The Australia/New Zealand wind actions standard

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ABSTRACT: In this paper, the main changes in the new Australia/New Zealand Standard on Wind Actions, compared to the previous editions in both Australia and New Zealand are summarized. The methods used to define wind speeds and multipliers, aerodynamic shape factors and dynamic response factors are described.

KEYWORDS: Australia, New Zealand, wind loading, wind pressure, building accelerations.

1 INTRODUCTION

The Australian/New Zealand Standard on Wind Actions, AS/NZS1170.2:2002 [1], is the first joint Standard on wind loads for the two countries, and is intended to succeed AS1170.2-1989 [2] in Australia, and the wind loading part of NZS:4203:1992 [3] in New Zealand. It was issued in Australia in mid-2002, and Amendment No.1, with mainly typographical corrections, will be issued shortly. In this paper, the main features of the 2002 Standard, and the changes from the previous editions in Australia are summarized.

2 MAIN FEATURES OF THE NEW STANDARD

2.1 *Differences between AS1170.2-1989 and AS/NZS1170.2:2002*

AS1170.2-1989 gave three independent design approaches – a 'Simplified Procedure', and two 'Detailed Procedures' – for 'Static Analysis' and 'Dynamic Analysis', respectively. Being independent procedures, three separate wind region maps, and three sets of multipliers, for terrain and topography were provided. In the new Standard, a single design method has been provided. The idea of a 'simplified' method with higher specified wind loads as a consequence of the simplification, has been abandoned, after strong feedback that the former Section 2 was very rarely used by designers in Australia, primarily because of its conservatism. The simplified method was not offered in NZS:4203:1992 [3].

Structures such as tall buildings, with the potential to experience dynamic resonant response under wind action, are also not treated separately as in the previous Standards. Instead, resonant dynamic effects are dealt with through a 'dynamic response factor' (see Section 5 of this paper).

There are some changes in the external pressure coefficients for rectangular enclosed buildings (mainly affecting buildings with high-pitch gable roofs) and all of these coefficients are now referenced to the average roof height, unlike AS1170.2-1989, in which the reference height varied with the wind direction.

A new feature in AS/NZS1170.2:2002 is the introduction of a Load Combination Factor, K_c in Section 5.4.3 and Table 5.5 of the Standard.

The Appendices of AS/NZS1170.2:2002 contain some additional material on hypar roofs, communication antennas and flags, with some revisions to free walls and hoardings, and pitched-free roofs.

New guidance is given in AS/NZS1170.2 on the cross-wind (vortex-induced) response of slender chimneys and masts of circular cross-section. A new Appendix gives advice on calculation of the along-wind and cross-wind serviceability accelerations of tall buildings.

2.2 *Alignment with ISO4354*

It is the policy of the Australian Government and Standards Australia to adopt recognized International Standards, whenever possible. As a result of the policy, the format of AS/NZS has been made, at least partially, consistent with ISO 4354:1997 [4]. This is apparent in Equation 2.4(1) in AS/NZS1170.2:2002 which is similar to Equation (1) of ISO 4354. The differences in AS/NZS1170.2 are as follows :

- The use of the symbol 'p' instead of 'w' for wind pressure
- The dynamic pressure q_{ref} is not explicitly used in AS/NZS1170.2
- The exposure factor C_{exp} in ISO 4354 is not used in AS/NZS1170.2

The reason for not adopting the exposure factor C_{exp} was primarily that the effect of terrain, topography, shelter etc. are dependent on wind direction and cannot be expressed as a single factor in a directional standard such as AS/NZS1170.2. Also, the multipliers for these effects are applied directly to wind speed, not to dynamic pressure, as in ISO4354.

ISO 4354 is in the process of revision; this presumably will require a 're-alignment' of AS/NZS1170.2 with the new version. However, no decisions or progress in this direction have yet been made.

3 WIND SPEEDS AND MULTIPLIERS

3.1 *Wind speeds*

There are three different wind speeds in AS/NZS170.2:2002. These are defined as follows:

- V_R is the regional wind speed – the subject of Section 3 in AS/NZS 1170.2.
- $V_{sit,\beta}$ is the site wind speed – a function of the wind direction for eight cardinal compass points (Section 2.2).
- $V_{des,\theta}$ is the design wind speed obtained for the orthogonal wind directions with respect to the structural axes (Section 2.3).

The regional wind speed, V_R, is a 3-second gust wind speed in metres/second, as was the basic wind speed in AS1170.2-1989. Values of V_R are listed as a function of the return period, R, (equal to the reciprocal of the annual probability of exceedence), and the Region in Australia or New Zealand of the site in question.

The regional wind speed is defined at the standard meteorological height of 10 metres, in open country terrain (Terrain Category 2 in AS/NZS1170.2:2002). In estimating the return period, R, for a particular value of wind speed, no distinction has been made on the direction from which a wind gust originated. Thus, V_R is often known as an 'all-direction' wind speed.

A major difference between AS/NZS1170.2:2002 and the previous Australian and New Zealand Standards is that the return period, or level of exceedence risk, is not defined in the wind actions standard itself, for ultimate or serviceability limit states. Although there is some flexibility in choice by the user (i.e. by the structural designer in consultation with his/her client), guidance on the appropriate value of R is given in Part 0 of the suite of AS/NZS structural standards [5], and, in the case of Australian buildings, by the Building Code of Australia [6]. Note that the BCA is not concerned with any New Zealand structure, or with Australian structures outside its jurisdiction, such as broadcasting and communication towers. For most low-rise buildings, R will be taken as 500 years, and for most high-rise buildings (occupancy greater than 5000), R will be taken as 1000 years.

The Australian system of four regions, A to D, with basic wind speeds increasing from A to D, has not changed in the new Standard. However, a fifth Region W has been introduced to cover the Cook Strait region of New Zealand; the rest of New Zealand is classified as Region A.

Region A has been divided into a series of Sub-Regions A1 to A7 in the new Standard. These all have the same all-direction wind speed, but differ with respect to the wind direction multiplier.

The regional wind speeds for Region A given in AS/NZS1170.2:2002 have resulted from a re-analysis of recorded wind speeds from most of the meteorological stations in Australia [7] and New Zealand [S. Reid, National Institute of Water and Air Research – unpublished], including data collected since the publication of the previous standards. As an example of this analysis, Figure 1 shows a plot of wind speed versus return period for the Sydney region. By combining data from three stations, a database of over sixty years is obtained. The data were separated into wind gusts produced by short duration thunderstorms, or ‘downbursts’ (usually occurring during summer months), and those produced by larger scale gales or ‘synoptic’ winds (mostly during the winter).

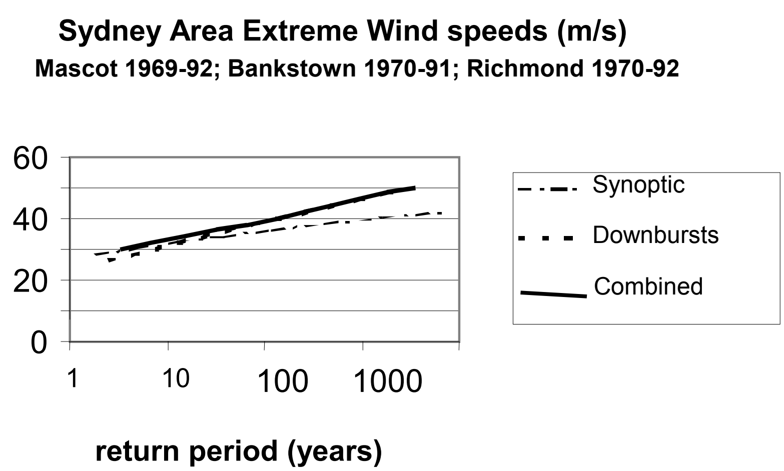

Figure 1. Extreme wind speeds for the Sydney area.

The site wind speeds, $V_{sit,\beta}$, for 8 cardinal wind directions (compass points) incorporate multipliers for directionality, terrain/height, shielding and topography. The square of the product of these multipliers can be regarded as a direction-dependent exposure multiplier as used in ISO 4354 [4].

i.e. $C_{exp} \cong [M_d\ M_{z,cat}\ M_s\ M_t]^2$ (1)

The multipliers, M_d, $M_{z,cat}$, M_s and M_t are discussed in some detail in the following section of this paper.

The design wind speed, $V_{des,\theta}$ for wind directions orthogonal to the structure, is obtained by selecting the largest value of $V_{sit,\beta}$ in a sector 45 degrees either side of the nominal direction, θ.

3.2 *Wind speed multipliers*

The wind direction multiplier, given in Section 3.3 of AS/NZS1170.2, accounts for the dominant, or prevailing, wind directions in the various Regions and Sub-Regions of Australia and New Zealand. For most parts of Australia and New Zealand, as for higher latitudes in most parts of the world, the dominant wind directions are generally from the western half. The Melbourne area (Region A5) is a special situation where strong northerly winds can be experienced especially during the summer months. The Wellington area (Region W) is dominated by the orientation and topography of the Cook Strait.

For Regions B, C and D affected by tropical cyclones, a single statistical direction multiplier of 0.95 is given for overall forces and loads in major structural elements. Since tropical cyclones can cross the coast either side of a site in question, and a single storm can produce winds over a range of wind directions, the prevailing direction effects from tropical cyclones are small (although there is a small tendency for stronger winds to come from the direction from which the storm is travelling – i.e. from the open ocean).

The terrain/height multiplier, $M_{z,cat}$, is largely unchanged from the previous Australian and New Zealand standards. The four terrain categories, defined in Section 4.2.1, are essentially identical to those in both AS1170.2-1989 and NZS4203:1992 (with only minor changes in wording). The numerical values of $M_{z,cat}$ are also identical to those in the old standards. As previously, there is a differentiation in values for non-cyclone situations and cyclonic situations.

The method of dealing with multiple terrain types for distances between one and four kilometres upwind of the structure (depending on the height of the structure), has changed in AS/NZS1170.2:2002. A simple averaging procedure is now given, instead of the sequential calculation at each terrain change required in the previous Australian Standard (but not in NZS4203:1992 [3]).

Although the wording in the section concerning the Shielding Multiplier M_s has changed in the new Standard, the applicability and method of calculation have not changed from the previous standards. Generally, for buildings less than 25 metres high, (for which the height z is normally taken as the average roof height, h, for calculation of wind loads on all walls and the roof), reduction for shielding is only obtained when there are upwind buildings of greater or equal height than the building in question. For taller buildings, reduction for shielding can be obtained from shorter upwind buildings, but only on the windward wall.

As in the previous standards, a default value of M_s of 0.85 is normally taken for houses in built-up suburban terrain, with upwind buildings at 'normal' spacings.

For elevated sites (over 500 metres) in New Zealand and Tasmania, the new Topographic Multiplier, M_t, is now the product of three terms, accounting for hill-shape (aerodynamic), mountain lee effects, and elevation effects. The Hill-shape Multiplier M_h is equivalent to the Topographic Multiplier in AS1170.2-1989. The second and third terms were in the New Zealand Standard, NZS4203:1992, but not in the previous Australian document.

The calculation of the Hill-shape Multiplier differs considerably from the method used for M_t in AS1170.2-1989. In the previous Australian and New Zealand wind load Standards, a table of multipliers applicable at ground level at the crest of the hill or escarpment, was given. These depended on the upwind slope, as well as the type of topography. Above ground level, that is at the calculation height, z, linear interpolation to a value of 1.0 at the top boundary of a ‘local topographic zone’ was specified. Horizontal interpolation upwind and downwind of the crest was also specified. In the new Standard, the hill-shape Multiplier is specified by two relatively simple equations. These can be programmed easily in a computer program or spreadsheet, and give a more realistic variation of the Multiplier with height, z. The correct variation has the Multiplier reducing with height at a much faster rate near the ground (i.e. low z) but ‘flattening out’ asymptotically towards 1.0 at greater heights. This variation is provided by the new formula (Equation 4.4(2) in [1]).

3.3 *Application to the Asia-Pacific Region*

Although AS/NZS1170.2:2002 has been developed primarily for Australia and New Zealand, it may be applied to structures in other countries, particularly in the Asia-Pacific area. Recognizing this, Standards Australia has published a Handbook HB 212-2002, [8], giving guidance on design wind speeds for nearly all countries in East Asia (including China), South-East Asia and Oceania.

In HB 212, five design wind speed levels I to V are defined, and every country or part of a country in the Asia-Pacific, is classified in that system. Nominal 50-year and 500-year return period 3-second gusts are provided for each of these levels. The top four of these levels (II to V) correspond approximately to the four basic Regions (A to D) of AS/NZS1170.2:2002.

Thus AS/NZS1170.2:2002 can be used together with HB 212, to generate design wind loads for any structure within the Asia-Pacific. However, as is made clear in the foreword to HB 212, this procedure is *not* intended to replace the statutory requirements for structural design in any country or jurisdiction.

4 AERODYNAMIC SHAPE FACTOR

The aerodynamic shape factor, denoted by C_{fig}, using the ISO notation, is obtained from Section 5 in AS/NZS1170.2:2002. Further information, for less-common shapes, is obtained from Appendices C to F.

4.1 *External pressures*

For external pressures on enclosed buildings, the basic relationship for the aerodynamic shape factor, C_{fig} , is given by the following equation :

$$C_{fig} = C_{p,e} K_a K_c K_\ell K_p \tag{2}$$

As noted previously, the external pressure coefficients are now used with a design wind speed at average roof height. This has led to some adjustment to the values of $C_{p,e}$ specified for the upwind and downwind slopes of buildings with high-pitch roofs, respectively. Recent studies of long buildings of high pitch, as used for sugar and mineral storage, for example, have shown that the loads on the framing near the ends of such buildings were greatly under-estimated by the coefficients in the previous Standards [9]. This has resulted in the considerable increases in the magnitude specified for the downwind slopes of long buildings with roof pitches greater or equal than 25 degrees.

Compared with the previous Standards, there has been a reduction in the positive roof pressure coefficients specified for the downwind end of flat, or near flat roofs, on the basis of wind-tunnel studies These positive pressures occur intermittently as a result of the reattached flow on these roofs, but have not always been recognized by other wind loading codes and standards.

The Area Reduction Factor, K_a, allows for a reduction in the peak wind loads on large areas of roof, or side wall, because the peak pressures (generated primarily by separating and reattaching flows) do not occur simultaneously on all parts of the roof. The factor reduces with increasing tributary area.

The combination factor K_c is a new factor in AS/NZS 1170.2:2002. K_c, with values between 0.80 and 0.95, is similar to K_a in that it allows reduction for the lack of correlation between fluctuating and peak pressures, having an influence on a load effect (for example a bending moment or axial force in a member or frame). In the case of K_a, the reduction is applicable to the pressures acting on a single surface – i.e. a roof or side wall; K_c is applicable when more than one surface is involved.

Although most other international codes and standards for wind loads do not include an equivalent factor to K_c, it is of interest to note that the current British Standard BS6399:Part 2:1997 [10], includes a reduction factor of 0.85 when combining loads from windward wall and roof surfaces with those from leeward surfaces, to calculate total horizontal wind loads.

The local pressure factor, K_ℓ, allows for the increased peak pressures, known to occur near the edges of roofs and side walls on buildings of all heights. These are essentially unchanged from the previous Standards. The tributary areas for the selection of the local pressure factor, K_ℓ, can be of any shape, provided their area satisfies the restrictions of Table 5.6 in AS/NZS1170.2:2002. Local pressure factors greater than 1.0 are only applicable to 'cladding, their fixings, the members that directly support the cladding, and the immediate fixings of these members'. This covers roof sheeting, and girts are included, but not columns or studs. This is a somewhat arbitrary division that has sometimes been questioned, as local pressures can sometimes have significant effects on major members such as portal frames, when their tributary areas are wholly or partially in zones near edges or corners of a building.

4.2 *Internal pressures*

There is little change of substance with respect to shape factors for internal pressures from AS1170.2-1989 and NZS4203:1992. However, an effort has been made to clarify the difference between 'permeability' and 'dominant openings'. The former refers to the inherent 'leakiness' of a surface caused by normal construction tolerances, and small openings included for ventilation reasons. The latter are large openings in a wall or roof surface, often accidental (such as a glass window failed by impact from flying debris, or a roller door failed by direct wind pressure).

The designer is expected to have some knowledge of the permeability and likelihood of dominant openings in a building envelope, in order to estimate internal pressures. In tropical cyclone areas (Regions C and D), the prevalence of windborne debris in severe storms is well-recognized, and it is normal to assume that large dominant openings in windward walls will occur. Dominant openings caused by windborne debris can also be generated in non-cyclonic regions, for example during thunderstorms, and users should consider the possibility of dominant openings due to open loading doors, for example. In these situations, large positive internal pressures may be generated.

4.3 *Shape factors for other shapes and structural sections*

Data required to calculate shape factors for shapes other than enclosed buildings of rectangular plan, and for structural sections is provided in several Appendices to AS/NZS1170.2.

Appendix C contains values of $C_{p,e}$ for buildings with multi-span roofs, curved roofs (i.e. arched and domed roofs), mansard roofs, and circular bins, silos and tanks. The only change of significance from the previous Standards is in the specified coefficients for curved roofs. The new table incorporates the important influence of the height-to-rise ratio (h/r), which was neglected in the previous standards.

Appendix D contains data on free-standing walls, hoardings, roofs and canopies. The shape factor, C_{fig}, comprises *net* pressure coefficients, $C_{p,n}$, and associated area reduction, local pressure, and porosity factors. For cantilevered roofs and canopies (e.g. grandstand roofs), a dynamic response factor, C_{dyn}, is also provided; this is applicable when the length exceeds 15 metres.

In the new Standard, there have been revisions to the values of $C_{p,n}$ for free-standing walls and hoardings, based on recent research. For oblique winds (45^{o} to the surface), the eccentricity of the resultant net pressure is given explicitly, and should give more realistic values for the wind-induced torque applied to the supporting structures.

The values of $C_{p,n}$ for flat free roofs (i.e. monoslope free roofs with zero roof pitch), pitched free roofs, have been changed in AS/NZS1170.2:2002 – usually smaller magnitudes are now specified. Additional data has been provided for hyperbolic paraboloid free roofs. When multiple values are given, it is important that all possible combinations of loads are considered, as the peak load distributions generating maximum horizontal forces, vertical forces and overturning moments, are generally different to each other (for example, see Reference [11], Appendix F).

Appendix E contains sectional force data for a variety of structural sections and members, including circular and rectangular sections. In addition, information on lattice towers has been incorporated. The latter includes data on ancillaries, including antennas, and correction factors for the aerodynamic interference between tower and ancillaries. Appendix F contains data on some three-dimensional bodies: flags and circular shapes like discs, spheres and hemispheres; this data is new in AS/NZS1170.2:2002.

5 DYNAMIC RESPONSE FACTOR

Section 6 in AS/NZS1170.2:2002 enables calculation of the dynamic response factor, denoted by C_{dyn}. This factor allows for an increase in effective wind loads as a result of resonant dynamic response (i.e. vibrations) induced by wind. In the case of along-wind response, C_{dyn} is calculated in Section 6.2, and used in combination with C_{fig} obtained from Section 5. However, for the cross-wind response of buildings, C_{dyn} is given only as a combination with C_{fig} in Section 6.3.

5.1 *Along-wind response*

The method of calculation of C_{dyn} for along-wind response is closely based on the Gust Factor calculation in AS1170.2-1989. However, there is a significant difference between the method in the new Standard and the previous version. In AS/NZS1170.2:2002, the Dynamic Response Factor acts on the quasi-static wind loads based on *peak gust* wind speeds, and gust envelope pressure distributions, whereas in AS1170.2-1989, the gust factor acted on the *mean* wind pressure distribution. In the previous Standard, a complete set of calculations for mean wind speeds with appropriate multipliers was included. This is not required in the new format, making several pages of the previous document now unnecessary.

Another advantage of the new format is that the factored gust pressure distribution obtained in the new Standard, is actually closer to the correct effective static load distribution [12] than is the factored mean pressure distribution in AS1170.2-1989.

A typical value of C_{dyn} for a dynamically-wind-sensitive structure is 1.1 to 1.2. A value greater than 1.0 indicates a significant contribution from resonant response. This is in contrast to the previous gust factor format, in which the value obtained (usually around 2) gave no explicit indication of the importance, or otherwise, of resonant response and the sensitivity of the effective loading to parameters like natural frequency and damping.

5.2 *Cross-wind response*

Cross-wind response in tall buildings, towers, and chimneys is caused primarily by the alternate shedding of vortices into the wakes of these structures (the 'dead' area downwind of a structure), with some contribution from turbulence, or gusting, across the general wind direction.

The cross-wind response of tall buildings and towers of rectangular cross section is specified in terms of an equivalent cross-wind static wind force distribution per unit height, and a base bending moment. These equations are based on the assumption of resonant response to random cross-wind forces at the design wind speed. The key parameter is the crosswind force spectrum coefficient C_{Fs}, which is given in both tabular and graphical forms. Actually, it is a generalized force weighted for a linear mode shape, and corrections are required for non-linear mode shapes. This quantity is a measure of the fluctuating cross-wind force (primarily due to vortex shedding) as a function of the reduced velocity, which itself is a function of the design wind speed and the structural natural frequency.

The maximum cross-wind response of slender structures with circular cross section, such as chimneys, lighting or utility poles and masts often occurs at wind speeds well below the design wind speeds for ultimate along-wind response. An equation gives a simple prediction formula for the maximum cross-wind tip deflection. This formula is derived from the assumption that the vortex-induced cross-wind excitation is *sinusoidal,* instead of *random* type as assumed in other parts of AS/NZS1170.2:2002. Another equation enables an equivalent static load distribution and hence stresses in the structure, to be obtained from the maximum deflection.

If large values of maximum deflection are obtained, it would normally be preferable to 'design out' of the situation using one or more of several possible solutions, such as increasing structural mass or damping, or by the use of auxiliary dampers, or aerodynamic devices, such as helical strakes, or shrouds.

5.3 *Accelerations for wind-sensitive structures*

Accelerations exceeding acceptable limits for human response at the top of tall buildings need to be considered for dynamically wind-sensitive structures. Appendix G in AS/NZS1170.2:2002 gives methods of estimating peak accelerations in both along- and cross-wind directions. These methods are based on the same assumptions used to derive base bending moments, as discussed previously. However, criteria for acceptable accelerations are not given in AS/NZS1170.2:2002, and must be obtained elsewhere.

6 DISCUSSION AND CONCLUSIONS

This paper has discussed the new combined Australia/New Zealand Wind Actions Standard that was issued in 2002. It is Part 2 of a complete suite of Standards for Structural Design Actions, that together are accepted by the Building Code of Australia for the design of occupied tions, that together are accepted by the Building Code of Australia for the design of occupied buildings in Australia. Part 2 will not be used in New Zealand until Part 4: Earthquake Actions is published (this part was available for public review in 2004).

The main changes in AS/NZS1170.2:2002 from the previous Australian Standard, and the current New Zealand one, are: some conformity with the terminology and notations of ISO4354:1997, and the use of a peak gust wind speed for all calculations, including dynamic response.

A Design Guide [13], intended as a companion to AS/NZS1170.2:2002, is in preparation. This will expand in more detail the material given in this paper, and, importantly for users, will feature many worked examples on the application of the Standard to all types of structures.

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