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Journal of Wind Engineering
and Industrial Aerodynamics 95 (2007) 1053–1064

JOURNAL OF
wind engineering
AND
industrial
aerodynamics

www.elsevier.com/locate/jweia

South African wind loading specifications: The Euro way?

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Abstract

This paper is a review of the development process of a new set of wind loading stipulations to be included in the proposed South African design standard for buildings and structures. A summary of activities that have taken place within the past 5–6 years is given, and the feasibility and implications of adopting the proposed EN 1991-1-4.6 are considered.

Keywords: Wind loading codification; South African wind loading code; Application of Eurocode

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1. Introduction

Like any loading to be considered in the design of structures and their elements, wind is a statistical quantity. In particular, its variation with respect to time and space is pronounced, and comparable to other environmental loads—such as snow or earthquake. In order to cope with such properties, design codes of various countries have developed individual systems for the loading to be adopted in designing for structural safety.

The current South African loading standard, SANS 10160-1989, was developed in the mid-1980s, with its wind loading stipulations, which form a substantial portion of the code, based on the old British Code (CP3, 1952).

In 1998, the South African National Conference on Loading took place. The aim of the conference was to provide a national discussion forum on loading specifications and to initiate a process which, in long term, would lead to the adoption of a unified approach to the design of structures. During the conference, various aspects of loading were reviewed,

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doi:10.1016/j.jweia.2007.01.017

and a need for an update as well as re-alignment with modern international codification was confirmed.

An overview and a comparative assessment of several wind loading stipulations were presented (Goliger et al., 1998), and a set of principles for future revision was proposed. A broad analysis of international codes (Goliger et al., 1998; Goliger and Niemann, 1998) has shown that, within the 10 years preceding the conference, several international wind loading standards underwent significant transformation and improvement. These standards were successful in adopting and codifying modern scientific thinking, as well as recent information obtained from a multitude of full-scale and wind tunnel studies carried out across the world.

As one of the outcomes of the conference, a National Loading Committee under the auspices of the South African Institute of Civil Engineers (SAICE) and the South African Bureau of Standards (SABS) was formed. This committee undertook the role of coordinating the development of South African loading code.

2. International codification

The idea of developing an original (i.e. unique) set of South African wind loading stipulations was discarded. This was in view of the lack of resources and also to avoid the proverbial 're-inventing of the wheel'. Instead, it was decided that the efforts should be directed at analysis of selected international standards, identification of those most relevant to the South African situation, and researching ways of further optimising and improving these documents (Goliger et al., 2001).

A reasonable assumption was made that, for this process, the loading standards of our major trading partners—i.e. Europe (at that stage ENV, 1991) and USA (ASCE 7-95)—should be considered. The Australian standard (AS 1170.2-1989) was also identified as being of interest, in view of its climatic similarities as well as technical and economical synergies with South Africa.

2.1. European code (ENV 1991-2-4)

An analysis of the relevant draft of Eurocode (ENV 1991-2-4), available to us at the time, was undertaken towards the end of 1999 (Goliger, 2000). The code was assessed as being comprehensive, inclusive and detailed. However, at that stage the document was clearly unfinished and contained several discrepancies, inconsistencies and errors.

A recommendation followed that, at that point in time, the adoption of draft Eurocode wind loading stipulations should not be pursued.

2.2. USA code (ASCE 7-95)

A brief analysis of the American document (Forbes and Goliger, 2000) revealed the general principles and logic of the code to be supposedly simple, albeit substantially different from those of SANS 10160. Furthermore, the overall format and layout of the code, as well as its user-friendliness, are questionable.

Although several differences between the codes were evident, of biggest concern were those less easily noticeable, which could lead to misinterpretations and become the source of errors.

An initial set of comparative calculations indicated the loads stipulated according to the ASCE procedure to be substantially larger than those obtained from SANS 10160. It was recommended that the ASCE specifications should not be adopted.

2.3. Australian code (AS 1170.2)

A preliminary analysis of the Australian code revealed it to constitute an excellent, well-structured and logical document. The respective procedures appear to be straightforward and their principles largely consistent with those stipulated in SANS 10160.

Perhaps the biggest differences are in the concept of three basic gust wind speeds (corresponding to the serviceability limit states, ultimate limit state and working stress design), as well as the principle of an average return period of 1000 years.

A proposed draft South African standard was developed on the basis of Section 3 (Detailed procedure: static analysis) of the AS 1170.2, with modifications and additions from other codes, where relevant and feasible. These modifications can be summarised as follows:

- Alternative order and hierarchy of subsections and appendices, aimed at improving the user-friendliness and consistency of the document.
- Definition of a single map of regional basic wind speeds, in line with the current SANS 10160 stipulations.
- Alternative treatment of changes in terrain category (in line with ISO 4354 and BS 6399).
- An introduction of a directional factor M_d (at this stage assumed to be 1.0), as opposed to a procedure based on modifications of the basic design wind speeds.
- Introduction of a new set of 'power-law' parameters to describe the increase of wind speed with elevation. These have been derived from a comparative analysis of wind profiles specified in SANS 10160, ASCE 7-95 and AS 1170.2.
- Reduction in the magnitude of the shielding factor (a maximum reduction of 0.9—i.e. a pressure reduction of up to 20% only).
- Introduction of a pressure-conversion factor as a function of the altitude above sea level (this is in line with the current SANS 10160).
- Adoption of a procedure for determining the internal pressure coefficients based on those presented in Eurocode.
- Introduction of additional information on pressure distribution for:
  - walls of buildings with re-entrant corners,
  - recessed bays and internal walls,
  - buildings with irregular walls,
  - inset storeys, and
  - non-vertical walls.

(For the above, data included in British code BS 6399 was used. In some cases, however, these data were simplified by adopting the controlling values only.)

3. Adoption of Eurocode

Towards the end of 2002, information reached the Loading Committee that indicated that preparatory work for a new version of the Australian wind loading standard was in progress. In view of this development, the merits of adopting an 'outdated' version of an overseas document became questionable. At the same time, a close relationship between the Eurocode committee and the South African loading committee was forged. This included several visits, discussions and participation in meetings.

It also became evident that United Europe embraces the role of a strong economic power bloc within the commercial construction environment of the Europe–Africa region. (It is symptomatic to note that, for some recent projects in Arab countries, which had traditionally relied on the British and American codification, requests were made to carry out additional wind loading analyses based on the draft European code.)

In view of the above developments, the loading committee decided on a re-analysis of the most recent wind loading stipulations of the Eurocode, and the implications of its adoption to South Africa. Subsequently, the latest copy of the draft code (from December 2003) was obtained from the Eurocode committee.

A brief overview of the code indicated this to be an excellent and state-of-the-art document, at a fairly advanced stage of finalisation. It also became apparent that adoption of the code would significantly increase the amount of design work. Furthermore, a review of the basic principles of the Eurocode indicated the problem of adopting the definition of the 'characteristic wind speed' in terms of the 10-min mean, as opposed to the 3-s gust wind speed, currently used in the SANS code. This issue will be discussed in the following section.

4. Wind speed and profile

4.1. *Three-second gust vs. 10-min mean*

The wind loading stipulations of SANS 10160 are in terms of a 3-s gust wind speed, while the ENV 1991-1-4 is in terms of a 10-min mean wind speed. This situation is seemingly neither unique nor critical, as the non-compatibility of definitions of averaging times represents a universal problem while evaluating and comparing various design codes across the world.

For mature winds, the conversion of the magnitude of wind speeds to correspond to various averaging periods constitutes standard textbook information. In fact, it can be derived that a multiplier of 1.1 must be used to convert an hourly mean wind speed to a 10-min mean, and a multiplier of about 0.7 to convert a 3-s peak gust wind speed to 10-min mean wind speed (Simiu and Scanlan, 1978).

4.2. *Wind climate of South Africa*

South Africa is a large country with a diverse climate. Figs. 1a and b are maps of the regional basic 3-s gust and the maximum hourly mean wind speeds included in the loading code. In Table 1, a comparison is made (based on Figs. 1a and b; SANS 10160-1989) between the coastal and inland areas of the country.

Table 1 indicates large differences in gust factor, and thus the complexity of the South African wind climate, in which the strong coastal winds originate in mature frontal storms, while strong inland winds develop as a result of convective activity (typically related to strong and intense thunderstorms).

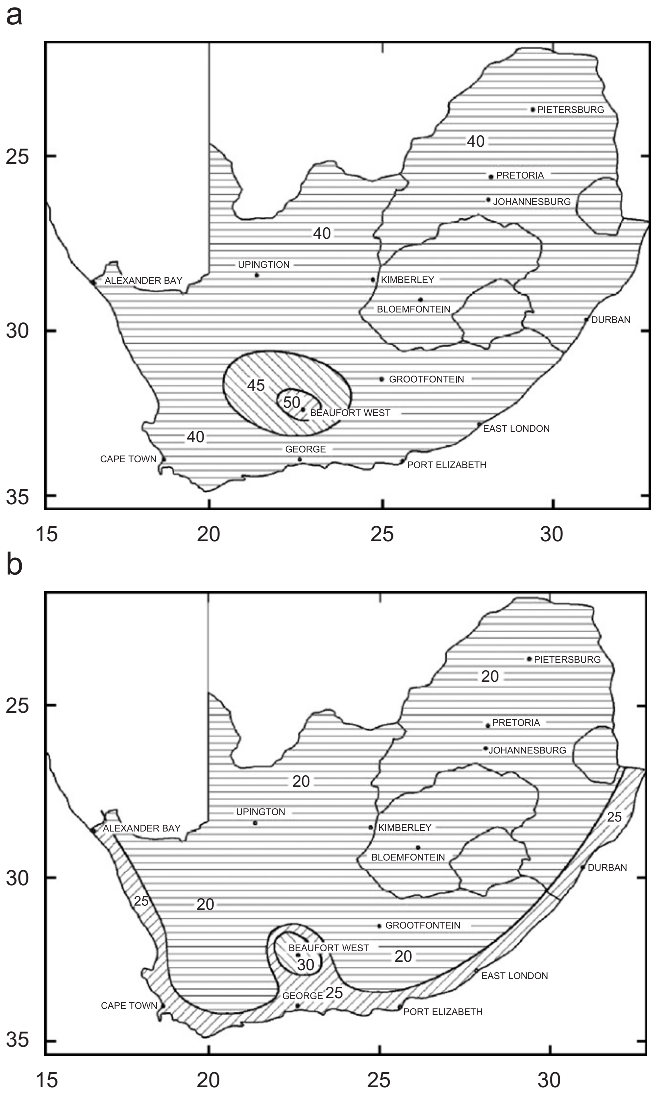

Fig. 1. (a) Isopleths of 3-s gust wind speed (50 year return period). (b) Maximum mean hourly wind speed (50-year return period).

Table 1
Comparison of wind speeds

Area	Regional basic wind speed, 3-s gust (m/s)	Maximum mean hourly wind speed (m/s)	Gust factor (open terrain)
Coast	40	25	1.6
Inland	40	20	2.0

4.3. Defining the 10-min mean for inland areas

As discussed in Section 4.1, for coastal areas conversion factors of 1.1 or 0.7, respectively, can be used to determine the magnitude of the basic wind speed in terms of the 10-min averaging period. Either way, a value of 28 m/s is obtained ($25 \times 1.1 = 27.5$ or $40 \times 0.7 = 28$).

Unfortunately, this conversion cannot be easily applied to inland areas, as two different values of the basic design wind speeds would emerge ($20 \times 1.1 = 22$ m/s or $40 \times 0.7 = 28$ m/s). This situation demonstrates the inability of design wind data, expressed in terms of large averaging periods, to represent adequately wind climates dominated by extreme winds of short duration generated in thunderstorms. The 10-min or hourly mean wind speeds are suitable for application to climates dominated by mature storms (e.g. Europe) and not by convective weather systems as in the case of Australia or South Africa.

A possible strategy to overcome this problem could be summarised as:

- Undertaking a set of comparative calculations for structures in coastal areas for a 10-min mean of 28 m/s (EN) and a 3-s gust of 40 m/s (SANS).
- Pending the outcome of these calculations, adopt an *actual* wind speed of 28 m/s for coastal areas (for all types of calculations) and an *effective* wind speed of the same magnitude for inland areas (for the design of cladding, fixing and structural elements).
- For dynamic calculations of structures located in inland areas, adopt the 'effective' wind speed of 28 m/s, but 'de-activate' the dynamic module (i.e. assume the resonant component $R = 0$) in calculating the $c_{\mathrm{s}}c_{\mathrm{d}}$ factor as below (EN 1991-2-4.6):

$$c_{\mathrm{S}}c_{\mathrm{d}} = \frac{1 + 2k_p I_v(z_e)\sqrt{B^2 + R^2}}{1 + 7I_v(z_e)}.$$

This will imply that only the correlation of pressures (background component B) is considered and an explanatory note to this effect would be made in the code, referring to an expert's advice in cases of dynamically sensitive structures.

An alternative would be to consider two loading cases, namely:

(1) static design with $V_{\mathrm{b}} = 28$ m/s and $R = 0$, and
(2) dynamic with $V_{\mathrm{b}} = 22$ m/s and $R \neq 0$,

and selecting the controlling loading case for each specific design. (It is likely that, for most structures, loading case 1 would be the controlling one.)

4.4. Terrain categories

Significant differences are present in the description of terrain roughness. SANS 10160 stipulates four terrain categories (1–4) in terms of typical descriptions of land cover and the character of the built environment. The division given in the Eurocode into five terrain categories (from 0 to IV), appears to be less ambiguous in a sense that is defined in terms of the mutual relationship between the average heights of obstacles and the relative amount of open space between them. In Table 2, a comparison of descriptions for an open type of terrain category is presented.

Table 2
Descriptions of terrain categories

SANS category 2	Open terrain with widely spaced obstructions (more than 100 m apart), having heights and plan dimensions generally between 1.5 and 10 m. This category includes large airfields, open parklands or farmlands, and undeveloped outskirts of towns and suburbs with few trees.
Euro category II	An area with low vegetation, such as grass and isolated obstacles (trees, buildings) separated by at least 20 obstacle heights.

Figs. 2a and b compare selected peak pressure profiles obtained from the SAN 0160 and EN 1991-2-4.6.

By definition, the above descriptions (i.e. terrain categories) should match, as in both standards they represent the terrain on which the regional basic wind speeds are based. This is also consistent with the stipulation of the World Meteorological Organisation regarding the full-scale measurement of regional wind speeds.

Of further interest is that the Eurocode does not stipulate a fully developed city terrain profile. This is in line with an approach (and argument) implemented in some of the recent European codes (e.g. BS 6399). In line with this argument, a development of the 'city terrain' profile is unrealistic, as it would require several kilometres of development length, which is not there in most cities of the world.

4.5. *Boundary layer profiles*

SANS 10160 stipulates a power-law profile, while the EN 1991 a logarithmic profile. Owing to the differences in definition of basic design wind speeds, a direct comparison of both profiles is not feasible, but they may be compared, rather, in terms of peak velocity pressure profiles, as presented in Figs. 2a and b (NB:. The Eurocode conversion to peak pressures takes place in its Section 4.5). It should be noted that in these graphs the additional limitations regarding the decrease of boundary layer at low elevations were ignored.

In Fig. 2a, profiles obtained for terrain category 2 (SANS) and category II (EN) are compared. The SANS profile was based on 40 m/s regional basic wind speed and the EN profile on 28 m/s 10-min basic wind velocity. By definition (see Section 4.4), both profiles should correspond. In Fig. 2b, the profiles corresponding to terrain categories 3 (SANS) and IV (EN) are compared. The rationale behind this comparison follows the argument presented in Section 4.4, regarding the SANS profile category 4 being unrealistic. Therefore, both profiles should stand for the 'roughest' (i.e. the most slowed down) approach boundary layer conditions in the respective standards.

(Note that in each graph the SANS profiles are represented by three lines which correspond to 3-, 5- and 10-s averaging periods—i.e. A, B and C classes of structures. This stipulation accommodates the correlation of flow, and is in line with the philosophy of the old CP3.)

It can be seen that in both cases the free-stream peak dynamic pressure profiles stipulated in the EN document are substantially larger, and especially so in the case of terrain category 2 (II).

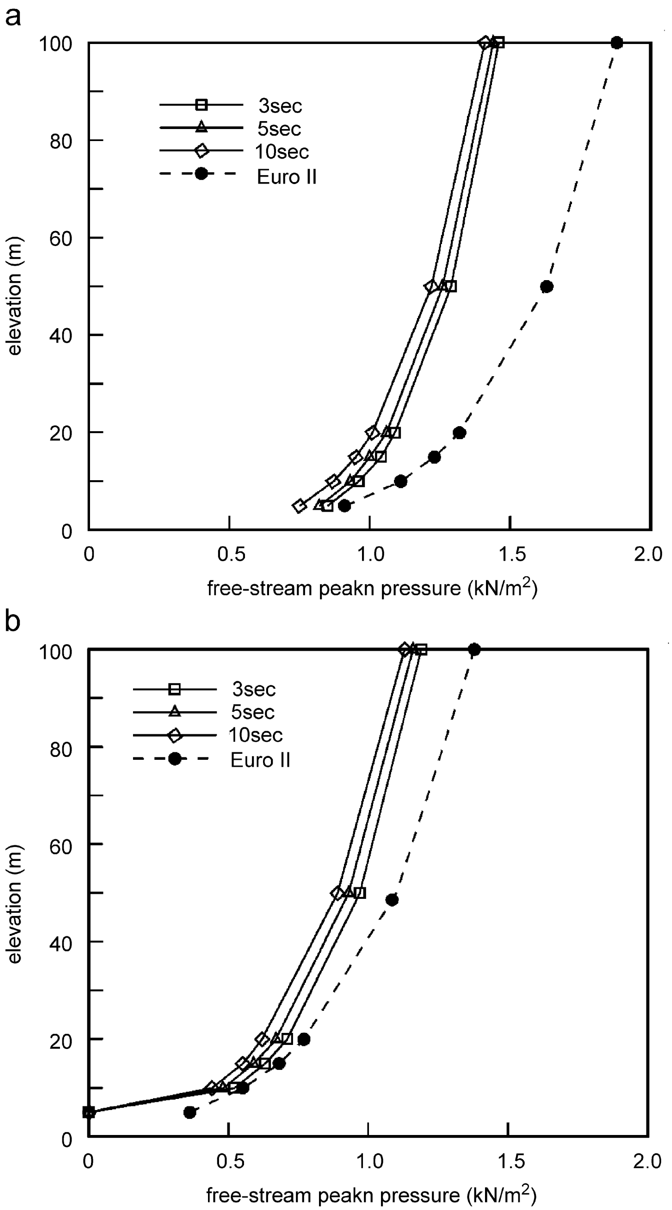

Fig. 2. (a) Comparison of peak pressure profile (SANS category 2 vs. Euro category II). (b) Comparison of peak pressure profiles (SANS category 3 vs. Euro category IV).

5. Initial comparative calculations

In view of the differences between the principles and stipulations of various national codes across the world, it is very difficult if not impossible to compare individual components of the design chain in isolation, and the only fair way to compare them would be at a level of the resulting (unfactorised) loads.

5.1. Low-rise buildings

Having in mind the discrepancies between the free-stream pressure profiles (Section 4.5), a set of initial comparative calculations was undertaken in order to assess the correlation of loads as determined by using both standards. For these calculations the structure of a typical large warehouse, located in a coastal area, was assumed, as shown in Fig. 3. Three roof slopes, $\alpha = 5^\circ$, 15° and 30°, were considered, together with terrain categories:

- 1 (SANS) corresponding to 0 (EN) as being the 'smoothest',
- 2 (SANS) corresponding to II (EN) by definition, and
- 4 (SANS) corresponding to IV (EN) by being the 'roughest'.

Selected results of calculations are presented in Figs. 4a and b, in a form similar to regression analysis, which is often used for comparisons of two independent sets of corresponding data.

The data are plotted in a way in which a specific load obtained for EN 1991-2-4.6 is plotted along the horizontal axis, and the load corresponding to the SANS code along the vertical axis. Each load is then represented by a single data point. The diagonal line at 45° (regression line of unity) represents the situation in which loads derived from both procedures are the same. A point below the regression line reflects the loads stipulated by Eurocode procedure to be higher.

Fig. 4a refers to local negative pressures over a tributary area of $5\,\mathrm{m}^2$, and Fig. 4b to resultant uplift force of the entire roof. It can be seen that, excluding few isolated situations, in both cases the loads that were derived from EN 1991 are significantly larger, especially for the localised areas.

The large discrepancy apparent in Figs. 4a and b result from a combination of differences in:

- the magnitude of free-stream dynamic pressure (Section 4.5),
- the magnitude of pressure coefficients stipulated in both codes,
- geometrical extent/definitions of loading zones, and
- the disparities in application procedures—i.e. the way in which the pressures/loads are referenced or combined.

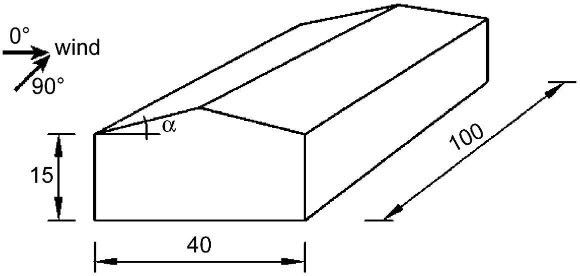

Fig. 3. Geometry of the building.

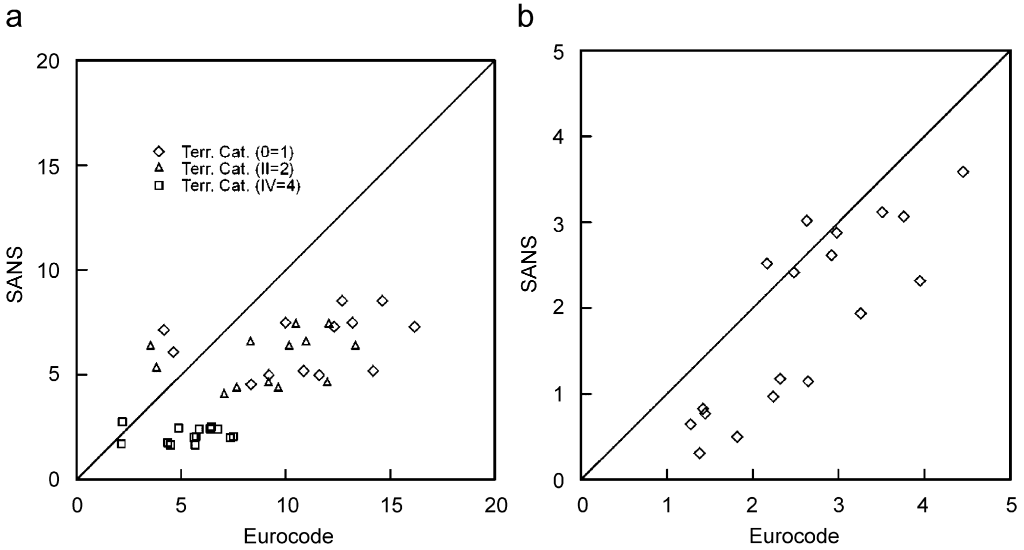

Fig. 4. (a) Comparison of local negative roof pressures. (b) Comparison of roof uplift.

Regarding the first two issues, it is widely accepted that the modern research data incorporated in the Eurocode enables much more accurate description of the distribution and magnitude of external pressures over buildings. This is especially evident in the case of local pressures.

However, differences are also evident in the way in which the information on pressure coefficients is applied or integrated. For example, according to SANS 0160, the zones of localised pressures are to be used for calculating the required fixings of elements and not for determining the overall loads over large surfaces. In Eurocode stipulations, pressure coefficients allocated to critical zones (e.g. edges and ridges) are given as a function of the contributory area, and should be combined with any other surface loads.

Another example of such differences is the issue of defining the reference height for walls of buildings with pitched roofs. The EN specifies it in terms of the free-stream dynamic pressure at the ridge height, and the SANS at the top of the wall. Seemingly, both stipulations are similar and, in fact, they do not matter in the case of gable walls. However, they may introduce significant differences for the remaining walls of houses with steep roofs.

5.2. *Medium-rise building*

A comparison of loads generated over the walls of a medium-rise building (with a height of 60 m and base 30 × 40 m) was also carried out.

The magnitude of pressure coefficients over the windward walls, as stipulated in both codes, was found to be similar. However, differences are apparent in the application method of pressure distribution over the elevation, as presented schematically in Fig. 5. Two methods of application are allowed in SANS 0160 (conservative and accurate), whereas EN 1991 prescribes a distribution in zones, defined in terms of the aspect ratio of the windward wall (i.e. the relationship between the height and breadth).

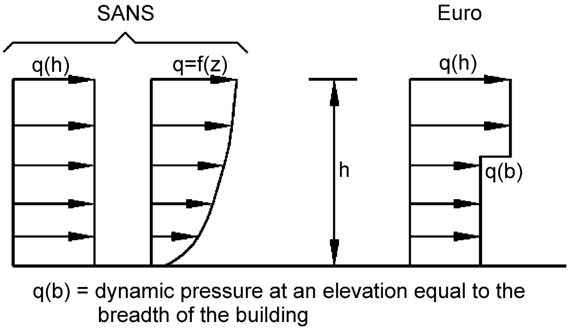

Fig. 5. Application of pressures over the windward wall.

A significant difference in overall horizontal loads (which in turn determine the overturning moment) can be attributed to the magnitude of the negative pressures over the leeward wall, stipulated in both codes. Depending on the aspect ratio, EN 1991 specifies values of between −0.3 and −0.7, and SANS 10160 between −0.2 and −0.4. Effectively, for certain ranges of aspect ratios, differences of more than twice are apparent (e.g. −0.55 vs. −0.25).

6. Conclusions and future work

A review of the development work carried out in the preparation of a new set of wind stipulations for South African loading code has been presented.

Adoption of the relevant Eurocode procedures appears to be most attractive, and is currently under investigation. In the context of climatic conditions, the biggest challenge will be the incorporation of the 10-min mean basic wind speed.

Initial comparative calculations indicate the magnitude of loads obtained from EN 1991 procedures to be significantly larger than those derived from SANS 10160. This is due to the differences in descriptions of the boundary layer, the information on pressure coefficients, and the procedures of application.

Without questioning the issue of modernism and comprehensiveness of the Eurocode, it could be hypothesised that the reasons for its conservatism could be assigned to its being derived from an amalgamation of adequate data and procedures, adopted independently each at their higher bound and not median values.

At the time of preparation of the current paper, a more comprehensive comparative calibration study was undertaken in order to quantify the differences between the loads obtained from SANS 10160 and EN 1991.

Acknowledgements

I would like to acknowledge the support of South African National Loading Committee, as well as the benefits of in-depth discussions with Dr. Rodney Milford.

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