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BY

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LA MESURE DES CHARGES DUES A LA NEIGE ET AU VENT SUR DES EDIFICES GRANDEUR ECHELLE EN VUE D'UN CALCUL PERFECTIONNE

Dans plusieurs pays le calcul des charpentes évolue vers la reconnaissance "d'états limites," par exemple la déformation excessive, la détérioration et l'effondrement. Cette conception repose sur deux principes: premièrement, les charges de calcul et les propriétés des matériaux doivent être définies sur une base plus réaliste (probabiliste); deuxièmement, les règles et les facteurs de sécurité à admettre doivent être liés plus étroitement aux risques et aux conséquences d'un effondrement. La Division des recherches en bâtiment du Conseil national de recherches du Canada, reconnaissant ces tendances, a mené sur le terrain des observations et des études approfondies des chargements, y compris les charges de neige sur les toits ainsi que la pression et l'aspiration du vent sur les murs des grands immeubles. Le présent article donne un bref aperçu des points saillants de ces travaux, y compris les méthodes d'observation et quelques-uns des résultats.

Measurements of snow and wind loads on full-scale buildings for improved design

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Summary

In many countries structural design procedures are undergoing changes toward recognition of "limit states", e.g., excessive deformation, unserviceability, collapse. The application of this philosophy has two prerequisites: first, design loads and material properties must be defined on a more realistic (probabilistic) basis; second, design safety rules and factors must be related more closely to risk and consequences of failure.

The Division of Building Research of the National Research Council of Canada, in recognition of these trends, has carried out extensive field observations and studies of loads, particularly snow loads on roofs and wind pressures and suctions on walls of high-rise buildings. The paper describes briefly the major features of this work, including observation methods and some of the results.

Along with the evident "building explosion," other, less obvious, changes are taking place that are of considerable significance to designers. Among these are changes in structural design procedures leading toward more rational methods based on a better understanding of structural behaviour, more elaborate computer-assisted methods of analysis, and more accurate determination of loads to be assumed in design calculations. The purpose of this paper is to outline how the measurements of loads on full-scale buildings can assist in developing more accurate design methods.

1. Snow Loads

In the past design snow loads were usually based solely on appropriate statistical maxima of recorded snow loads on the ground and were applied by the designer as a uniformly distributed load on all roof surfaces. Actual snow loads on roofs, however, are often many times larger or smaller than the ground load existing at the same time, mainly because in many northern regions the effect of wind is to redistribute the snow thoroughly (Fig. 1). Other factors, such as uneven melting and snow sliding from sloped roofs, further modify the roof snow cover so that it becomes essential to provide the designer with additional information to enable him to make realistic load assumptions based on the ground load as the basic climatological information.

In Canada the specified ground load which has a 30-year return period and is determined from observations of snow depths at meteorological stations, varies from about 20 to 120 psf (1 to 6 kPa) in the more populated areas (Fig. 2) and reaches values of more than 300 psf (15 kPa) in some mountainous areas of western Canada. Ground loads are given in the Climatic Supplement [1] of the National Building Code [2]; roof loads can then be determined from coefficients given in a Structural Supplement [3].

Data on the magnitude and distribution of actual roof loads have been obtained from a survey carried out by the Division of Building Research for several years with the help of many observers across Canada. The results of the survey show that average snow loads on roofs are significantly lower than the ground snow load but that often the maximum drift loads exceed the ground load by several times. Ideally the designer should modify the value of the ground load to account for all effects of roof shape and size as well as the aerodynamic influence of buildings, trees and topographic features surrounding the proposed building. In practice, however, a more simple route is followed based on a set of snow load coefficients for common types of roofs. Fig. 3 indicates the evolution of snow load provisions in Canada.

The reduction of the basic roof load to 0.8 of the ground load (0.6 for wind-swept roofs) means that, on the average, roofs designed for the new loads are lighter. At the same time safety is not sacrificed because roof areas subjected to drift accumulations are designed for heavier loads. A cost-benefit estimate of the annual saving resulting from these reductions was made based on a total area of 150 million square feet

(13.5 km^2) of roofs constructed annually in Canada, a figure calculated from available statistics on the consumption of asphalt and tar in building construction. The savings in costs due to the reduced design snow loads were in the order of \$8,000,000 per year as compared to the \$22,000 yearly cost of the project.

2. Wind Loads

Another area in which full-scale observations on buildings have contributed a better understanding of the loads is wind effects on tall buildings.

Climatological data and shape factors derived from wind tunnel tests and, in some cases, dynamic characteristics of the building itself, provide the information from which design wind loads are determined. Measurements on full-scale buildings are a fourth source. The main objective is to ensure a background of practical experience for the proper assessment, integration and application of information from the various sources.

The basic design wind pressure, having a suitably low probability of being reached or exceeded, is based on meteorological records gathered at many stations across Canada, often located on flat open terrain at airports. Building sites, on the other hand, are rarely at airports, and terrain roughness varies from completely open exposure to heavily built-up city cores.

Wind tunnel tests have evolved from the traditional low-turbulence, constant-velocity tunnels commonly used to determine shape factors in building areodinamics of 10 to 15 years ago. Now it is realized that natural wind gustiness, i. e., turbulence created by flow over rough terrain, the increase of wind speed with height above ground, and the systematic effects of neighbouring buildings in "shaping" the flow on the building in question, have to be considered in the search for more accurate wind simulation in "boundary layer wind tunnels."

Success in meeting the modelling requirements for information relevant to real buildings can only be gauged by comparison with field measurements. This is particularly true in the case of design wind loads for windows, cladding, and other localized areas of the building surface.

The Division of Building Research has contributed to the record of field experience by making measurements on full-scale high-rise buildings ranging from 9 to 57 storeys in height.

After a pilot study on a 9-storey office building involving only 12 pressure sensors a study of a 34-storey building permitted a first comparison between on-site measurements and wind tunnel tests in which encouraging agreement was found. [4] An improved data acquisition system was set up in the next structure studied, a very slender, 47-storey building. Again, wind tunnel tests were carried out for comparison with the field measurements, but in this case there were significant differences which have not yet been completely explained.[5]

A fourth building, a 57-storey office tower with a total of 48 sensors, is now under study. The installation of a typical sensor for pressure involves the drilling of a hole through the curtain wall (Fig. 4) and the running of signal cables and reference pressure tubes from each tapping location to a room near mid-height where the computer and tape recorder are located. Some sensors measure wind speed and direction above the roof; others measure barometric pressure and changes in strain at selected locations on structural steel members.

The pressure differences measured at each tapping location on the building are expressed in terms of non-dimensional "pressure coefficients," or fractions of the dynamic reference wind pressure measured at the highest wind sensor, some 160 feet (50 m) above the roof. Of course, the wind velocity and hence the dynamic pressure vary continuously both in time and space and even several wind sensors can only give a partial description of the wind flow on such a large building. The reliability of pressure coefficients, which are estimated by least squares techniques, depends on having good correlation between surface pressures and the reference dynamic pressure at the top wind sensor.

Observations to date have generally shown good correlation for prevailing wind directions but the scarcity of data for other wind directions still makes an over-all assessment premature.

3. Basis of Design

This information on actual climatic loads on structures is required for the new, more rational, "limit states" design method, briefly described in the following.

The limit states identify the basic structural requirements of safety and serviceability and include, for example, collapse of various kinds, excessive deflection and vibration. Structural failure corresponds to the occurrence of any one of the limit states. The limit states of interest for snow loads include collapse and deflection and, for wind loads collapse, lateral deformation and vibration.

Besides identifying the conditions corresponding to failure, limit states design aims to provide acceptable failure probabilities for the different limit states. Failure probabilities are controlled by defining loads and material properties on a statistical basis and by the use of partial safety factors.

The statistical definition of loads and material properties is given in terms of characteristic" values, corresponding to a limiting probability level for unfavourable values. For material properties this level is of the order of 1 to 10 per cent; for loads, it is often expressed in terms of a return period of the order of 10 to 100 years. Where statistical data are lacking, traditional nominal values are used for the time being.

To provide sufficiently low failure risks for particular limit states, the characteristic loads are multiplied by load factors and the characteristic resistances are multiplied by material or performance factors; another factor may be applied to reflect the seriousness of collapse.Given a knowledge of uncertainties in loads and material properties, all these factors can be chosen to give reasonably consistent failure probabilities for the limit state under consideration.

4. Conclusion

The determination of characteristic loads and load factors to give a reasonably consistent failure probability for each limit state under consideration requires a sound knowledge of the actual loads and resistances that occur. The Division of Building Research, having recognized the need for data on actual loads some years ago, has collected data on actual loads, particularly snow and wind, to assist in improving both the safety and the economy of building structures.

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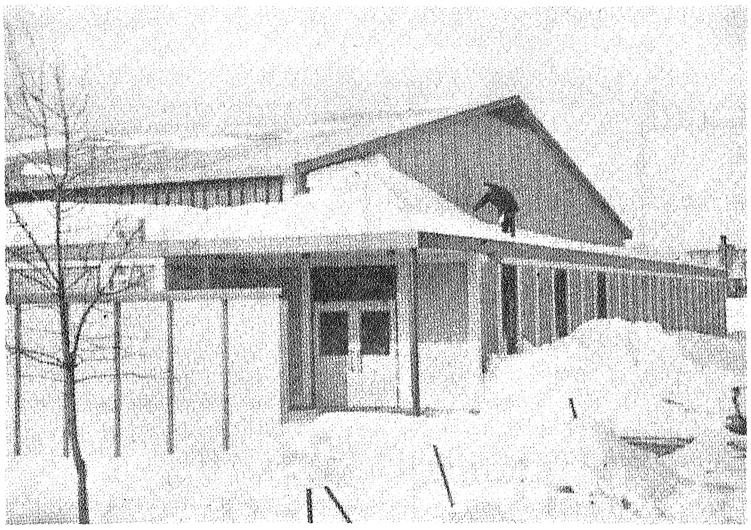
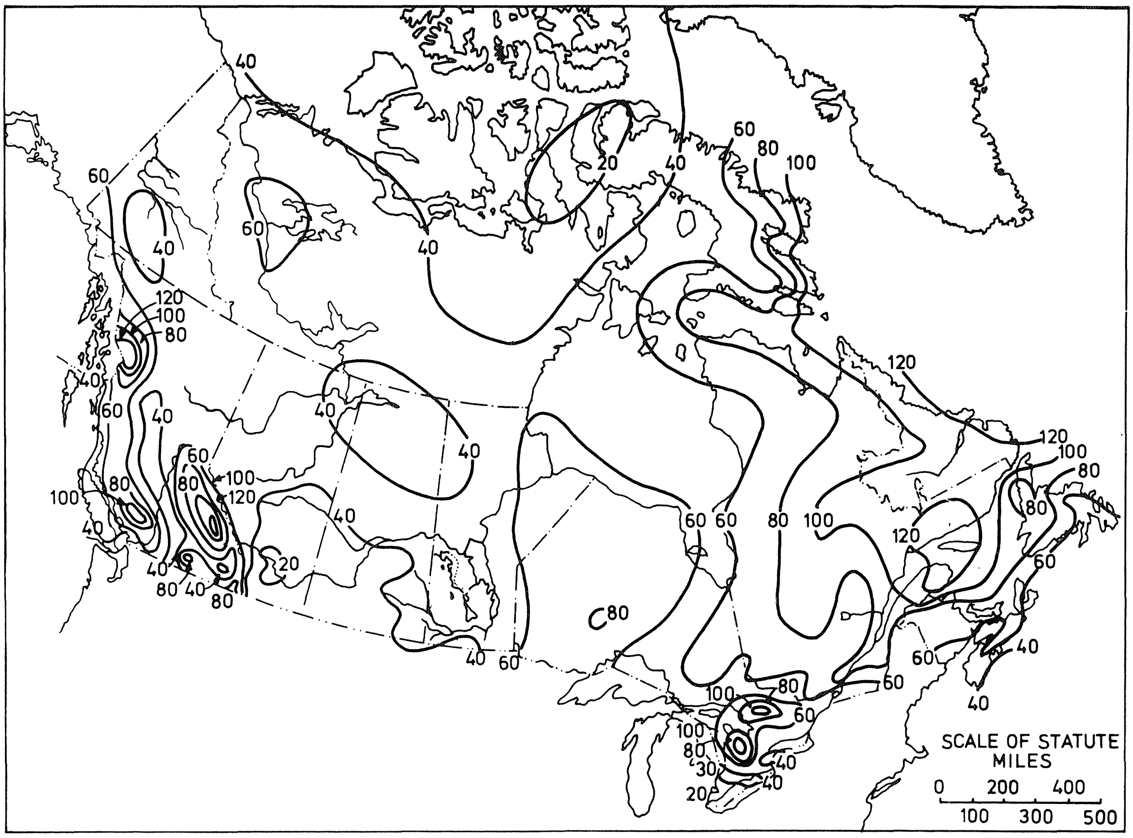




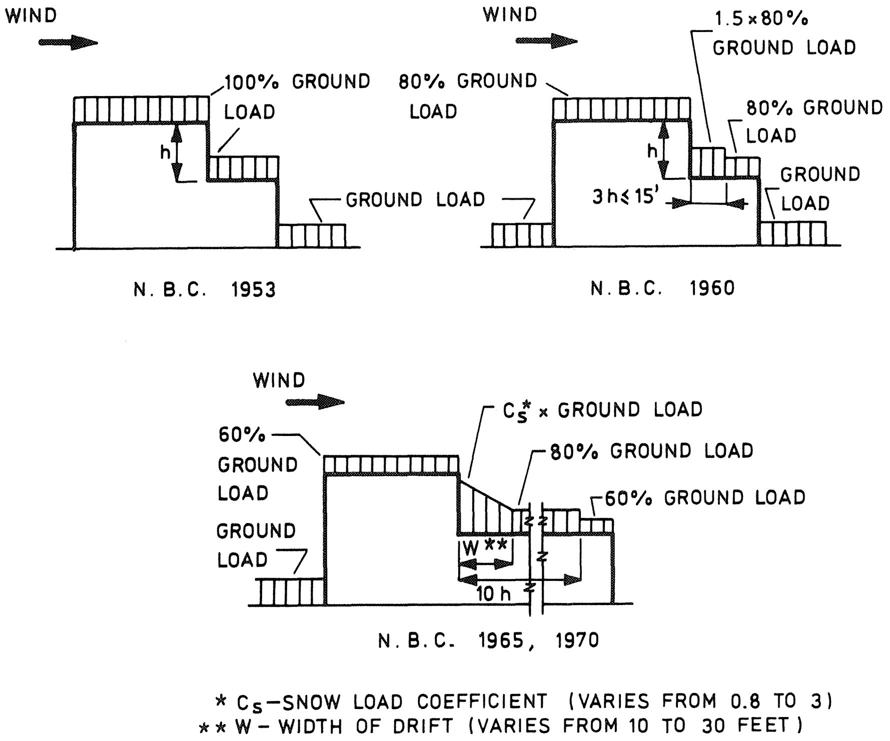
1

Example of heavy drift load produced on a flat lean-to roof along the gable wall of an arena by wind blowing diagonally over the building. Maximum load was 128 psf (6 kPa); ground load, 12 psf (0.5 kPa).

2

Chart of the National Building Code of Canada 1970 showing snow load on the ground. (Divide by 20 to obtain approximate kPa.)

3



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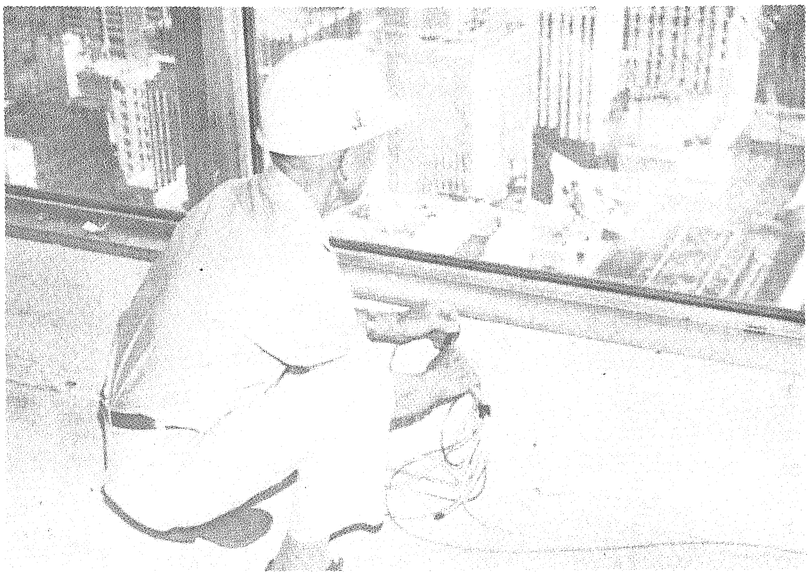

3

Example of the evolution of the design loads recommended in the National Building Code of Canada from the 1953 edition to that issued in 1970. Design loads on wind-swept roofs have been reduced; those occurring on sheltered, lower roof have been increased.

4

Technician installing signal cables and reference pressure tubes to pressure sensor on 25th floor of 57-storey building for wind pressure measurements.

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