

Technical Note No. 5

WIND TUNNEL TESTING

This Technical Note is one of five on wind loading for the window and cladding industry. The series comprises:

- TN 2 Introduction to wind loading on cladding*
- TN 3 Wind loading on wall cladding and windows of low-rise buildings*
- TN 4 Issues relating to wind loading on tall buildings*
- TN 5 Wind tunnel testing*
- TN 6 Pressure equalisation*

Introduction

The estimation of wind effects on and around building structures is not an exact science and the guidance given in BS 6399: Part 2 is a conservative simplification of the pressures expected over a range of building structures. It is because of the unpredictability of the wind and the difficulties of conducting full-scale experiments, that the method of wind tunnel testing has evolved. These methods of assessment are considered to be of much greater direct use to the designer and are the only practical way of determining wind loads on the structure before construction.

In many cases, the justification for model tests is to obtain data which allows the position and size of the structural components to be optimised. The degree of optimisation depends on how well and how early the tests are integrated into the design process:

- At worst - when the design is already complete - tests only serve to verify the adequacy of the design;
- At best - when tests are made before the external shape is finalised - the data can be used to modify the shape to reduce the wind loading.

When wind tunnel tests are necessary

BS 6399: Part 2 states:

'Wind tunnel tests are recommended when the form of the building is not covered by the data within this Standard, when the form of the building can be changed in response to the test results in order to give an optimised design, or where loadings are required in more detail than are given in this Standard'.

A further situation where wind tunnel testing might be considered is when the building has an unusual site location, for example, where a building is in close proximity to other tall buildings, or the topographical features are capable of altering the upwind flow (this is explained in more detail in Technical Note 4 *Issues relating to wind loading on tall buildings*).

Properly conducted wind tunnel tests provide a tailored assessment of wind effects by accurately modelling both the building and its immediate surroundings to produce realistic simulation of the local wind conditions. In some situations this may be the only way that a building can have assured structural and environmental performance, and that economy of design may be realised.

The decision as to whether or not to undertake a wind tunnel study will be clear in cases where wind has a major influence on the design and/or the building is outside of the scope of the prevailing wind codes. In other situations the decision may be less clear and the potential benefits of testing must be justified, both technically and economically.

Commissioning wind tunnel testing

Many engineers and architects are not familiar with commissioning, and interpreting the results of, wind tunnel tests. Hence, wind tunnel tests are often used as a last resort to provide design data when adequate information can not be found from appropriate literature, historic data or codified designs. The wind tunnel tests can, however, be a very powerful tool and can play a much more effective role in the design process than simply quantifying the wind loads. The full potential of wind tunnel studies can only be fully realised when undertaken at the earliest stages of design. The shape of the structure will affect

the wind pressures on it, as will the massing of buildings in the development. Furthermore, the shape of the structure will affect the wind speed and direction of the flow around the structure and predominately make the difference between an environmentally-friendly designed site which does not create excessive wind speeds, to one which does, and dissuades people from using it as a result. The flow chart shown in Figure 1 shows the fundamental issues that need to be considered when the structure falls outside of the scope of the codified design guides.

Figure 1

If wind tunnel studies are commissioned at the conceptual design stage, the size and shape of the building can be optimised to take full advantage of the possibilities of avoiding high wind loads and wind speeds. The effects associated with these high wind speeds around tall buildings and the close proximity of surrounding buildings can potentially increase loads, due to flow interference effects such as wake formation at the rear of buildings and channel flow in confined spaces. The building orientation can also be tested in a number of configurations to maximise the benefits of shelter, both from surrounding built and natural features. Even when the basic form and orientation are fixed, there is still often scope for minimising wind effects through minor changes or additions to the design of the facade.

Wind tunnel techniques

For all wind tunnel testing it is essential to generate a mean velocity profile and scale and intensity of turbulence which are representative of those likely to be found at full-scale for the site under investigation. At full-scale, the turbulence is determined by the type of terrain upstream from the site and the degree of natural or man-made obstructions. A critical aspect of wind tunnel testing is the ability to model the surrounding topography and structures to the required scale, so that pressures on the building are accurately simulated. In the wind tunnel tests, turbulence is determined by means of:

- different size grids, to generate large-scale eddies,
- walls, to slow the air down at ground level, and
- long stretches of small roughness elements which generate the small-scale eddies.

It is the combination of these elements and their selected sizes which help simulate the air flow that would occur under real site conditions. The four criteria to consider at the design stage are:

- Up wind topography
- Local topography
- Surrounding buildings
- Building design/features

Wind pressures can be measured using pressure-tapped models which measure the localised pressure over an evenly distributed section of the structure, as illustrated in Figure 2. Each pressure-tap consists of a pipe set into the surface of the model which connects to a pressure transducer, allowing measurement of local wind pressures on the surface of the model at the position of the tapping. The measurements from each pressure tap are statistically analysed to give appropriate full-scale equivalent data, and the results used to draw contours of constant pressure over the building surface.

Figure 2 Tapping of a model building to measure air pressures

Wind tunnel models

Models vary from simple block models used when investigating environmental flow around structures through to pressure-tapped models which may incorporate several hundred taps. In all cases it is usual to model surrounding structures as simple block models in order to simulate any interactive effects which may occur between a building and its surroundings, and to make final adjustments to the boundary layer.

Flow visualisation

Flow visualisation techniques may be used to give a true feeling of the dynamics of the wind flow around the building under consideration and its surroundings. The principle aim of these tests are to:

- Determine flow direction on horizontal and vertical surfaces;
- Determine windy and sheltered areas on horizontal surfaces;
- Determine general flow patterns around buildings and groups of buildings.

Common visualisation techniques include:

- Particle erosion tests
- Smoke traces

The particle erosion tests principally work by covering the modelled area with appropriate fine particles (e.g. ground almonds) before the test and then examining the area of the model after the test to see where no particles remain. These zones can then be highlighted as potential windy zones which may be analysed in more detail before the structure is finalised. Smoke traces are used mainly for tracing the passage of smoke or chemical effluents to assess their potential effect on surrounding buildings, depending on the direction of the wind.

Assessment of wind action

Buildings and structures are immersed in the lower region of the earth's atmosphere, and within this region the wind is essentially random, varying both in time and space due to turbulence. This phenomena increases with increased roughness of the ground and the fluctuating wind generates pressures which vary in both magnitude and position. A typical pressure-time history plot of the wind would look like that shown in Figure 3, which illustrates the variation of pressure on the structure over a period of time. It is this fluctuating pressure that needs to be modelled if realistic pressures are to be measured on the building.

Figure 3 Typical plot of the variation of pressure with time

With codified design, the fluctuating wind pressures P are expressed in a non-dimensional time-average form as pressure coefficients (C_p) where:

$$C_p = P / \frac{1}{2} \rho V^2$$

where:

- C_p is the pressure coefficient
- P is the measured pressure
- ρ is the air density
- V is the mean wind speed at a reference height over the approach terrain

The pressure coefficient values are zoned across the front sides, rear and roof of the building for various building shapes and roof types. The codified zoned areas go some way to model the distribution of pressure over a building, which varies depending on the wind direction. BS 6399: Part 2 goes further and allows for modifications to the pressure coefficients to account for funnelling where buildings are in close proximity to each other and where excessive suction pressures are likely to occur between the building.

It is because of the complexity of the wind flow around buildings that wind codes and standards have been derived exclusively from wind tunnel test data. Therefore, it is no surprise to learn that most wind loading codes allow the use of data from properly conducted wind tunnel studies in lieu of codified design.

Assessment of wind pressure data

The problem with trying to analyse the wind pressure over a building or cladding panel is to account for the large fluctuations of recorded pressures, as illustrated by Figure 2. The fluctuations with time on the wind-ward face show the variation in pressure at one point on the building. The pressure taps are used to distinguish between local and global coefficients which are expressed in non-dimensional terms to obtain appropriate pressure coefficient values for the purpose of design. A typical trace of pressure coefficient plot (C_{pe}) is shown in Figure 4 and for the purpose of analysis:

- C_p indicates the mean value
- C'_p indicates the route mean square value (RMS)
- C_p indicates the maximum (most positive) value
- C_p indicates the minimum (most negative) value

Figure 4 Typical trace of C_{pe} with time

In the case of analysing the loading actions, both the maximum (most positive) and minimum (most negative) pressures need to be considered. For the purpose of design, the load-time trace is taken over a period of time - typically one hour - from which the complete trace may be considered in its entirety. However, cladding design is based around a

three second gust period and the question of what part of the pressure-time plot should be used is common. It is considered inappropriate to design for the maximum positive pressure and the highest suction pressures for economic reasons; hence it is not appropriate to test for the peak value of the pressure-time plot because this will be distorted by the fluctuations over the recorded period. However, an alternative value that is considered more statistically valid is the route mean square value which gives a statistical method for indicating the pressure with the maximum likelihood of being experienced by the structure under consideration.

Conclusion

When using codes and design guides for assessing wind effects on structures there will always be an element of uncertainty due to their inherent simplification and generalisation which cannot take into account local architectural and topographical features and surrounding buildings. In general, codes give safe upper-bound values for the majority of structures but the level of uncertainty increases as the building's configuration deviates from the codified design. Properly-conducted wind tunnel tests provide a tailored assessment of wind effects by accurately simulating both the model and its immediate surroundings as well as the local wind conditions.

References

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