**Zeitschrift:** IABSE reports of the working commissions = Rapports des commissions de travail AIPC = IVBH Berichte der Arbeitskommissionen

**Band:** 3 (1969)

**Artikel:** Effects of wind

**Autor:** Newberry, C.W.

**DOI:** https://doi.org/10.5169/seals-5007

**Loads and Other Acting Forces; Statistical Data; Probability of Unfavourable Combinations of Forces**

Les sollicitations; données statistiques; probabilité des sollicitations défavorables

Äussere Belastungen; statistische Werte, Wahrscheinlichkeit für das Auftreten ungünstiger Belastungskombinationen

PART — PARTIE — TEIL

**Effects of Wind**

Effets du vent

Windeinflüsse

C.W. NEWBERRY
Great Britain

voir page 111 / siehe Seite 111 / see page 111

Leere Seite
Blank page
Page vide

**Loads and Other Acting Forces; Statistical Data; Probability of Unfavourable Combinations of Forces**

Les sollicitations; données statistiques; probabilité des sollicitations défavorables

Äussere Belastungen; statistische Werte, Wahrscheinlichkeit für das Auftreten ungünstiger Belastungskombinationen

PART — PARTIE — TEIL

# Effects of Wind

Effets du vent

Windeinflüsse

C.W. NEWBERRY
Great Britain

Developments in structural design methods over the past decade have led to a situation in which further progress is now often limited by the quality of the loading data available to the designer. Among these data, wind loads are important for the majority of structures, and may be of paramount importance in some cases, and yet data on wind loads are seldom adequate.

Investigation of wind damage has shown that wind forces are frequently greater than has been assumed in the past, and it appears that many buildings have survived wind storms only because they have an in-built strength that is greater than was called for in their design. The extra strength and stiffness contributed by members that were considered to be non-loadbearing, and by cladding, has helped provide a margin of safety beyond what was apparent, and it is this hidden reserve which has in some cases masked a deficiency in the designed provision for wind load. With more sophisticated design procedures now available and coming into use, there is a danger that the hidden reserves of the past may be eliminated in current and future construction. It is therefore imperative that a new and realistic assessment of the probable imposed loads should be undertaken without delay.

Wind loads used in structural design have been based on the results of experiment by many persons working under many different circumstances. The work of Sir Benjamin Baker[1] in the 1880's in connection with the estimation of wind loads for the Forth Bridge and subsequent early work by Irminger[2] in Copenhagen and some by Stanton[3] at the National Physical Laboratory was carried out partly in the natural wind, but the difficulties inherent in taking measurements in a wind flow that is far from steady soon led to a widespread recourse to model testing in wind tunnels where the wind flow was steady and controllable. The problems to be faced in the determination of wind loads, and the recognition of the differences between conditions in the natural wind and those in the tunnel, were enunciated in considerable detail by Irminger and Nokkentved[4] in 1930; but nevertheless the assumption that the results of such model tests could be applied to full scale buildings has been widely accepted with some reservations for many years, and most codes of practice for wind loading now current are based on model tests in smooth flow. Recent work has shown, however, that there may be important differences between what has been generally measured in the wind tunnel and the loads that are significant in the design of structures, and this present review centres largely on recent attempts to ensure that the estimation of wind load is as realistic as possible.

Prior to the past decade there were three main sources of error in most wind tunnel measurements of structural loading. These were as follows. First, the tests were made in uniform smooth flow whereas the natural wind has a vertical gradient of velocity and is turbulent. Secondly, apart from a few notable exceptions, it was usual to test isolated models, ignoring the influence of neighbouring structures; and thirdly it was, and still is, general to take time - averaged load and pressure measurements over time intervals that often mask the significant transient loads which occur in practice.

It is really only in the last few years that serious attempts have been made to simulate in the wind tunnel the gradient of mean velocity which occurs in the natural wind.

There are of course difficulties in knowing what gradient to simulate since the gradient varies with the nature of the surface roughness of the ground and its superinposed vegetation and structures, but broad guide lines have now been established. The data are most complete for open country conditions and derive largely from the work of Sherlock(5)(6) and Deacon(7) and from compilations by Davenport(8) and Shellard(9). In the first 300 m. above the ground the mean wind speed may be assumed to increase with height, following a power law

$$\frac{V_z}{V_{10}} = \left(\frac{Z}{10}\right)^{\alpha}$$

where $V_z$ is the wind speed at height Z. The value of $\alpha$ may be taken as 0.17. It is to be noted however that the exponent for gusts is about half this and is generally taken at 0.085.

As the surface roughness increases with the presence of trees and buildings, $\alpha$ for mean winds increases to about 0.20 over well-wooded farmland and parkland, and to about 0.25 over major cities, but the exponent for gusts remains at about 0.085 except within the general building layer and about 20 m. over it. Within this zone there is considerable variation in wind speeds from one site to another and some uncertainty as to the optimum basis for design. Detailed investigation of the gust profile has been reported by Arakawa and Tsutsumi(10) for the city of Tokyo, and by Shellard(11) for several sites in the United Kingdom, including one in central London.

Baines(12) demonstrated the significant differences produced in the pressure distribution on a tall rectangular building when a velocity gradient was introduced into the wind tunnel, and many others have presented evidence on a range of structures, so that now it is accepted that the effects of velocity gradient must generally be taken into account when pressure distributions are measured. Figure 1 shows a comparison between the distribution of pressure over the windward face of a slab block under (a) uniform flow and (b) flow with a velocity gradient. It is evident that the effect of the velocity gradient is very significant.

Turbulence has long been recognized as a feature of the natural wind, and indeed common experience reveals a wide spectral band of turbulence ranging from small eddies spanning only a few centimetres, and passing in a fraction of a second, to major disturbances that may span hundreds of kilometres and have a time period measured in days. The significance of turbulence in its effects on wind loads has not however been widely recognized until comparatively recently and data are still sparce. Difficulties arise, first from a lack of adequate knowledge of the turbulence characteristics of the wind in the boundary layers that are of most interest to builders, and then from the current inability to reproduce appropriate turbulence linked to a velocity profile in the wind tunnel. This latter problem must be overcome before any considerable volume of data on turbulence effects can be made available.

There are several aspects of turbulence that need to be considered. It has been shown by full scale measurement of wind pressures on buildings that the pressure distribution in turbulent flow differs from what has been found in smooth flow in wind tunnels. Newberry, Eaton and Mayne(13) found a marked reduction in the leeward suction on a tall rectangular building in central London as compared with a model test of the same building, and the same effect has been found by Jensen(14) in measurements on a model house in the natural wind. This effect of turbulent flow has been confirmed by Vickery(15) in wind tunnel experiments in which some turbulence was introduced into the tunnel flow, but Vickery showed that there are limitations to the circumstances in which a reduced drag may be experienced, and Bearman(16) showed that on thin plates the drag can actually be greater in turbulent than in smooth flow. In consequence of this, any reduction of calculated wind load to take account of turbulence must be applied with caution until the subject has been more fully explored.

Apart from the effect of turbulence on the general flow characteristics and pressure distribution around a building, there are two features of turbulent flow that need to be considered. Both follow from the basic fact that in turbulent flow the load on a structure or element is varying with time. The first of these features deriving from the turbulence is the peak transient load that may be imposed by a single discrete gust or eddy on a structure or part of a structure whose natural period is short compared with the gust duration. The second feature is the dynamic loading which may be developed as a result of resonance between the structure and the turbulence spectrum. This latter feature has been studied by a number of workers, prominant among whom are Davenport,(17) Vickery(18) and Harris(19). The methods developed for the calculation of dynamic structural loading due to wind will become increasingly valuable as more knowledge becomes available regarding the wind spectrum. For the present the technique is of value mainly in the case of the more flexible structures having natural periods of several seconds and longer, because it is only this part of the wind spectrum that has, up till now, been investigated sufficiently to provide a basis for calculation. Investigation of the higher frequency end of the wind spectrum has lagged because of the lack of adequate instruments with which to carry out a study, but some progress has been made recently in this direction, particularly by the Electrical Research Association, whose perforated sphere gust anemometer has a working range up to frequencies of about 10 Hz.

Since the great majority of buildings have natural periods of less than about 2 seconds, and their components and sub-structures typically have frequencies of several cycles per second, it is not generally feasible to investigate their dynamic response to turbulence because of the lack of knowledge of the appropriate part of the wind spectrum. It is for such structures, in particular, that it is important to take account of the peak transient loads that are produced by discrete gusts. Recent work at the Building Research Station(13) has indicated that gust loadings over an interval as short as one second may be highly significant on a major building. For example, on a building 60 m. high and having a frontage of 45 m. the total wind load measured over 3 seconds was 60 per cent greater than the load averaged over one minute which was the basic wind averaging time used in a number of codes of practice until recently. The significance of gust loading has been measured also by Dalgliesh et al[20] on a tall building in Montreal, and by Ishizaki[21] at the Disaster Prevention Research Institute at Kyoto, Japan, and is currently being investigated also by Prof. Mackey at Hong Kong University.

The second main deficiency in the wind tunnel results that are available to the designer is that the tests have generally been made on models in isolation from their environment. Bailey and Vincent[22] showed, as early as 1943, that wind loads on a building may be considerably influenced by other buildings in the vicinity but, owing possibly to the complexities of testing under any but simple conditions, little more has been done in this field until recently, and the effects of neighbouring buildings on wind loads are inadequately understood. An example of the difference in the pressure distribution on the windward face of a slab block when it is in isolation and when partially shielded is shown in fig.2. There are some scattered references in the literature to cases where the wind speed in the wake of a building has been markedly increased by the presence of the building, and there are many examples where a building suffers from turbulent buffetting induced by a neighbouring structure. Examination of storm damage has shown many cases where maximum damage has occurred within a building complex rather than at the windward periphery indicating an aggravation of the wind loading at positions which might have been considered to be sheltered. On the other hand, the measurements of wind load on a tall office block in London showed a marked reduction in load when the wind blew from certain directions that afforded what appeared to be only partial shelter.

In addition to the problem of whether shelter should be considered as a factor in the estimation of wind load, there is the matter of proximity effects to be taken into account. When the wind is channelled between buildings there is in general an increased suction on the walls that bound the flow. The effects are seen in the failure of the gable ends of houses built as semi-detached pairs with narrow gaps between them. A similar problem has been examined at the University of Toronto by Hamilton[23] who found that the negative pressure coefficient could be more than doubled as compared with that on a building in isolation. Other work on proximity effects has been carried out recently at the National Physical Laboratory, particularly in connection with the grouping of cooling towers, and studies have also been made of the mutual effects of pairs of tower blocks.

The third feature of most wind tunnel results that affects their direct application to practical design is that they are based on time-averaged measurements. As already indicated in the discussion of the effects of turbulence, the real wind is extremely variable with respect to time. Full scale measurements indicate that in the assessment of general loading on the face of a structure it is necessary to consider gusts that may have a duration of only a few seconds, while, in assessing loads on cladding units, transient suction loads of the order of 0.1 seconds are relevant, and these may be many times greater than the mean load on the element over a period of time. These transients on cladding appear to be the result of vortices generated by the building itself. It seems to be important that these transients should not be ignored in wind tunnel testing, but their measurement raises some difficult problems. The time scale in the wind tunnel may be typically about $\frac{1}{100}$ of full scale so that a time resolution of about 0.001 sec. becomes necessary on the model scale. Not only does this introduce instrumental difficulties, but it involves a considerable increase in the volume of data to be handled. However, the problems are being faced, and considerable progress has been made recently, particularly in the University of Bristol[24] where some promising comparisons have been made between model work and full scale.

From the foregoing it will be seen that there remains a considerable need to develop wind tunnel testing for structural purposes and, through an integrated programme of full-scale measurement, to ensure that there is adequate correspondence between model and full-scale results. It will never be possible to test more than a very limited range of full scale buildings and the wind tunnel must provide the data required by the designer for a whole range of building and structural shapes and in a wide variety of environmental conditions.

The investigation necessary is very considerable, and in spite of much that has been, and is being, done, there is need for a co-ordinated effort on an international scale. A starting point must clearly be to improve the meteorological data. It is required to investigate the spectrum of gustiness in strong winds to an upper frequency of at least 10 $H_z$, and to determine this and the velocity profile over the range of height which concerns the structural engineer and in the various environments such as open country, suburbs and industrial complexes, and city centres. It is also necessary to investigate the principal effects of topography in so far as they modify wind speed, and to draw up some rules for guidance as to the effects of hill and valley configuration on design wind speeds.

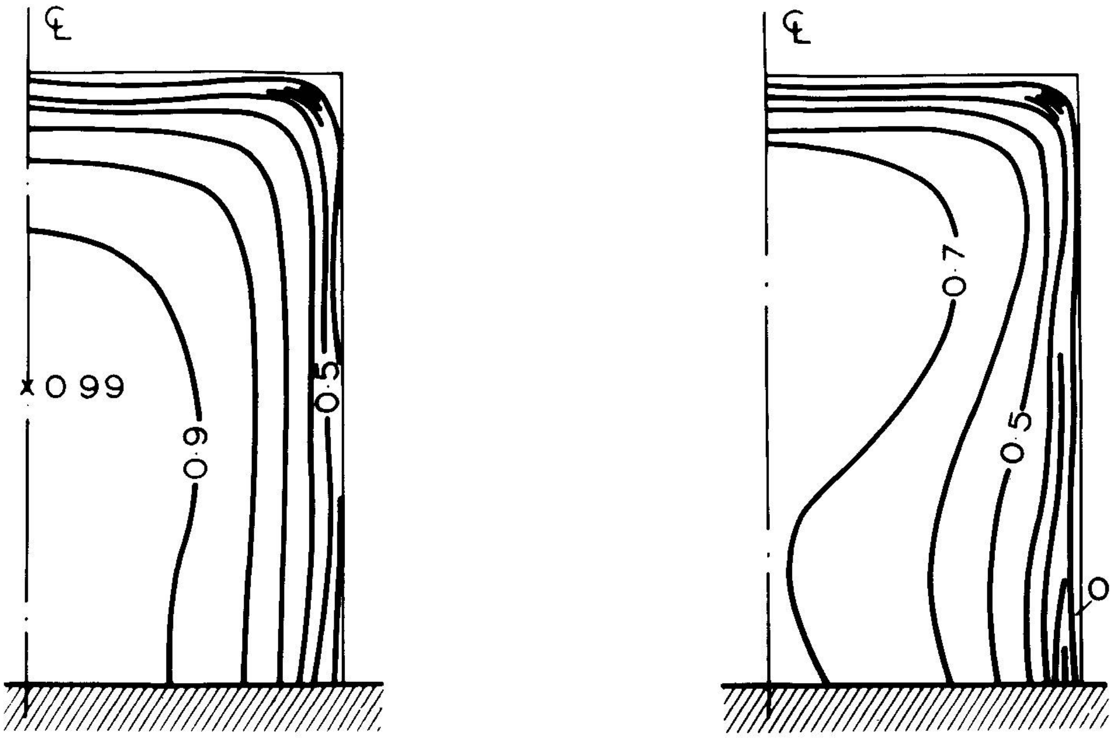
The determination of pressure and force coefficients on selected structural shapes in a variety of turbulence conditions should be undertaken at full scale, and at the same time measurements should be made of the structural response for correlation with the dynamic characteristics of the structure.

Incorporated also into the programme should be some investigation of the effect of shelter by other buildings. The correlation of this programme with a model programme is imperative to ensure a proper development of model techniques. The stage is then set for a comprehensive investigation of pressure coefficients on the model scale to provide design data for a wide range of buildings and structures in a variety of environements.

In spite of the known imperfections in the data currently available, the techniques for applying wind date for structural design have been considerably improved in recent years. Most of the technologically advanced countries have re-drafted their codes of practice to take account of recently acquired wind data and to present them in a form that enables the designer to take account of the various differences of structural form and environment that distinguish one project from another. This diversity of loading undoubtedly calls for more expertise from the designer, but it enables him to design with the maximum economy linked with safety. Changes in the techniques for calculating imposed loads do lead to the suggestion, however, that as load estimation becomes more exact, so the load factors in design codes need to be adjusted to conform to the new standards. The two processes must indeed go along in step with each other so that the profession may derive full advantage from the improved data available.

## Acknowledgement

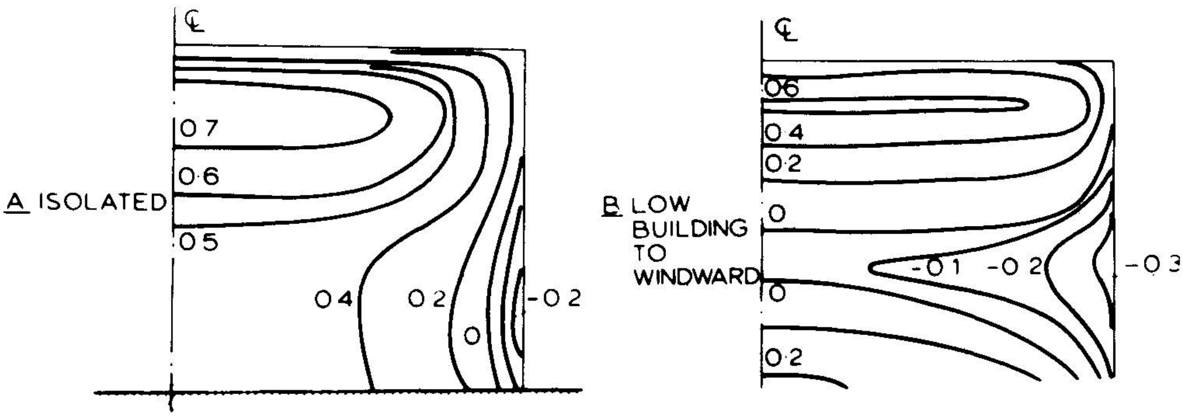
This paper was prepared as part of the programme of the Building Research Station and is published by permission of the Director.




A. NO VELOCITY GRADIENT

B. WITH VELOCITY GRADIENT

1. Comparison of $Cp_e$ distribution on windward face of slab block in (a) uniform wind flow (b) flow with velocity gradient (67.479.4)




2. Pressure distribution on the windward face of a slab block (a) in isolation (b) with a low building to windward. (67.479.3)

## References


(1) Baker, B. The Forth Bridge, Engineering vol.38 (1884) pp. 213-215 and 223 - 225

(2) Jensen, M. Introductory Lecture, International Research Seminar on Wind Effects on Buildings and Structures 1967. Proceedings, Vol.1. University of Toronto Press 1968

(3) Stanton T.E. Report on the measurement of the pressure of the wind on structures, Proc.I.C.E. vol.219 (1925) pp.125-158

(4) Irminger, J.O.V. and Nokkentved Chr., Wind pressure on buildings, Ingeniorvidenskabelige Skrifter A Nr.23 Copenhagen (1930)

(5) Sherlock,R.H. Variation of wind velocity and gusts with height. Trans. ASCE paper 2553 (1953)

(6) Sherlock,R.H. The nature of the wind Proc. ASCE Vol.84 No. ST4 (1958)

(7) Deacon,E.L. Gust variation with height up to 150 m. Quart. J. Roy.Met.Soc. London Vol.81 (1955)

(8) Davenport,A.G. Rationale for determining design wind velocities. Proc. ASCE Vol.86 no ST5 (1960)

(9) Shellard H.C. Wind records and their application to structural design - Met.Mag. Vol.96 (1967) pp. 235-243

(10) Arakawa,H.and Tsutsumi,K. - Strong gusts in the lowest 250 m. layer over the city of Tokyo. J.App.Met. Vol.6 (1967) pp.848-851

(11) Shellard H.C. Results of some recent special measurements in the United Kingdom relevant to wind loading problems - Wind Effects on Buildings and Structures Vol.1 paper No.19 Univ.Toronto Press (1968)

(12) Baines W.D. Effects of velocity distribution on wind loads and flow patterns on buildings. NPL Symposium - Wind Effects on Buildings and Structures. Vol.1 HMSO (1965) pp 198-223

(13) Newberry,C.W., Eaton, K.J., and Mayne,J.R. - The nature of gust loading on tall buildings - Wind Effects on Buildings and Structures Vol.1 paper No.15. Univ. Toronto Press (1968)

(14) Jensen, M. Model-scale tests in turbulent wind (Part II) Danish Technical Press - Copenhagen.

(15) Vickery, B.J. Load fluctuations in turbulent flow J. ASCE Feb. 1968 EM.1. pp.31-46

(16) Bearman, P.W. Some effects of turbulence on the flow around bluff bodies. Proc. Symposium on Wind Effects on Buildings and Structures. Loughborough Univ. Technology (1968) Paper No.11

(17) Davenport,A.G. Gust loading factors ASCE Environmental Engineering Conference Dallas, Texas (1967)

(18) Vickery, B.J. On the assessment of wind effects on elastic structures - Civil Eng. Trans. (Australia) Oct.1966 pp.183-192

(19) Harris,R.I. The effect of wind on some simple structures Proc.Sym. on Wind Effects on Buildings and Structures - Loughborough Univ.Tech.(1968) Paper No. 15

(20) Dalgliesh,W.A., Wright,W., and Schriever, W.R. Wind pressure measurements on a full-scale high-rise office building - Wind Effects on Buildings and Structures Vol.1 paper No.6. Univ.Toronto Press (1968)

(21) Ishizaki,H., and Murota,T. - The duration of wind pressure on walls and its distribution Prevention of Disaster Research Institute, University of Kyoto (1966)

(22) Bailey,A., and Vincent,N.G.D. - Wind pressure on buildings including effect of adjacent buildings J.Inst.Civil Eng. 1943

(23) Hamilton, G.F. Effect of velocity distribution on wind loads on walls and low buildings Univ. Toronto Dept.Mech.Eng.TP6205 (1962)

(24) Lawson, T.V. Measurement of rapidly varying pressures Proc.Sym. on Wind Effects on Buildings and Structures - Loughborough Univ. Tech.(1968) paper 33

SUMMARY

Improvements in design and construction techniques are reducing the hidden reserves of strength in buildings. It is therefore necessary to have a better knowledge of actual loadings.

Deficiencies in the current basis of wind load estimation are examined, and recommendations are made to provide realistic assessment of the effect of the characteristically turbulent wind.

RESUME

Le développement dans les méthodes théoriques et de construction a réduit les réserves de résistance cachées des bâtiments. Par conséquent, on a besoin de connaissances plus avancées des charges effectives.

La déficience des connaissances actuelles dans l'estimation des charges du vent a été examinée, et on a recommandé une évaluation réelle de l'effet caractéristique du vent turbulent.

ZUSAMMENFASSUNG

Die verborgenen Kraftreserven von Gebäuden werden durch Verfeinerung der Entwurfsmethoden und der Konstruktionstechnik vermindert. Es ist daher notwendig, die wirklichen Belastungen genauer zu kennen.

Die Mängel der jetzigen Grundlagen für die Schätzung der Windkräfte werden hier untersucht und es werden Empfehlungen für eine realistische Einschätzung der Wirkung des normalerweise turbulenten Windes gemacht.