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Comparisons of EN1991-1-4 and AS/NZS1170.2, an end user's perspective

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Abstract

This paper is written by consultant engineers, that interact with both EN1991-1-4 and AS/NZS1170.2 on a daily basis.

Two issues are examined within the paper. The first is qualitative: What are the benefits/drawbacks of each standard from an end user's perspective? The second is quantitative: How similar are the outputs of each standard?

The findings offer an insight into the benefits and drawbacks inherent in both standards for the end user. There is also a discussion around features that would be of interest to practicing engineers in future versions of both standards.
This paper may help those producing loading standards better understand the needs of practicing engineers and to refine the content of standards accordingly.

Introduction

Structural design engineers will need to interact with wind loading standards during their career. Some designers will use wind standards every day, some will only have an occasional need to consult a wind loading standard. Whatever the need of the designer, it is essential that wind load standards offer clear and concise methodologies that allow the designer to arrive at safe wind loads.

This paper compares the features of EN1991-1-4 and AS/NZS1170.2, from the perspective of the structural designer. For simplicity, EN1991-1-4 is taken as the EN text, without reference to any National Annex. The paper also addresses how compatible the respective codes are for designers operating in both the European and Australian markets.

Part 1 - Qualitative findings

Design Life

At the beginning of the design process, a designer must decide the working life of their structure. Designers using AS/NZS1170.2 must refer to AS1170.0 and/or the BCA to establish the appropriate return period R. This value is then used to establish regional wind speeds.

In EN1991-1-4, design life is an input into the probability factor, c_{prob}. The value of c_{prob} will typically be 1 for structures of a 50-year design life. c_{prob} can also be readily manipulated for higher and lower design lives.

For the purposes of manipulating design life in calculation tools, the EN1991-1-4 methodology is more straightforward.

Wind Speeds

AS/NZS1170.2 provides the designer with peak gust wind speeds, based on a moving average time of approximately 0.2s. This moving average has been recently amended from 3s, based on the work of Holmes and Ginger, 2012.

The Eurocode provides the designer with characteristic 10 minutes mean wind velocity.

This paper will not delve into the respective merits of either system, but suffice to say the fact that there is a difference makes the codes less readily compared.

Wind Maps

The National Annexes to the Eurocode provide designers with contoured wind maps, to select their location specific wind speed.

A notable feature of the Australian Standard is the layout of the wind maps into regions. This regional layout has its' origins in the fact that the large parts of northern Australia are susceptible to cyclones.

Consequently, some of the wind speed changes between regions shown in Figure 3.1(A) of AS/NZS1170.2 are significantly more abrupt than the contoured maps of Eurocode National Annexes.

Terrain Roughness

Both standards assign specific roughness lengths, z_0, to Terrain Categories. However, the vales of roughness length and Terrain Categories do not agree between EN1991-1-4 and AS/NZS1170.2. As noted by Holmes (2012), "the four principle terrain categories chosen [in AS/NZS1170.2] were based on values of surface roughness that were judged to be appropriate for Australian terrain types. These may differ from other parts of the world."

Both standards offer a method for quantifying changing upwind Terrain Categories. The Australian Standard diagrammatic explanation for the transition of terrain categories is easier for the designer to follow than the Eurocode method outlined in Annex A.2. The addition of a diagram or mathematical expression in the Eurocode to accompany the written guidance would be a significant presentational improvement.

Topography/orography

Both codes offer similar definitions of hills and escarpments. The designer must assign fixed values to the topography, including the height of the hill, and also the upwind length of the hill. Both codes also give 3 different expressions for topographic effects depending on upwind slope. Once a designer has classified the various parameters relating to the hill and structures, calculating the multiplier is a straightforward task.

The Eurocode offers the designer 2 paths to finding the orographic factor, c_o, one using equations and the other using tables. The option to use tables is a welcome feature for designers looking for quick or preliminary values for c_o.

AS/NZS 1170.2 allows the designer to capture a local increase in slope at the peak, which the Eurocode does not. However, for very steep escarpments, AS/NZS 1170.2 can be extremely sensitive to the point the designer chooses as the base of their hill. Neither code gives clear guidance on how to determine the bottom of the hill, but the AS/NZS 1170.2 commentary does offer designers a useful suggested method.

The separation zone for the crest defined in AS/NZS 1170.2, does not feature in EN1991-1-4. This difference in approach can produces significantly different topographic factors for steep hills between the two standards.

Pressure Coefficients

An exhaustive comparison of different shape coefficients is beyond the scope of this paper. Both codes offer a similar range of pressure coefficients.

A feature of AS/NZS 1170.2 is the addition of a dedicated section for solar panels. This is a welcome feature for designers. Most designers welcome having such specific guidance by structure type, as do the authors.

Dynamic effects

AS/NZS1170.2 evaluates dynamic effects using the Dynamic Response Factor, C_{dyn}, while the Eurocode uses the Structural factor, c_sc_d. The Eurocode structural factor can be further subdivided into a size factor c_s and a structural factor, c_d,.

Both codes list structures that can excluded from dynamic effect. AS/NZS1170.2 gives a blanket exclusion for structure with a first mode natural frequency greater than 1Hz, while EN1991-1-4 offers a greater number of structures specifically excluded from dynamic effects.

The calculation of either factor is quite rigorous in comparison with codified calculations typically encountered by structural designers. The Eurocode provides the designer with more background on evaluating dynamic effects. The tables offered in Annex D of the Eurocode do give a designer a feel for typical c_sc_d values. Another useful feature of the Eurocode is to provide some guidance for natural frequencies within the body of the code itself, in Annex F. Designers using AS/NZS1170.2 must turn to the commentary for similar guidance.

However, it is the authors opinion that the AS/NZS1170.2 C_{dyn} factor is a more user friendly calculation in comparison with EN1991-1-4.

Dynamic effects do not lend easily lend themselves to standardisation, and both codes rightly highlight to structural designers that caution is required when dealing with dynamically sensitive structures.

Other Observations

Turbulence Intensity

EN1991-1-4 recommends equations for turbulence intensity in Section 4.4. These equations require the designer to decide on terrain category, orography and the turbulence factor.

$$I_1(z) = \frac{q\ (z)}{q} \qquad (1)$$

AS/NZS 1170.2 simply prescribes turbulence intensity values in Table 6.1. For the end user, these values are solely dependent on terrain category selection.

Minimum Wind Load

Neither code gives explicit guidance on what should be considered in a minimum wind situation. Guidance on minimum wind speed would be a welcome development, and would remove confusion for structural engineers who need to deal with very short duration, yet wind sensitive designs.

Part 2 – Quantitative findings

The commentary to AS/NZS1170.2 states the following; “It was recognized that the site exposure factors are universal in their derivation and for that reason they are kept separate. This arrangement provides for the direct comparison between national codes and, at the same time, allows for the site exposure factors to be used in other calculations.”

Therefore, the authors have elected to compare exposure factors in part 2 of this paper. AS/NZS1170.2 does not give an expression for the exposure factor in the standard itself but the commentary goes on to state the exposure factor “effectively equals the square of the factors covered in Section 4 $(M_{z,cat}M_SM_t)^2$. To account for the fact that the AS/NZS1170.2 regional wind speed is a short duration gust value, the Australian exposure factor, c_{exp_AS}, has been defined as follows:

$$c_{exp\_AS}(z) = (1.44.M_{z,cat.}M_t)^2. \qquad (2)$$

Using the parameters defined within the Eurocode, the European exposure factor, $c_{exp\_EC}(z)$ can be expressed as:

$$c_{exp\_EC}(z) = [1+7.\ I_v(z)].(c_r(z).c_o(z))^2 \qquad (3)$$

As terrain categories between the codes do not align, the authors elected to use the Terrain Category definition in AS/NZS 1170.2 as a baseline. The AS/NZS1170.2 definitions of terrain category have been used to calculate terrain roughness in both codes.

Terrain Category	Roughness Length, z_0(m)
1	0.002
2	0.006
3	0.2
4	2

Table 1: AS/NZS1170.2 Terrain Categories and Equivalent Roughness Lengths, z_o(m)

Case Studies

Comparative analysis for the exposure factors were undertaken for 3 site locations, two in Australia, one in Ireland.

In the case studies the same bottom of the hill and hill slope were deliberately kept constant in each standard.

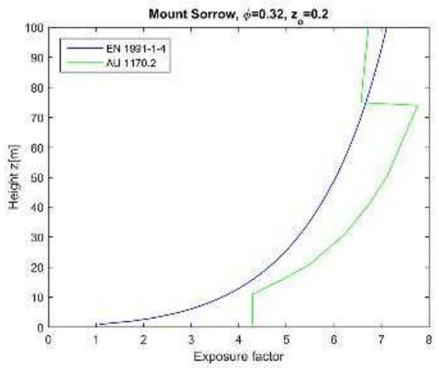

Figure 1: Comparison on exposure factors determined for Mt Sorrow Australia

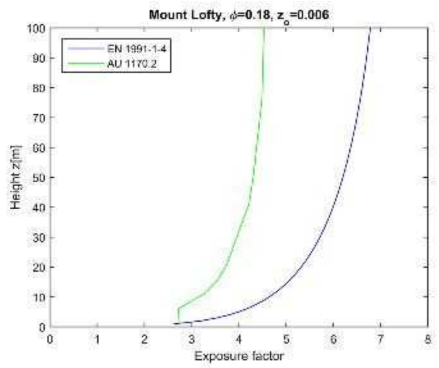

Figure 2: Comparison on exposure factors determined for Mt Lofty Australia

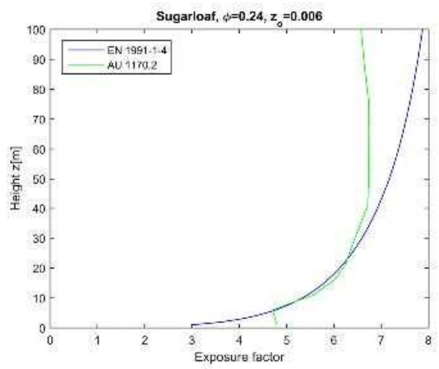

Figure 3: Comparison on exposure factors determined for Sugarloaf Ireland.

Simulations

It is apparent from the comparison of the exposure factors for the three sites displayed in Figures 1 – 3 that significant differences can occur in the exposure factors determined in accordance with each of the standards. To analyse this further we have directly compared the terrain and orographic/topographic multipliers for scenarios with similar roughness length, z_o.

It is apparent from Figure 4 that c_r and c_v converge to approximately the same value as the height, z, tends toward zero. However, as z increases so too does the difference between the two standards.

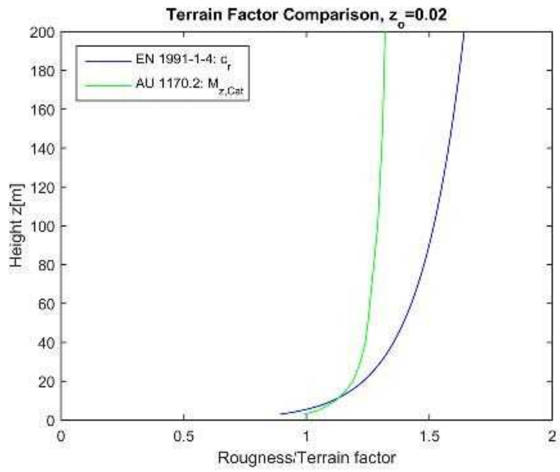

Figure 4: Comparison of Roughness, c_r, and terrain, $M_{z,cat}$, multipliers determined in for a roughness length, z_o =0.02, as a function of height, z.

Figure 5 compares the Orography, c_o, and Topography, M_t, multipliers determined for a similar roughness length, z_o =0.02, as a function of height, z. Yet again differences do occur, with EN 1991 providing a more conservative (higher) value in this instance.

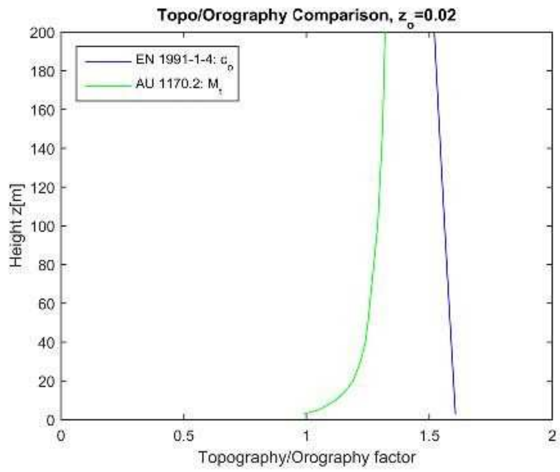

Figure 5: Comparison of Orography, c_o, and Topography, M_t, multipliers determined for a roughness length, z_o =0.02, as a function of height, z.

Figure 6 comparison of Orography, c_O, and Topography, M_t, multipliers as a function of slope for a simple hill. It is apparent from the figure that the magnitude of both multipliers converge to the same value at slopes of 0.05 or less. In this instance EN1991-1-4 is more conservative between slopes of 0.05 and 0.45 after which the AS/NZS1170.2 provides a higher value. The clear turning point in the graphs at slopes at 0.05, 0.3 and 0.45 can be related back to the equations describing the topographic multiplier and orography factor in the AS/NZS and EN standards respectively

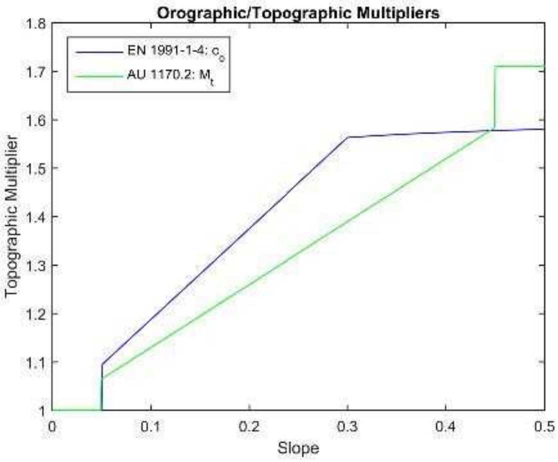

Figure 6: Comparison of Orography, $c_{o,}$ and Topography, M_t, multipliers determined in for a roughness length, z_o =0.02, as a function of slope for a simple hill.

Although the analysis is of an overly simplified in the scenarios considered in Figure 4 to Figure 6, it clearly highlights that differences in the predicted wind load will typically occur due to differences in the topography/orography and terrain factors in both standards.

Discussion

Desktop Study

From the 3 sites chosen for the desktop study, it is clear that c_{exp_EC}, will tend to be more conservative as height increases. This is consistent with the findings of Bashor (2015). At lower heights, AS/NZS1170.2 can be more conservative. This is due to the separation zone in the Australian Standard, and also the differing treatment of the upwind length when calculating topographic effects.

Further comparison of the multipliers within the respective exposure factors indicates that both terrain and topographic factors differ as a function of height and hill slope.

Topography/orography

There are clear differences in the approach to topographic multipliers between the standards. Also within each standard, there is much subjectivity, regarding the definition of hill height and hill slope. It is the authors' own experience that practising engineers can arrive at significantly different values for topographic multipliers when faced with the same site.

As noted by Flay (2015), neither standard provided adequate factors to account for the actual speedup measured at Belmont Hill, New Zealand.

Considering the fact that topographic effects have a major significance on the final wind load of structures located on hills, the authors feel more codified guidance on selecting the base of hills and for undulating terrain would be welcome additions to both standards.

Working across borders

This foreword to each Eurocode states the following:

"In 1975, the Commission of the European Community decided on an action programme in the field of construction, based on article 95 of the Treaty. The objective of the programme was the elimination of technical obstacles to trade and the harmonisation of technical specifications".

Over the past 12 months, the authors have worked on projects in multiple countries within Europe. There is no doubt that the Eurocodes have achieved their stated objective of removing technical obstacles to trade. Once an engineer becomes familiar with the structure of the Eurocode, and each relevant National Annex, the application of the code itself becomes a relatively mechanical process.

Many non-EU countries have now adopted Eurocodes. If Australia and New Zealand adopted Eurocodes it is the authors view that this would be a positive development for structural design engineers in both regions, and would improve collaboration and trade between Europe and Australia/New Zealand.

This adoption would seem extremely unlikely, as Holmes (2015) noted, "It is becoming harder to make changes to the Standard due to pressure from the many stakeholders, and the increase in bureaucratic procedures required to initiate a project to amend it."

Conclusions

EN1991-1-4 and AS/NZS1170.2 undoubtedly share a broadly consistent approach in arriving at wind loads on a structure. However, both codes differ significantly in a number of specific areas such as regional wind speeds and the calculation of topographic effects.

For the practising engineer, these differences can create obstacles to utilising codes. As noted by Bashor, "Globalization of the construction industry and the development of unified international codes and standards intensifies the need to better understand the underlying differences between the major international wind loading standards.". Considering the deep economic ties between Europe and Australia, closer alignments of the respective codes would bring many benefits to structural designers.

References

Bashor R., Kareem A., (2009) Comparative Study of Major International Standards

EN 1991-1-4 (2005) (English): Eurocode 1: Actions on structures – Part 1-4: General actions – Wind actions

Flay R.G.J, Nayyerloo M, King A.B., Revell M, (2015) Comparison of Wind Speed Hill-shape Multipliers Calculated by Seven Wind Loading Standards with Full-scale Measurements

Holmes J.D., and Ginger J.D. (2012) The gust wind speed duration in AS/NZS 1170.2, Aust. J. Struct. Eng., Vol. 13, pp 207-217

Holmes J.D., (2015) AS/NZS 1170.2 – Past, present and future

Holmes J.D., Kwok K.C.S, Ginger J.D. (2012) Wind Loading Handbook for Australia and New Zealand, Australasian Wind Engineering Society, AWES-HB-001-2012

Standards Australia, Structural Design Actions. Part2: Wind actions, Australia/New Zealand Standard AS/NZS 1170.2:2011 (including amendments 1,2 &3)