Wind Loading Codes: International Users' Perspectives

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Abstract

Most buildings are designed using wind loading codes rather than wind tunnel testing. This paper discusses some of the experiences of using a range of international codes in an international design practice. A comparison of wind loads predicted by a range of wind loading codes for two building types, a city centre tall building and an isolated low-rise building with a long-span roof, are then presented.

Introduction

Code-based predictions of wind loading may be used throughout the design of a building, or may just be used as an intermediate step before wind tunnel testing is conducted. Most buildings fall into the first category, with the decision to wind tunnel test usually being made on the basis of unusual form or size of the building. Perceptions of unusual form or size or the necessity for wind tunnel testing are also based on local experience and past experience of wind tunnel testing.

For example, in Hong Kong, as in the rest of the world, it is unusual to wind tunnel test residential buildings. In Hong Kong, however, most residential buildings are around 150 m high, a height that would almost guarantee wind tunnel testing in most other countries. In Hong Kong, with this percentage of tall buildings located around steep topography in a typhoon region, it would be reasonable to expect that there would be a very advanced wind loading code. In fact, the opposite is true and Hong Kong currently has one of most basic wind codes in the world.

Wind engineering education is still quite rare, and most engineers have no more education about wind engineering than a working knowledge of use of local codes. The extent to which engineers understand building aerodynamics is thus often directly related to the complexity of the code with which they are familiar. As the simplest codes are the ones which are the ones which are going to cover the fewest number of cases it is, perversely, the users of those codes who are least equipped to recognise where the code is not appropriate or to suggest alternative design approaches.

It is now common for overseas engineers to work on projects in countries with which they are not familiar. An example later in this paper is of a building in Beijing being designed by engineers in Sydney. At the initial design stage many engineers will use the wind design codes with which they are familiar to gain an initial estimate of loads and/or responses. Obviously to do this requires the input of a site-specific wind speed consistent with the code being used. If the use of a different code during initial design leads to significantly different results to the local code (which will most likely have to be used for design submissions) then this can have a significant impact on the design process. It is therefore important for design engineers to understand the limitations of any design codes that may be used. Similarly, knowledge of the limitations or conservatisms inherent in different codes informs the decision on where wind tunnel testing is necessary or where it can result in significant design economies.

This paper illustrates two examples of code calculations for different building types: a high-rise building in a densely built-up urban environment and a large-span low-rise structure in fairly open terrain.

Wind loading codes

Wind loading codes come in many shapes and forms, sometimes being stand-alone documents, sometimes part of larger loading codes and sometimes part of structural design codes (Figure 1).

Figure 1. Selection of wind loading codes used in this paper.

This paper does not seek to provide an exhaustive comparison of the features of different wind codes, as such information is readily available elsewhere (e.g. Holmes 2001, Kijewkski & Kareem 1998, Mehta 1998). However, some of the key features for engineers seeking to mix-and-match elements of different codes are highlighted below. These are the areas where potentially costly mistakes are often made.

Basic wind speeds and pressures. The starting point of any wind code is to define a basic wind speed or pressure. Some codes are based on gust wind speeds, some on 10-minute mean wind speeds, some on hourly mean wind speeds and some on fastest mile wind speeds. Alternatively, some codes use dynamic pressure as a starting point and this, again, may be expressed in terms of a mean or a gust value. It is vital the wind speed or pressure used is consistent with the code in terms of averaging time.

It is also common to find anomalies in the wind speeds between adjacent regions covered by different wind codes. An example of this is Hong Kong and Macau, with the Macau design wind pressures between 10 m and 30 m in height in open terrain being 40% higher than those in the Hong Kong code. This is partially due to the pressures in the Macau Code being nominally 200-year return period pressures compared with the 50-year pressures in the Hong Kong Code. However, a meteorological analysis suggests that the increase in pressure due to the increased return period should only be around 30% higher. Neither of these values are particularly consistent with analyses of typhoon data for the region. It is therefore important to use a wind speed that will be acceptable to the local regulatory authority, rather than a best-estimate wind speed.

Pressure coefficients. The pressure coefficients in wind loading codes are necessarily tied to the averaging time of the wind speed or pressure. Care needs to be taken, however, not to just use pressure coefficients from one code directly with another. For example, BS6399 gives clear zones of different pressure coefficients for use with a gust pressure to give cladding design pressures. AS/NZS1170.2, however, requires the pressure coefficients to be multiplied by a local pressure factor to reflect the variation in pressure over a surface. GB50009-2001 is based on a mean basic pressure, but the pressure coefficients are designed to be used with a gust pressure, another factor being introduced to convert the mean basic pressure to a gust pressure.

Some codes present nett pressure coefficients (e.g. Hong Kong) while most present external pressure coefficients that need to be combined with an internal pressure coefficient to determine a nett pressure. In this case, it needs to be remembered that the negative external wall pressures in codes refer to sidewalls. For wall pressures, the worst nett pressure is likely to occur from an opening in the windward wall causing a positive internal pressure with the negative external pressure on the side wall. In practice, this is quite likely to happen as areas of positive pressure are most likely to be struck by debris. On long-span roofs, however, the worst loading case is often caused by negative internal pressure that can lead to a nett downward wind force that acts in the same direction as the self-weight, live loading and any snow loading.

Dynamic response mechanisms. Most wind loading codes now have methods for calculating along-wind response of tall buildings. Of course, for slender buildings it is the cross-wind response mechanism that is most likely to result in the largest dynamic responses. This is covered by far fewer codes, and in a much more varied way than the along-wind response. As a result the predictions vary widely between codes. Interestingly, although the Chinese wind loading code does not cover cross-wind response, there is a section on this and a calculation method in the steel tall building code. Also, as this is a response mechanism with which many structural engineers and architects are unfamiliar (as it doesn't appear in many codes), the results of wind tunnel tests showing loads and responses larger than those given in code predictions can be the source of some disbelief. Most designers do not realise that wind codes do not always give conservative results.

Sample codes and example calculations

Calculations have been conducted using a range of codes for two example buildings: a high-rise building located in built-up terrain and a low-rise building with few surroundings. The codes used for the two buildings described below were:

ASCE7-98: The U.S. national standard for minimum design loads. This has since been replaced by ASCE7-02. This is based on a 3 second gust wind speed.

AS/NZS1170.2:2002: The Australia/New Zealand wind loading standard. This code uses a gust wind speed and contains both along-wind and cross-wind loading predictions. The cross-wind prediction mechanism is based on wind tunnel tests of isolated sharp-edge rectangular plan-form buildings.

GB50009-2001: The Chinese national loading code. This uses a 10 minute mean pressure and has an along-wind loading method.

Hong Kong Wind Code 1983: The current code of practice on wind effects in Hong Kong. This is the most basic of the wind codes examined and does not contain any dynamic response method, but assumes highly correlated gust loading. The code is based on gust pressures.

Draft Hong Kong Wind Code 2003: The current draft of the revised code of practice for wind effects in Hong Kong. It is expected to be issued by early 2004. Design wind pressures at upper levels have been reduced, and a dynamic response factor has been introduced using an hourly mean pressure as its starting point.

NBCC1995: The Canadian national building code. This starts with an hourly mean wind pressure and has both along-wind and cross-wind calculation mechanisms based on hourly mean wind speed. Unlike the AS/NZS code, the cross-wind prediction method is semi-empirical.

Example Building 1 – High-rise. The high-rise building is a 180 m high office building with plan dimensions of approximately 65 m by 33 m. The building is located in a densely built-up urban environment on Hong Kong Island (see Figure 2). The structure has a conventional reinforced concrete core and perimeter columns. Wind tunnel testing was conducted to investigate wind-induced structural loads and responses and local pressures on the building envelope. Based on past experience, it was expected that the wind tunnel tests would result in a reduction in structural loads.

It was also expected that cladding design loads could be decreased over large parts of the building, while identifying areas where pressures would be higher than code predictions.

Figure 2. Building 1 – October 2003.

The results of the comparison are shown in Figure 3. This shows along-wind base moments predicted by a range of codes, normalised to the wind tunnel test results. The basic wind speeds were all normalised to a given 10 m gust wind speed. The results show a high level of consistency between the codes. Each of the codes gives, as desired, slightly conservative results. The Canadian code predicts a higher load than other codes. for this city centre building.

The cladding pressure tests showed, as expected, a number of areas where pressures were under-predicted by codes, particularly near building discontinuities and around the base.

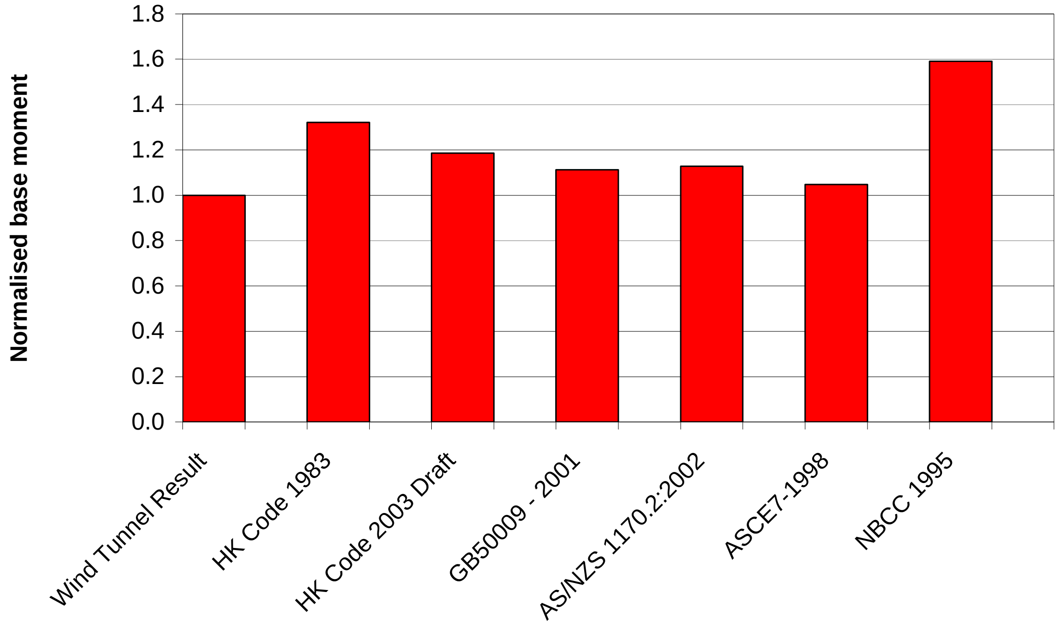

Figure 3. Comparison of along-wind base moments about one axis of Building 1.

Building 2 – Low-rise. Building 2 is a large sports building being designed in Beijing. It has dimensions of approximately 185 m by 185 m by 31 m (see Figure 4). The structure design is based on a common natural pattern, that of the natural formation of soap bubbles and was inspired by the solution of Weaire and Phelan (1994). Thus, the structure appears very organic and random, but is in fact highly repetitive and buildable. Although this is a relatively complex structural form, the exterior of the building is very aerodynamically simple, being a large cuboid.

The cladding initially proposed for the structure was bubble-like ETFE. The cost of ETFE is dependent on the number of layers of material and this led to a desire to predict as accurately as possible the areas of roof that would be subjected to high enough pressures to require more expensive panels. It is to be expected that wind code approaches would be fairly accurate for this type of structure. However, wind tunnel testing will be conducted in order that measurements can be taken to coincide with actual irregular cladding panels. At the time of writing, the wind tunnel testing had not yet been conducted.

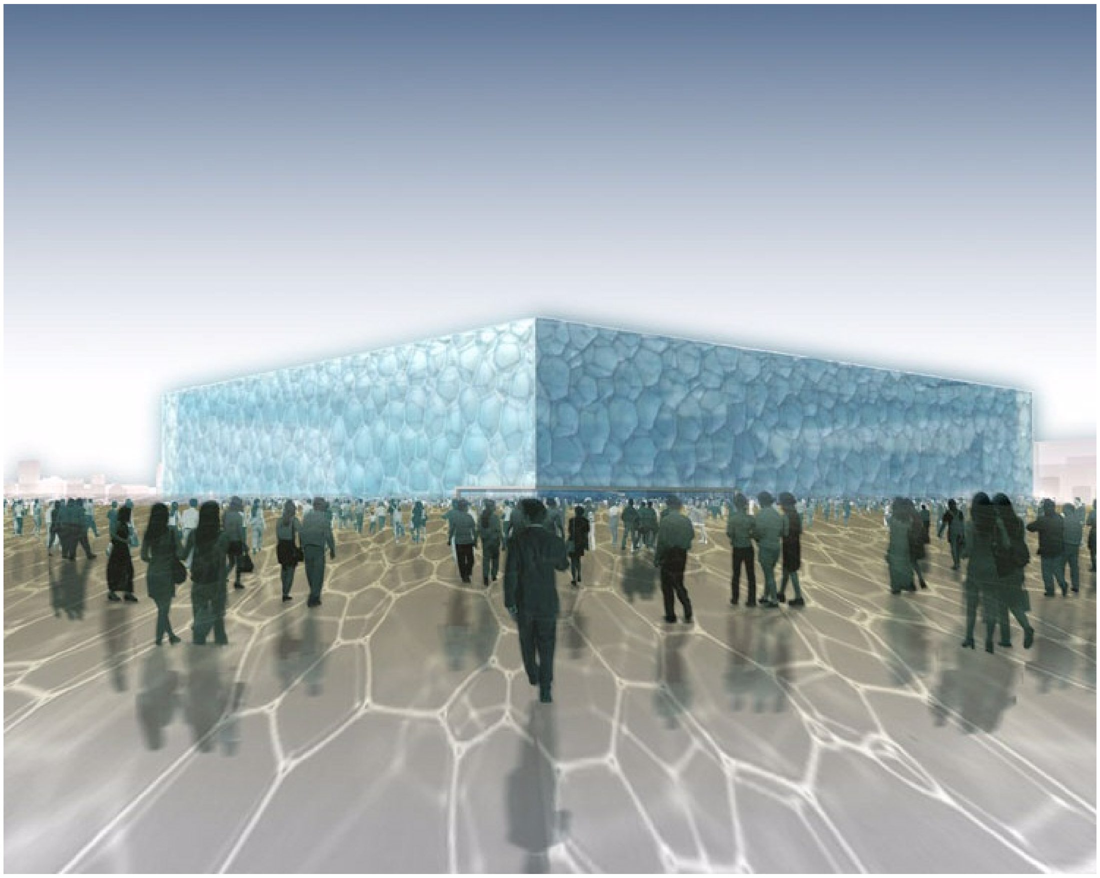

Figure 4. Building 2. (Picture © PTW & CSCEC)

Code comparisons of external pressure coefficients for cladding design are shown in Figure 5. These do not include an allowance for internal pressure, with the exception of the Hong Kong code in which only 'total' pressures are given based on an assumption of a fully sealed building. It can be seen that there are wide variations between the predictions from each of the codes. For cladding, ASCE7-98 has the most onerous loads near the corner of the building.

Most of the codes show only a narrow edge effect, with the exception of AS/NZS1170.2, which shows a gradual reduction in pressures across the building. The edge effect is designed to reflect the extent of the separation bubble over the roof. This is largely dependent on the height of the building, rather than its depth. It is expected, and hoped, that the wind tunnel tests will show a fairly narrow edge zone.

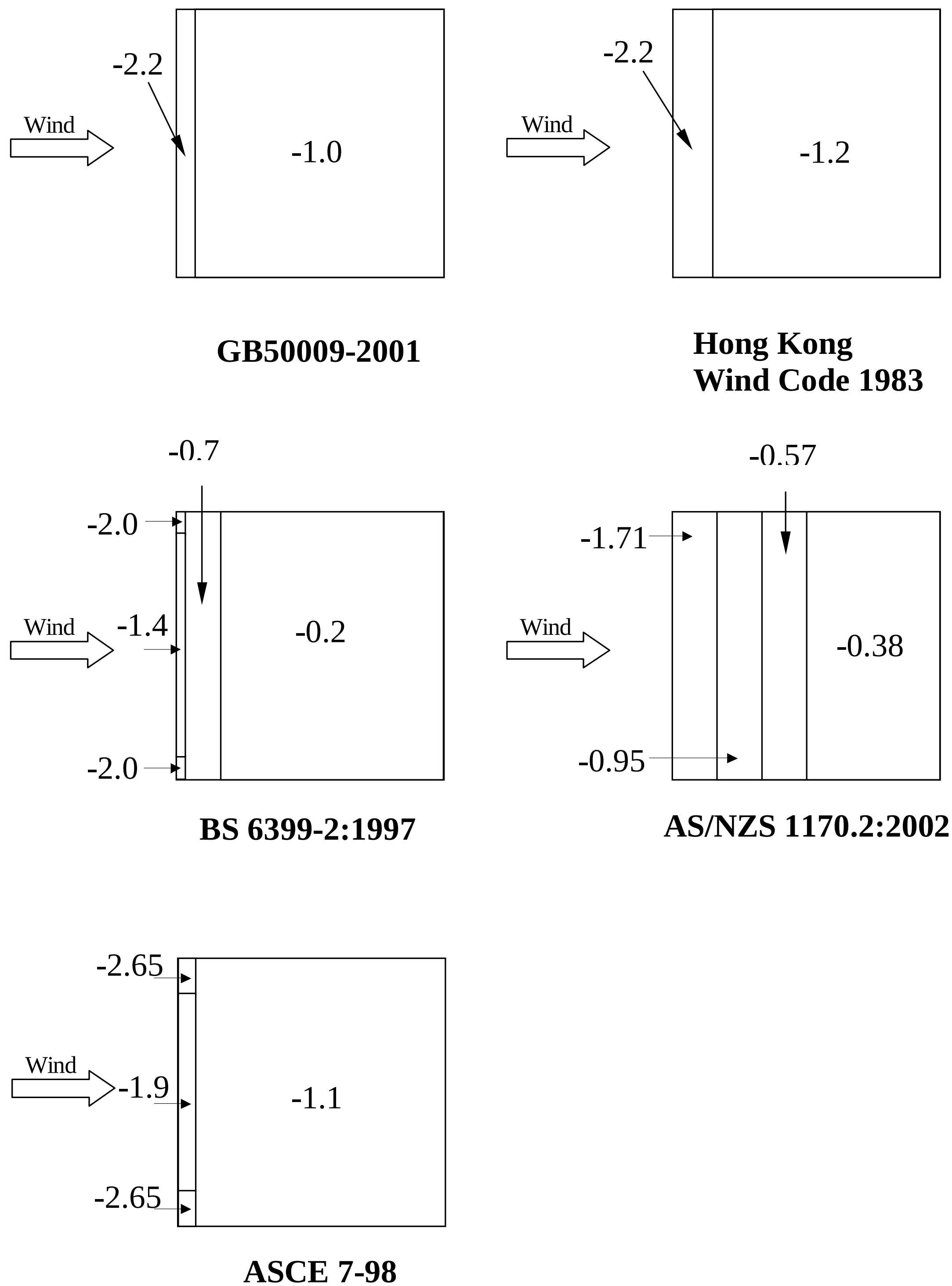

Figure 5. Comparison of local external pressure coefficients.

Conclusions

Consulting engineers working in an international environment often use a wide range of national codes and standards. Many are not familiar, however, with wind loading and find it difficult to combine elements of different codes. The differences in predictions between different codes can also lead to difficulties if the design code used for submission of design documents is not the one used for preliminary design. This paper describes some of the differences and presents examples of typical buildings for which code calculations have been conducted.

The authors commend current efforts towards international standardisation of code formats. This is a necessary step towards ensuring a consistent level of design performance around the world.

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