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EXPERIENCE WITH WIND PRESSURE MEASUREMENTS ON A FULL-SCALE BUILDING

BY

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MESURES EXPERIMENTALES DE LA PRESSION RESULTANTE DU VENT SUR UN EDIFICE EN VRAIE GRANDEUR

SOMMAIRE

Les mesures de la pression résultante du vent effectuées durant une période de quatre ans sur les faces d'un édifice de 34 étages dans le centre de la Ville de Montréal ont servi à obtenir les données nécessaires pour vérifier et améliorer les techniques de soufflerie qui permettraient de reproduire dans la soufflerie l'écoulement du vent et le comportement aérodynamique des bâtiments. Des comparaisons avec les mesures sur les modèles sont faites en fonction des pressions moyennes, des écarts normaux, des transformées de Fourier de corrélation, des fonctions de corrélation entre des paires choisies de pression mesurée à divers points sur l'édifice. Des mesures sont maintenant recueillies sur un édifice de 600 pi (180 m) de hauteur en utilisant un système plus raffiné d'acquisition par lequel il sera possible d'obtenir les renseignements désirés plus efficacement.

EXPERIENCE WITH WIND PRESSURE MEASUREMENTS ON A FULL-SCALE BUILDING

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Wind pressure measurements made over a 4-year period on a 34-story building in downtown Montreal were used to obtain data for checking and improving wind tunnel techniques of modeling flow characteristics of wind and aerodynamic behavior of buildings. It had been hoped that the measurements could be applied directly to certain problems of design such as evaluation of peak suction load over small wall areas. The small number of pressures recorded, however, combined with limitations of field measurements made direct application of the data extremely difficult.

The major problems involved in making field measurements and in comparing them with wind tunnel measurements were found to be:

(*a*) difficulty of establishing a static reference pressure and its relation to the static pressure in the wind tunnel;

(*b*) inadequacy of wind velocity information, which in this case consisted of one anemometer and wind vane located 1,500 ft southwest of the building;

(*c*) lack of stationarity and homogeneity of the velocity field as compared with the wind tunnel situation.

Comparisons with model measurements are made on the basis of mean pressures, rms pressures, power spectra, and the correlation between selected pairs of pressures measured at various points on the building. Examples have been found of excellent agreement in almost all respects, but for some wind directions the comparisons gave unsatisfactory correlation. The lack of agreement is attributed mainly to differences between indicated and actual on-site wind direction, but this cannot be shown conclusively because of incomplete wind information.

The total cost of the project over the 4-year period was of the order of $100,000. A greater expenditure would have been advisable, primarily for instrumentation to permit a better definition of the wind velocity around the building. Measurements are now under way on a 600-ft office building using a much more sophisticated data acquisition system by means of which it should be possible to acquire the desired information more efficiently and in a shorter period of time.

Key words: Buildings; full-scale tests; power spectra; pressure fluctuations; wind loads; wind tunnel modeling.

1. Development of Methods for Wind Research

Investigation of wind effects on buildings and structures by the Division of Building Research, National Research Council of Canada, began in 1958 when an extensive survey of the available literature [1]* was made in connection with the revision of design wind load information for the 1960 edition of the National Building Code. In this code, as in most other building codes, the conversion from design wind speeds to design wind pressures and suctions on various building surfaces was given in the form of pressure coefficients determined experimentally by testing small-scale models in wind tunnels.

1.1. Need for Full-Scale Data on Pressure Coefficients

Study of the literature revealed serious discrepancies among pressure coefficients for geometrically similar models tested by different researchers. Modeling laws were obviously a matter for debate, which brought into serious question the applicability of the results to full-scale structures [2].

A need clearly existed for field measurement of wind pressures on full-scale buildings to answer the questions of applicability to full-scale situations, and the correctness of similitude rules. There was surprisingly little full-scale information available, however, up to 1960, and the few comparisons with model results that had been made were at best inconclusive.

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* Figures in brackets indicate the literature references at the end of this paper.

1.2. Objectives for Field Measurements in Canada

A project was therefore set up within the Structures Section of DBR/NRC to measure pressures and suctions on full-scale buildings. The main objectives were to check wind tunnel data and possibly to indicate how to improve modeling techniques. It had been thought at first that such field information might also prove directly useful to designers in assessing, for example, peak suctions over small areas or for similar problems of detailed conditions in which wind tunnel results seemed inadequate. The limited instrumentation, however, coupled with other problems to be discussed in Section 3, made direct design application of these particular measurements very difficult.

1.3. Full-Scale Measurements in Other Countries

In contrast with the limited activity before 1960, interest in field investigations of wind effects on structures since that time has been very great. In England an extensive program of full-scale measurements of wind pressures has been under way for nearly 10 years, and interim results from measurements on a 200-ft tall slab-like office building have been reported [3, 4, 5]. The program for the future involves measurements on the new 600-ft G.P.O. tower in London.

Full-scale measurements of wind pressure were also carried out on a 150-ft slab-like university building in Melbourne, Australia. Results were compared with wind tunnel tests of a conventional type and with those using a turbulent boundary-layer flow [6]. Dissatisfaction with the correlation achieved led to more fundamental laboratory work on the flow around wall-mounted bluff objects (buildings on the ground).

Wind loading of a 145-ft slab-like apartment building in Delft, Holland, was investigated without the use of pressure taps, using instead a single deformation gage mounted on one of the steel columns [7]. These results were correlated to some extent with calculations based on the statistical approach to wind loading proposed by Davenport [8].

The widespread interest in full-scale measurements shows no sign of slackening. Construction is now well advanced on a 10-story welded steel-frame building in Hong Kong to be used exclusively for full-scale research on wind forces during typhoons [9].

1.4. New Developments in Wind Tunnel Techniques

The special problem of building aerodynamics as opposed to conventional aeronautical wind tunnel work has also been receiving attention [10], with great emphasis on simulating the turbulent shear flow usually found during strong winds. One method of creating a turbulent shear flow that has been used with considerable success involves the so-called boundary-layer wind tunnel, in which a thick boundary layer is allowed to grow over the long, specially roughened floor of the tunnel. Over the past 3 or 4 years the boundary-layer wind tunnel has been applied as a design tool for predicting wind loading on several major structures [11].

The parallel development of laboratory and field techniques, and the availability of full-scale results for comparison with model results have already explained some of the discrepancies of earlier wind tunnel work, but much checking and improvement remains to be done. The measurement of wind pressures and suctions on a full-scale building in downtown Montreal, Canada, constitutes the most recently completed portion of the investigations under way in the Structures Section of DBR/NRC. These results have been compared with wind tunnel tests done in a boundary-layer wind tunnel. A brief description of the field measurements, of the problems of analysis and interpretation of the results, and of the correlation with wind tunnel results follows.

2. Instrumentation of 34-Story Office Building

Arrangements were made with the owner of a 34-story office building in Montreal to permit the instrumentation of the two mechanical floors for wind pressure measurements. Most of the office floors of the building had already been rented at the time of instrumentation (spring, 1964), and this made it impossible to instrument other levels without seriously inconveniencing the tenants. The mounting of an anemometer and tower on the building itself was not practicable, and wind speed and direction signals were transmitted through telephone wires from instruments mounted in the fall of 1964 on an existing 200-ft mast atop a 600-ft building to the southwest.

2.1. Influence of Surrounding Terrain

The location of the two buildings involved and the nature of the surrounding terrain are shown in Figure 1. As may be seen from the ground contours,

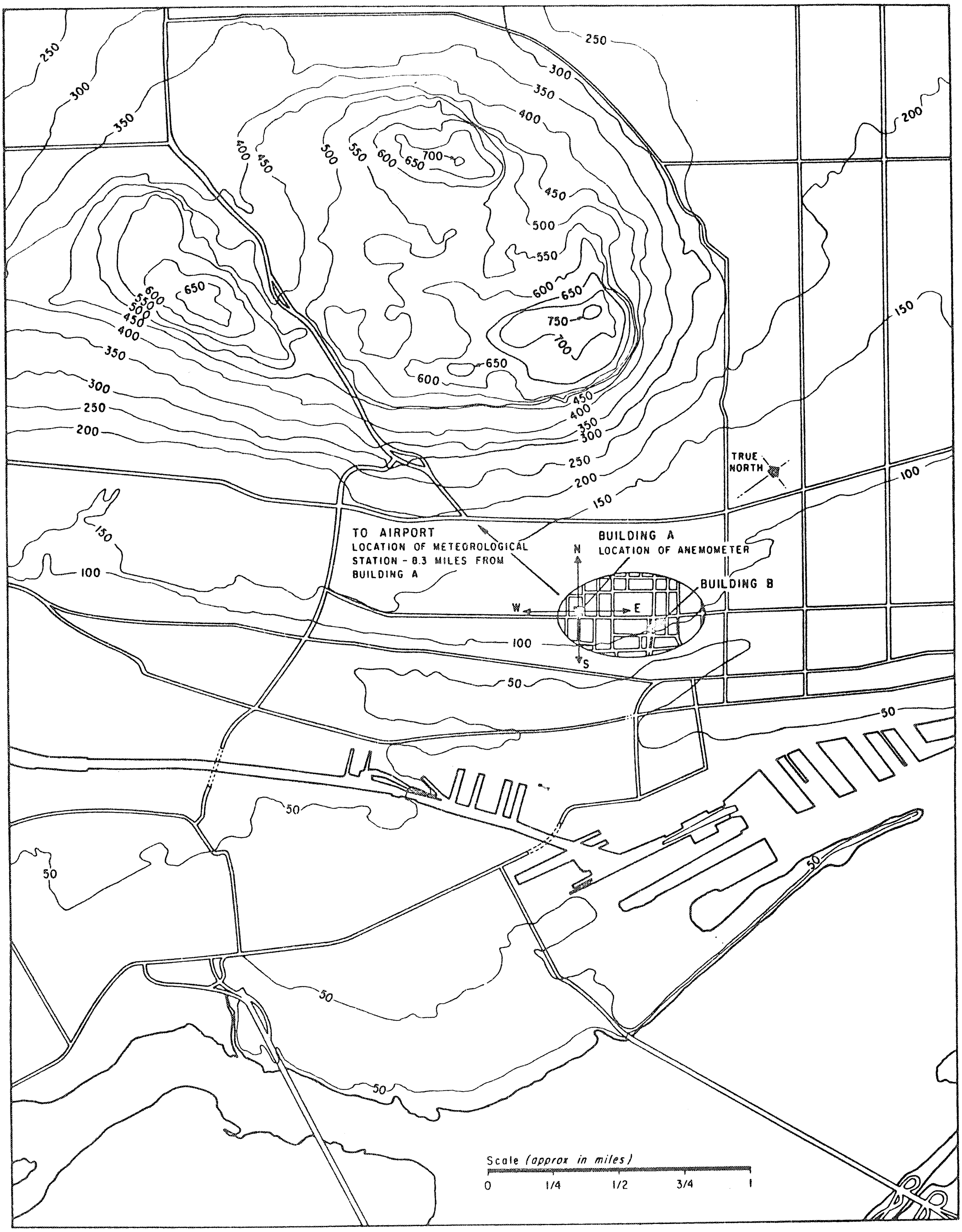

FIGURE 1. Contour map of the terrain surrounding test buildings.

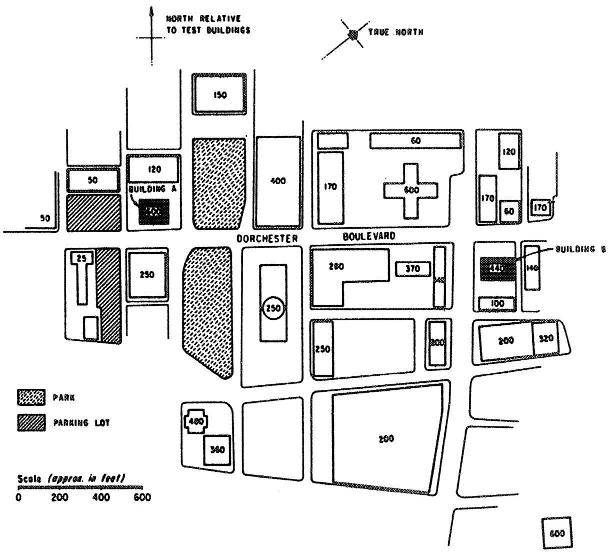

Figure 2. Plan showing heights of adjacent buildings.

the area is fairly level except for Mount Royal to the northwest. Figure 2 is an enlarged view of the immediate surroundings. Wind pressures on the 34-story building (building B) were found to be significantly influenced by the presence of the nearby tall buildings, particularly the 600-ft cruciform building to the northwest.

2.2. Installation of Pressure Taps

The instrumented floors are the 10th and the 33d, at heights, respectively, of 134 and 413 ft above the street. The total height of the building is 440 ft and the plan dimensions are 119 by 173 ft. The exterior wall surface is plane except for 8-in. deep mullions, 4 ft 8 in. apart, which run the full height of the building. At the mechanical floors, however, there are horizontal louvers, and the curtain wall is set back about 5 in. from the plane of the exterior wall. The louvers show up as dark bands on the wall surfaces in figure 3.

Holes ⅛-in in diameter were drilled through the curtain wall into the space behind the louvers about 2 ft above floor level at intervals of approximately 24 ft all around the building at the two levels, except where locations were inaccessible because of equipment placed in the way. Any 12 of a total of 49 holes could be used as outside pressure taps for the 12 transducers, which were used to convert pressure differences into electrical signals for convenient transmission to a central recording location.

Figure 3. Thirty-four-story office building looking southeast (relative to building). Dark bands are at 10th and 33d floors, where mechanical services are located and wind pressure measurements were taken.

2.3. Sensors and Recording Equipment

The turbulent nature of wind requires that speed, direction, and pressure at several locations on the building be recorded simultaneously and continuously for periods preferably longer than 10 or 15 minutes at a time. The response of the sensors and the capacity of the recording equipment should be sufficiently high to record fluctuations with frequencies up to several cycles per second. The equipment used for the instrumentation of the 34-story office building met most of the requirements, but in the final analysis of the records an upper frequency limit of 0.5 cycle/sec was imposed to keep the task of manually preparing digitized records within reasonable bounds.

The pressure sensor, or transducer, of which there were 12, comprises an elastic steel diaphragm dividing a chamber connected, on one side, by about 2 ft of plastic tubing to the outside air pressure tap, and on the other side by up to 200 ft of plastic tubing to the air pressure at a central location inside the building. The pressure difference between the two sides of the chamber is measured in terms of the diaphragm deflection by an unbonded 4-arm resistance strain gage bridge. The power and signal are transmitted by strain gage cables over distances of up to 600 ft to the central recording location on the 10th floor.

The wind vane and 3-cup anemometer are of the type U–2A used by the Meteorological Branch of the Canadian Department of Transport and were located about 1,500 ft away at a height of 800 ft above street level on building A (see Figs. 1, 2). Electrical wind speed and direction signals, transmitted via telephone lines, were recorded with the 12 pressure signals on an 18-channel ultraviolet light beam type oscillograph. Chart speed was limited to 4 in./min for most of the recording, and the full-scale deflection of each signal was made ±2 in. (±10 psf).

2.4. Field Trips and Processing of Records

Trips were made from Ottawa to Montreal (120 miles) whenever strong winds seemed imminent. It was necessary upon arrival to select the 12 most desirable tapping locations (depending on the wind direction), set up transducers, and begin recording. Set-up time was usually about 1 hour and recording usually continued for 1 to 3 hours longer. Of the results obtained on eight such trips between 5 March 1964 and 23 September 1966 five sets were selected for detailed study.

After visual examination of each strip chart record, portions representing recording intervals from 15 min to over an hour were selected and digitized, using a semiautomated procedure, at time intervals of 1 sec. The digitized values, either on punched cards or digital magnetic tape, were then processed by a digital computer.

3. Differences Between Field Measurements and Wind Tunnel Measurements

The model scale investigations were made in a boundary-layer wind tunnel rather than in a conventional low-turbulence aeronautical wind tunnel because of the undoubted importance of modeling the gustiness of real wind. Care was taken to simulate field conditions as closely as possible, but in spite of this certain differences remain. As an example of the precautions taken, the model of building B was carefully machined from plastic to a scale of 1:400, including the mullions. Pressure taps were made at locations corresponding to those where full-scale taps on the two instrumented levels were situated, and three additional levels were tapped to give a more complete picture of pressure distribution than was possible in the field measurements. All major structures within a 1,600-ft radius were modeled to the 1:400 scale from wood, and upwind land contours and surface roughness were also simulated, as is shown in Figure 4.

A fundamental difference between the field measurements and the wind tunnel measurements is related to control of flow conditions and the reproducibility of an experiment. The main advantage of wind tunnel testing over full-scale testing is the fact that investigations can proceed systematically and efficiently. Full-scale measurements, on the other hand, are dependent on the random behavior of weather, making systematic investigations impractical. This is particularly true for such features as the phenomenon of extreme suctions near the corners of the buildings, for which wind angle is fairly critical.

3.1. Stationarity and Homogeneity of Flow

The basic difficulty associated with field measurements arises because of the random nature of wind. Not only is the acquisition of useful records made difficult and time-consuming, but the interpretation and comparison with laboratory results may become confusing. Much of the confusion can be avoided if a distinction is made between "weather" and "gustiness" on the basis of the time scales involved. The shortest period associated with weather changes and, in particular, strong winds is usually an hour or more, except for thunderstorms, whereas the longest period associated with gustiness is about 5 minutes. Thunderstorms may have to be treated somewhat differently from other types of strong wind storms.

The randomness of the gusts superimposed on the mean wind speed can be analyzed using statistical procedures developed over the past 20 years by communications engineers and others [12, 13]. These statistical procedures have been applied recently to wind effects on structures [8]. The application of established methods for measurement and analysis of random data is greatly simplified if it can be assumed that the wind is at least weakly stationary and homogeneous. This implies that the means and variances of wind velocity and pressures are con-

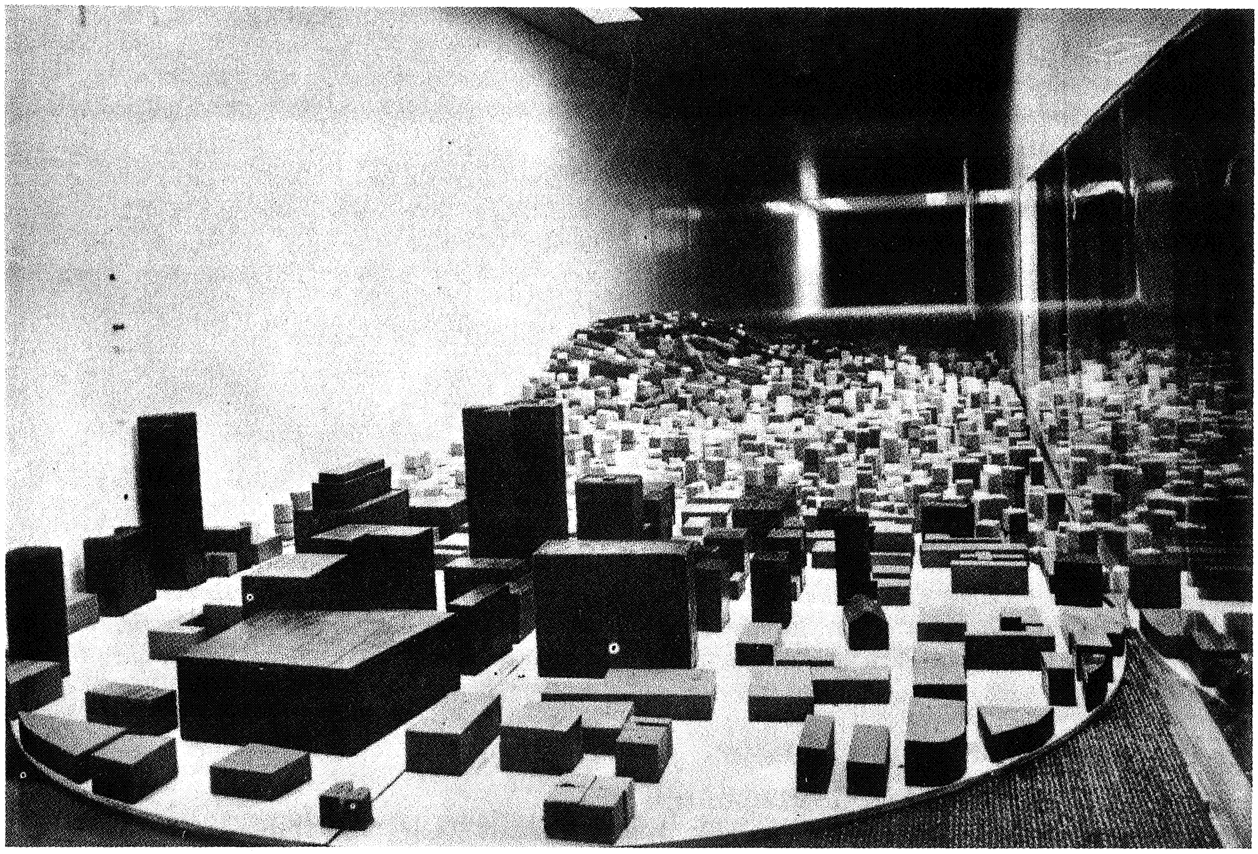

FIGURE 4. Model of downtown Montreal with major topographical features in the boundary-layer wind tunnel at the University of Western Ontario for comparison with full-scale measurements.

stant with respect to time and with respect to position in space. Stationarity and homogeneity hold only approximately for field measurements, if at all, and then only if care is used in selecting suitable portions of the total record for detailed analysis. In principle, it would be best to use as long a record as possible to improve the reliability of estimates of means, variances, and distributions of variances according to frequency (power spectral density). It was found, however, that portions of record much over 5 to 10 minutes often contained "trends" or variations in the mean value, and these complicated the analysis.

There was no particular difficulty in satisfying the requirements of stationarity in the wind tunnel, but in consideration of the objective of simulating field conditions it was thought more important to reflect the nonhomogeneities of the prototype situation rather than to have the theoretical advantages of the homogeneous flow. The land contours of the eastern end of Mount Royal were, therefore, modeled in order to introduce the same sort of spatial variation of velocity as might be found in the field (Fig. 4).

3.2. Time Scaling

The time interval over which mean velocities and pressures were averaged was chosen to distinguish between (a) the random fluctuations about the mean, and (b) the much slower variation of the mean wind velocity and the corresponding pressures in response to changing weather conditions. A scaling parameter with respect to time must therefore be considered when comparing field and model measurements.

For purposes of comparing averaging times the nondimensional parameter to be kept the same for model and full scale is:

$$\frac{Vt}{L}$$

where V = mean velocity in ft/sec,
t = time in sec,
L = characteristic length in ft.

The ratio of mean velocity in the tunnel to mean velocity in the field ranged from about 0.50 to 0.75, and the length scale for the model was 1:400. An averaging time of 30 min in field measurements would therefore be represented by a tunnel time of 6 to 9 sec. The averaging time actually used in the tunnel was 30 sec, and the length scale of the gusts proved to be approximately 1:700; the corresponding full-scale averaging time would be about 175 to 260 min, based on the scale of turbulence. A much longer averaging period can be used in the wind tunnel because the slow-moving trends associated with the weather system in the field situation are not present.

3.3. Reference Static Pressure

Wind tunnel measurements of pressures on a tapped model are expressed in terms of differences from a reference static pressure, divided by a reference dynamic pressure. The resulting nondimensional ratio, the pressure coefficient, is defined as follows:

$$C_{p_i} = \frac{P_i - P_o}{\frac{1}{2}\rho V^2} \qquad (1)$$

where C_{p_i} = pressure coefficient,
P_i = pressure at ith tap,
P_o = reference static pressure, lb/ft^2,
ρ = mass density of air, slugs/ft^3,
V = reference mean velocity, ft/sec.

The usual reference static pressure P_o is the ambient barometric pressure inside the tunnel, measured either at a flush wall tap or at the static side of a pitot tube mounted upwind of the model.

The reference side of each transducer in the field measurements was connected by a long plastic tube to the ambient barometric pressure at a point near the center of the 9th floor of the 34-story building. The reference tubing was present to ensure that all transducers were at least measuring with respect to a common reference pressure, even though it was not necessarily completely static.

The difference between the reference static pressure in the field and that used in the tunnel proved to be one of the most troublesome aspects of the comparison of results. The difference, of the same order of magnitude as the measurements themselves, was caused by a combination of factors:

(a) chimney action—the temperature differential during cold months, combined with the very considerable effective stack height, caused pressure differences of the order of 2 to 5 lb/ft^2;
(b) operation of the air-handling equipment—building pressurization of as much as 1 or 2 lb/ft^2 was common;
(c) wind effect—assuming an internal pressure coefficient of -0.3, the action of the wind could produce a lowering of the internal pressure by 1 or 2 lb/ft^2.

Simulation of these effects would be extremely complicated in the wind tunnel because of the very complex system of flow resistances and leakages throughout the building. As a result, no adjustment was made to the wind tunnel technique; a correction was made, instead, in the comparison of the pressure coefficients.

3.4. Reference Dynamic Pressure

The dynamic pressure of the reference mean velocity of equation (1) was measured in the wind tunnel at a height of 24 in. midway between building A and building B (see Figs. 1 and 2). This height corresponds to 800 ft in actual field measurement, but the pitot tube had to be moved away from building A to avoid the interference effect of the tunnel wall.

The use of this dynamic pressure as a reference in the wind tunnel should not seriously affect comparison, provided the spatial variation of velocity is small from building A to the pitot tube location, and similar in model and full scale.

4. Comparison of Field and Wind Tunnel Results

When the mean pressure coefficients, C_{p_i}, derived from the field measurements, were first compared with the C_{p_i} from the wind tunnel, allowance had not yet been made for the difference in reference static pressure. The comparison was consequently quite unsatisfactory. The effects of chimney action and building pressurization by the air-handling system were frequently sufficient to overcome the wind pressure on the windward wall. The transducers at all locations around the building therefore registered suctions in relation to the reference internal pressure.

A correction was then applied to the reference static pressure at each level for each of the records of full-scale measurements. Corrections were calculated using the least squares principle to produce the best fit of the full-scale pressure distribution to the model pressure distribution. This procedure seems reasonable as long as there is a definite correlation between the two sets of pressure coefficients and the deviations that remain after fitting appear to be small and random. It is interesting to note that corrections made in this way to the reference static pressure are independent of the dynamic reference pressure. The same correction of the reference static pressure (in lb/ft^2) is obtained even if completely different dynamic reference pressures are used in the wind tunnel and in full scale. The corrections arrived at by least squares fitting were checked in each instance and found to be consistent with approximate calculations of chimney action and building pressurization.

4.1. Comparison of Mean Pressure Distribution on 34-Story Building

The relation between full-scale and model mean pressure distributions in terms of the nondimensional pressure coefficients, C_{p_i}, is plotted for two different wind directions in Figures 5 and 6. The agreement in the first case (wind at right angle to building), particularly at the 33d floor level, is very good with regard to both distribution and scale. Many similar portions of record for approximately the same indicated wind angle gave equally good agreement in terms of pressure distribution, but no other sample was as close to the model results in terms of dynamic pressure, which governs the scale of the pressure distribution.

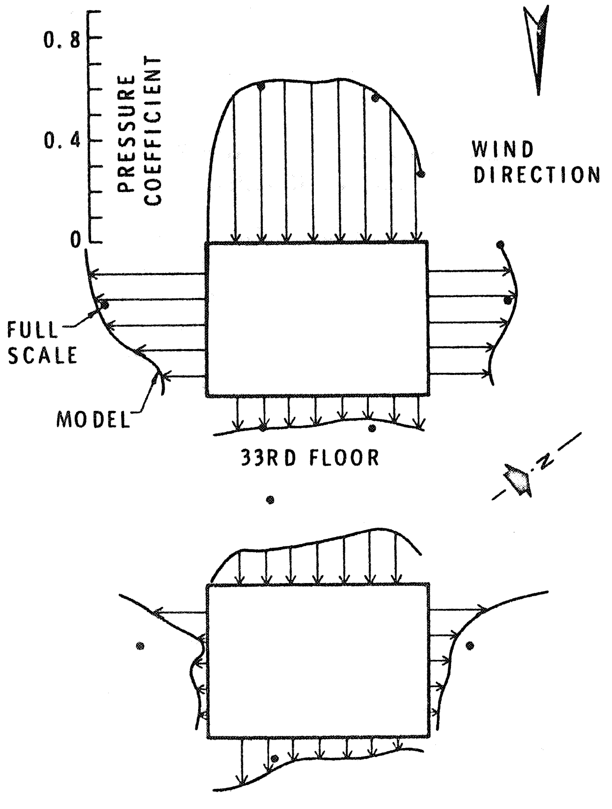

FIGURE 5. Comparison of full scale with model results; mean pressure coefficients on 34-story office building, northwest wind.

Figure 6 does not show the same agreement for distribution. The probable explanation for suction on the southwest wall of the 33d floor in the full-scale result is that the indicated wind direction at building A (where the anemometer and vane are located) may have differed by perhaps as much as 10° from the actual wind direction at the building. If such a difference existed it was evidently not simulated by the model.

4.2. Comparison of Mean Pressure Distribution in the Empire State Building

Agreement between wind tunnel tests and full-scale tests, unless it is either uniformly good or com-

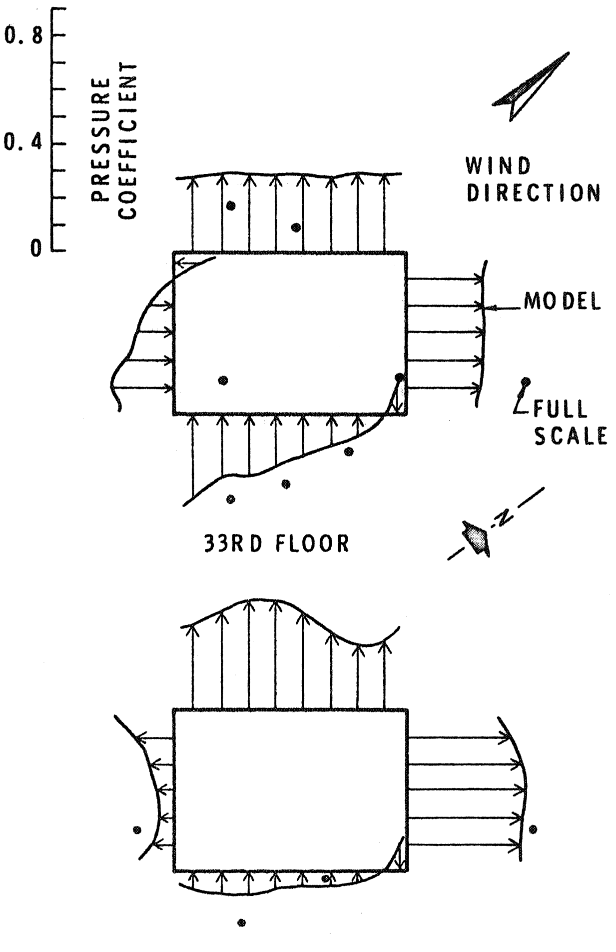

FIGURE 6. Comparison of full scale with model results; mean pressure coefficients on 34-story office building, south wind.

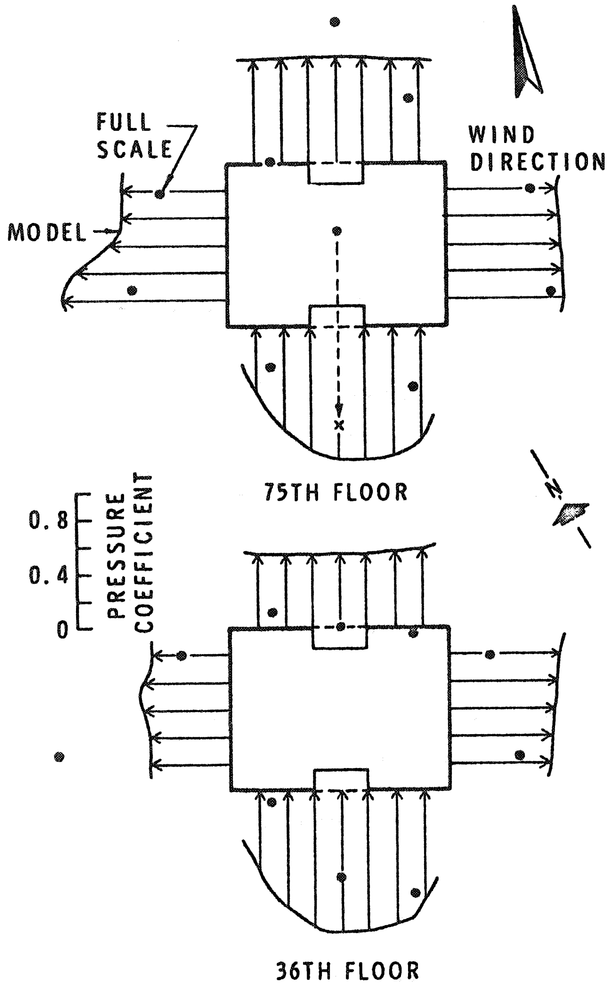

FIGURE 7. Comparison of full scale with model results; mean pressure coefficients on Empire State Building, SSW wind (from Rathbun, Dryden, and Hill).

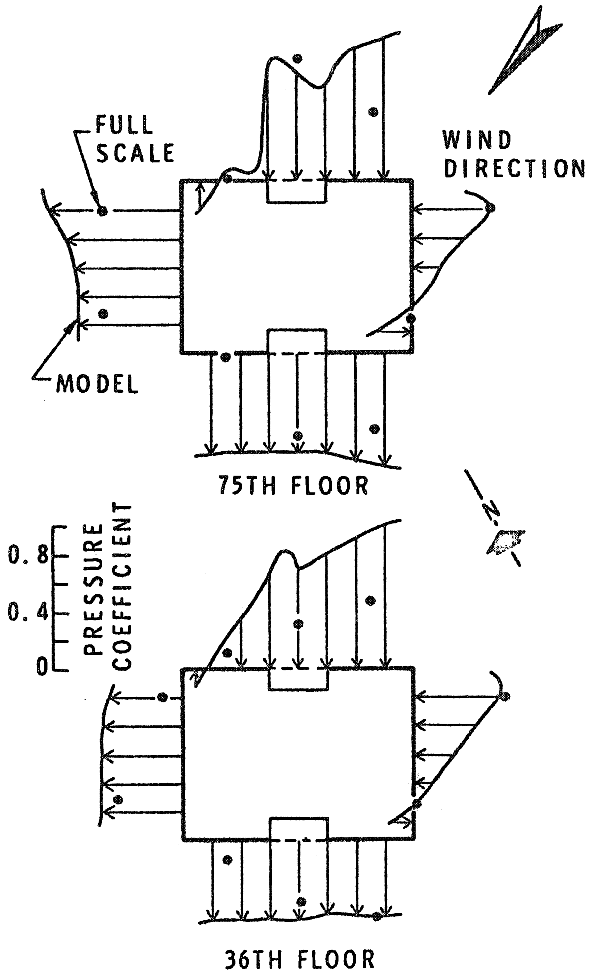

FIGURE 8. Comparison of full scale with model results; mean pressure coefficients on Empire State Building, ENE wind (from Rathbun, Dryden, and Hill).

pletely unsatisfactory, is hard to assess in objective terms. To help establish some perspective for making at least a subjective assessment of the results the author studied comparisons made by others who had done full-scale tests [5, 6].

Of particular interest were measurements on the Empire State Building, reported nearly 30 years ago by Rathbun [14]. The wind tunnel tests for this building were carried out at the National Bureau of Standards and the results were presented in 1933 by Dryden and Hill [15]. No comparison of the pressures on the model and those on the building was presented in the paper by Rathbun, presumably because there appeared to be very little agreement.

The author therefore made several comparisons similar to the two illustrated in Figures 5 and 6 for the 34-story building. Agreement was poor for some of the "items" tabulated by Rathbun. There were, however, other items for which the agreement in pressure distribution was good, except that the scale (i.e. the reference dynamic pressure) seemed considerably smaller for the full-scale results. The two examples given in Figures 7 and 8 were chosen to parallel as closely as possible the examples of Figures 5 and 6. One reading on the 75th floor in Figure 7 seems to be a clear case of mistaken sign, and has been plotted at its probable value as a cross.

The deviations from the model pressure distributions in Figures 7 and 8 are rather larger than those in Figures 5 and 6, and the scale is consistently smaller. The improved agreement of the recent comparison can be attributed to improvements in both the instrumentation of the full-scale building and the modeling techniques used in the wind tunnel.

The disparity in scale of the work on the Empire State Building probably results from use of a constant velocity profile and the absence of terrain roughness or the shelter of other buildings in the wind tunnel. A similar difference in scale would no doubt have been found for the Montreal building if the effects of terrain roughness and the other tall buildings nearby had not been simulated. Thirty years ago pressures were measured by **U**-tube manometers, either by observers or by photographing the manometer banks; in either case it was difficult to get an accurate record of mean pressures. Much of the scatter and disagreement of the results must have been caused by gustiness in the wind that could not be accounted for in the analysis of the records. Modern data acquisition systems now make it possible to distinguish between mean and gust readings to a large extent and to treat mean and fluctuating components separately.

4.3. Analysis of Fluctuating Components

For purposes of analysis the fluctuating component of a record of wind speed or pressure versus time is treated as a stationary random process. The parameters estimated by analysis of the records are useful for determining equivalent static loads or for estimating the probable number of load cycles at different stress levels. It is consequently a matter of considerable importance to demonstrate agreement between full-scale and model results for parameters relating to the fluctuating component such as standard deviation, or rms pressure coefficients, and power spectral density as a function of frequency.

Agreement of shape and location on the frequency axis of the power spectral density curve implies a proper scaling of the turbulence in the wind tunnel. Figure 9 is a combined plot of both full-scale and model information for the pressure records obtained at a corresponding tap location on the 33d floor on the windward wall. An empirical curve based on wind speed data, suggested by Davenport, is also shown. The scale of turbulence was probably about 1:700 in this particular model test, and did not therefore agree with the length scale of the building (1:400). The ratio of velocities happened to compensate for the difference to a large extent, and as a result the spectral peaks appear to occur at approximately the same reduced frequency.

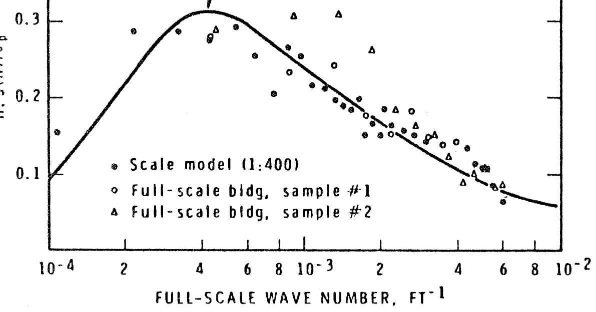

FIGURE 9. Sample power spectral density curves obtained from both model and full-scale experiments on an office building in Montreal.

5. Evaluation of Field Measurements

The sample comparisons in Section 4 are fairly representative of the sort of agreement that has been found between wind tunnel tests in a boundary-layer type wind tunnel and measurements of wind pressure on the full-scale building in Montreal. The need for considerably more full-scale information is indicated although the results can be considered encouraging in many respects.

5.1. Suggested Improvements

Several improvements in instrumentation and data processing can be suggested on the basis of experience with that part of the project now completed. There is merit in recording data in a visual form, such as an oscillograph chart, for pilot studies or short-term projects. For the main part of an investigation, however, data processing should be handled by computer. The data acquisition should therefore employ punched cards, paper tape or magnetic tape storage, compatible with computer input requirements.

A second improvement would be an automated system for initiating recording whenever suitably strong winds occur. Approximately five of eight trips to Montreal produced successful runs in the project just completed but many good storms were undoubtedly missed because of insufficient forewarning.

The third suggestion for improved procedure concerns the scheduling of wind tunnel tests. One of the weaker areas of field installations is often the acquisition of wind velocity records. On the one hand, one can strive for more and better anemometer sites; on the other, maximum use should be made of the wind tunnel in searching for those conditions, particularly angle of attack, that best simulate a particular field experiment.

Measurements of building accelerations, strains in columns, or deflections can provide valuable information about the integrated effect of wind over the whole structure, and comparisons can be made on models articulated at the base and suitably adjusted for damping and period of vibration.

The separation of wind effects into a mean component and a superimposed fluctuating component made the analysis and the comparison between model and full scale much easier to understand. It was necessary to apply a correction to the reference static pressure for the mean component of the pressure, and the difference in time scales had to be taken into account in dealing with fluctuating components.

5.2. Approximate Costs

The part of the project involving measurements on the 34-story building covered the period from spring 1964 to approximately December 1967. The overall cost for the 4 years was approximately $100,000. Of this, instrumentation, including installation, maintenance, and field trips accounted for $30,000, engineers' and technicians' time about $60,000, and computer processing at standard commercial rates $10,000.

6. Conclusion

Wind pressure measurements are now under way in the building marked A in Figures 1 and 2. This is a 600-ft high office building with a much more open exposure, particularly to the southwest. A new data acquisition system incorporating most of the suggested improvements has been installed at a cost of nearly $40,000, and arrangements are being made to record the particle velocity of the top of the building. The main objective, as in the previous measurements, is the gathering of essential field data for the development and checking of wind tunnel techniques so that eventually they can be used with confidence for the determination of wind effects on buildings and structures.

Field measurements on the 34-story office building could not have been made without the permission of the owners. The Division of Building Research is grateful to Dorchester University Holdings Limited for their cooperation. Many people have contributed in various ways to the project; all are appreciated; in particular, the efforts of Mr. W. von Tobel deserve special recognition.

The wind tunnel tests were made at the University of Western Ontario Boundary-Layer Wind Tunnel under the direction of Dr. A. G. Davenport and N. Isyumov. Their interest and assistance is gratefully acknowledged.

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