is still responsible for applying information to arrive at the design of the roof. Sometimes what he needs is unavailable or only obtainable through *ad hoc* wind tunnel tests, but in any case the designer's task will be much easier if he has a good basic understanding of how pressure distributions are formed on buildings, and when and where to expect potentially serious conditions.

Basic Ideas

Figure 1 illustrates the simplest case of a "sharp-edged" obstruction to air flow over the ground. The obstruction is an infinitely long wall so that the flow is two-dimensional. The wall changes the momentum of the flow by pushing the streamlines upwards, and this creates a positive pressure on the wall. In Figure 1 there is a triangular vortex region in front of the wall in which the "trapped air" is under

positive pressure compared with the pressure in the undisturbed flow.

The streamlines, in addition to showing the direction of flow, indicate changes in speed; the closer they are crowded together, the greater is the speed at that section because the same amount of fluid must pass between two streamlines at any section. The pressure at any point in streamlined flow can be computed from the speed because the total energy, which is the sum of velocity energy and pressure energy, is constant.

The mathematical relations between velocities from point to point and the constancy of total energy can be applied to give the pressure distribution only if the flow is divided into a streamline zone and a turbulent zone containing the obstruction. If the obstruction were itself streamlined in shape, the streamlines could follow its surfaces and vortex regions would not form.

The shape of the boundary separating the vortex regions from the streamlined flow must be known before velocities and pressures can be calculated, although in fact the exact shape is usually not known. In practice, pressure distributions on sharp-edged shapes are found by experiment on scale models in a wind tunnel rather than by mathematical analysis. These ideas have been presented, not to enable one to compute pressure distributions, but to give a qualitative picture of wind flow around buildings that will help the understanding of pressure distributions found from wind tunnel tests.

One final hint in applying these basic ideas will be useful in visualizing where pressures and suction occur: wherever the boundary of streamline flow is pushed up, pressure occurs; and wherever it curves back, suction occurs. The sharper the curvature of the boundary, the greater the pressure or suction will be.

Application of Basic Ideas

Despite the actual shape of the obstruction to flow (a right-angled projection into the flow path), it may be seen in Figure 1 that the streamlines are deformed just as if the obstruction were shaped like a smooth hump. The deficiencies of "streamlining" are made up by the formation of a positive vortex region in front and a larger, negative vortex region behind.

sucked back down to re-attach itself to the roof surface, so that the vortex region is effectively sealed off on all sides, preventing any reverse flow along the roof to relieve the high suction.

Parapets

Simple roofs without parapets or overhangs have so far been considered in this Digest. Such roof elements, however, have a considerable effect on pressure distribution. Recent model tests at the University of Toronto show that parapets can help to reduce the high local suction just described. If it is of the proper height, a parapet can lift the flow and the separation lines high enough to prevent their re-attachment to the roof surface, so that one large vortex region forms to "absorb" the small, tightly sealed one.

If the parapet is too low, on the other hand, the local suction can be even worse. An empirical formula has been derived from model tests at the University of Toronto that enables the parapet wall height to be chosen as a function of the dimensions of the building. For example, a building 50 feet wide, 100 feet long, and 25 feet high needs a parapet wall 5 feet high to reduce local suction maxima from -3.3 to -1.2 .

Internal Pressures

The internal pressure of the building has been tacitly assumed equal to the barometric pressure in the undisturbed flow, the reference datum or "zero" pressure. This will be true, however, only if the building is tightly sealed or if the distribution of "leaks" is fairly uniform, with the right proportion in pressure regions and suction regions. If openings predominate in a suction region, the internal pressure will tend toward suction, and if the openings are mostly on the windward side, the internal pressure will be positive.

The importance of internal pressure, whether positive or negative, to the resultant uplift forces on the roof is apparent. To take an extreme case, an airport hangar with huge

doors open on the windward side receives the positive pressure of the front vortex region under the roof. This adds to the external suction to cause uplift. With the wind coming from the opposite direction the effect is reversed. Thus wind from all directions must be considered in design, although obviously the critical case for uplift is with pressure inside. One should be clear as to which element of the roof is actually experiencing the pressure differential. If the air-tight element is not also the load-bearing element, trouble may arise.

Conclusion

It has been the aim of this Digest to present the basic ideas of wind effects on roofs in such a way that detailed discussions and the implications of the relevant factors can be readily appreciated by the designer. Wind loads in Canada, except for tornadoes, do not present especially difficult problems for the successful design of roofs, but the basic nature of the phenomenon must be understood. It should also be recalled that even when the wind is not blowing strongly enough to cause serious structural loads, suction and pressures exist that may seriously affect the operation of a roof system, exhaust fan outlets, ventilators and the like. In all these situations there is nothing to replace a sound understanding of what actually happens when the wind blows around a building.

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