Wind actions on single storey buildings

David Brown of the SCI comments on some of the issues frequently raised when determining the loading on this common form of construction.

Single storey buildings

Portal frame buildings and other single storey structures are said to account for around 45% of the structural steel used in the UK. Considering the steel tonnage used in a single multi-storey building, there is obviously considerable demand for industrial, retail, storage and distribution buildings. "Single storey" may be an inappropriate description as some storage and distribution structures are equivalent in height to three or four-storey offices. This article covers some of the questions on BS EN 1991-1-4 which arrive at the SCI's Advisory Desk.

First, the pressure

Who would ever want to undertake calculating this by hand? Many companies who manufacture purlins and side rails provide software to assist in the design and selection of appropriate members. This software will always need to calculate the peak velocity pressure q_p and will usually present the information for each 30° segment around the site. At a stroke, the heartache of working through the standard and the UK National Annex has been bypassed.

Some warnings are however necessary. Several programs use "BREVe" to determine the wind pressure, a component which has been around for some time, leading to some compatibility issues with operating systems. Users will generally be presented with a table of intermediate results, inviting the user to modify the assumed values. Although it may be tempting to simply accept the table, users really should ensure they are content with the presented values. The important values to check and adjust if necessary are:

- Site altitude
- Distance from the sea (or significant inland water)
- Distance from edge of town
- If in town, the average obstruction height and spacing (h_{ave} and x respectively, from A.5 of BS EN 1991-1-4)

Since the underlying data has a certain granularity (for example, altitude might be anywhere within the surrounding 2 km) users should expect some odd values if comparing with OS maps. As the database reflects a point in time, subsequent urbanisation may have an impact on the assumed values.

The default values for h_{ave} and x may be 6 m and 20 m respectively. The value of 20 m was suggested in BRE Digest 436, Part 1, from 1999, which gave guidance on BS 6399-2. The 1999 version of the digest is not readily available, having been completely updated to reflect the Eurocode. The value of 6 m may reflect an assumed two-storey shelter height. Local knowledge is essential to determine the correct values. It is assumed that "irreversible urbanisation" will mean that shelter only increases, which seems optimistic in reality.

Peak velocity pressure without software

Manual calculation is of course possible, though for the author, not desirable. Calculations could consider the same 12 segments as software. The SCI recommendation is to consider four 90° quadrants and determine the most onerous values of the various factors in each quadrant. The peak velocity pressure would then be the most onerous of the four. This "by quadrants" method generally gives reasonable results compared with considering twelve segments, and avoids the significant conservatism of taking the most onerous value from anywhere around the site and assuming these most onerous values all apply to wind blowing from one direction.

Whichever approach is followed, the assessment to this stage has only considered the site – the orientation of the building is not yet relevant. In most cases it is not necessary to know the building orientation, unless there is particular benefit in calculating a different pressure for each face. It would be unusual to have different side rails on different faces of the structure (for example). Pressures on individual faces may be important if the building is not symmetric, there is some ground feature affecting one side only or there are openings on one face only. If pressure on an individual face is important, the pressure on a face must be determined considering a range of directions ±45° from the normal to each face as shown in Figure 1, not just the direction perpendicular to each face – the full 360° around the site must be included.

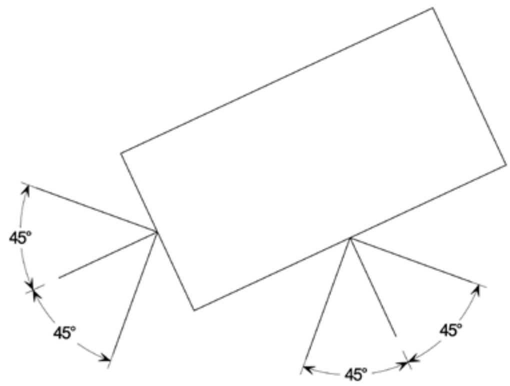

Figure 1: Wind pressure on individual faces

Designers undertaking manual calculations will need to interrogate figures NA.7 (reproduced below) and (if in Town) NA.8. SCI is not aware of any expressions which define the curves in these figures. Some time ago, csv files were available via IStructE, which could, with some thoughtful interpolation, be used to determine a value, but these are no longer available.

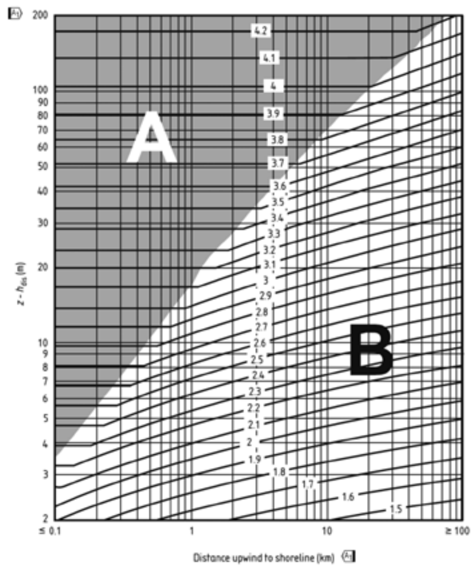

Figure 2; Figure NA.7 (from the UK NA to BS EN 1991-1-4)

A helpful free tool is available to download from *www.rwdimedia.com/encalculator_program.html* which will enable precise values to be determined.

Internal pressure coefficients

Mature designers will immediately recognise two values, of +0.2 or -0.3. These values appeared in Appendix E of CP3:Chapter V from 1972 and Table 16 of BS 6399-2 from 1997. The same values appear in Note 2 to clause 7.2.9(6) of BS EN 1991-1-4, presented as an option if the designer is unable to, or does not wish to, calculate the precise value based on building geometry and opening ratio.

BRE Digest 436 Part 1 from 1999 offered further guidance that "the positive value C_{pi} = +0.2 is now less likely to be a critical design case. The positive value can only occur when the side walls are impermeable and the front face is permeable". The Digest also advised that "The internal pressure coefficient for completely clad enclosed warehouse-type buildings without opening windows, may be taken as C_{pi} = -0.3."

The reference to opening windows relates to a dominant opening, discussed later. After BRE Digest 436 was published, many designers of "warehouse-type" buildings changed their practice to only consider a coefficient of -0.3, though some considered an additional coefficient of zero as a replacement to the +0.2.

Generally, it is advantageous to calculate the actual internal pressure coefficient, using Figure 7.13 and expression 7.3 from the Eurocode. If it is reasonable to assume that the roof is impermeable and the elevations equally permeable, the calculation is simply based on area.

With a 15 m tall portal frame building, 36 m span and 90 m length (Figure 3), the wind may blow parallel to the ridge, or perpendicular to the ridge.

Wind parallel to the ridge

Area of elevations with suction = 2 × (90 × 15) + (36 × 15) = 3240 m²

Area of all elevations = 3240 + (36 × 15) = 3780 m²

$$\mu = \frac{3240}{3780} = 0.86$$

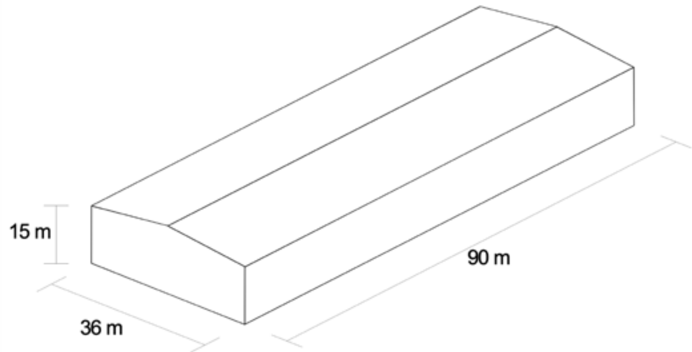

Figure 3: Example building

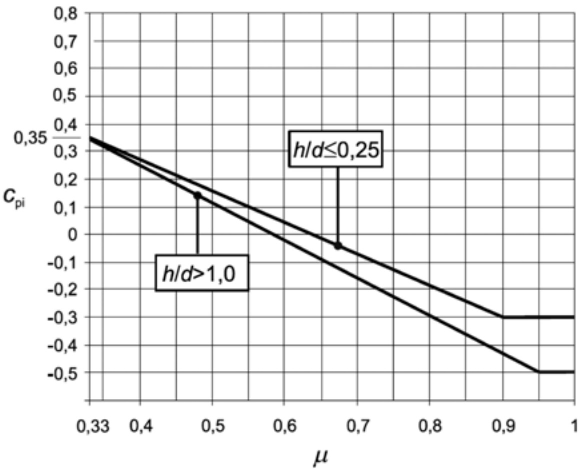

Figure 4: Figure 7.13 from BS EN 1991-1-4

For Figure 7.13 (reproduced as Figure 4), h/d = 15/90 = 0.17

From Figure 7.13, C_{pi} = -0.25

Wind perpendicular to the ridge

Area of elevations with suction = (90 × 15) + 2 × (36 × 15) = 2430 m²

Area of all elevations = 3780 m²

$$\mu = \frac{2430}{3780} = 0.64$$

For Figure 7.13 (reproduced as Figure 4), h/d = 15/36 = 0.42

From Figure 7.13, with interpolation, C_{pi} = -0.02

Particularly for wind blowing perpendicular to the ridge, this is a considerable improvement from the use of C_{pi} = -0.3. Only unusual geometry will result in a positive internal pressure, supporting the advice in the BRE Digest.

Dominant openings

CP3:Chapter V has the guidance that C_{pi} should be taken as the more onerous of +0.2 and -0.3 "when there is only a negligible probability of a dominant opening occurring during a severe storm". It is not clear how this should be assessed. It would be expected that certain structures, such as fire stations or lifeboat buildings might well have open doors in a severe storm. Perhaps a 24-hour distribution warehouse might also need to continue operations. Allowing for a dominant opening will serve to inflate or deflate the building and will probably increase the required member sizes since C_{pi} is up to 90 % of C_{pe} at the location of the opening. In the author's experience from previous decades, tenders might be qualified in small text that "it has been assumed that in the event of a severe storm, all openings will be shut", which was code for "we have not allowed for dominant openings".

The Eurocode does not allow this practice – clause 7.2.9(3) insists that if openings that would be dominant are assumed to be shut, the condition with the door or window open should be considered. Fortunately, the Eurocode also specifies this as an accidental combination of actions, meaning that equation 6.11b from EN 1990 should be used to verify this case. The actions are unfactored in the accidental combination, which may mean that the original member sizes remain satisfactory. An opening does not need to be large to be dominant – advice is given in clause 7.2.9(4) of BS EN 1991-1-4.

Note that zone A (just around the corner from the windward face) has a more onerous coefficient than zone E, the leeward face, as shown in Figure 5. A dominant opening in zone A could be particularly onerous.

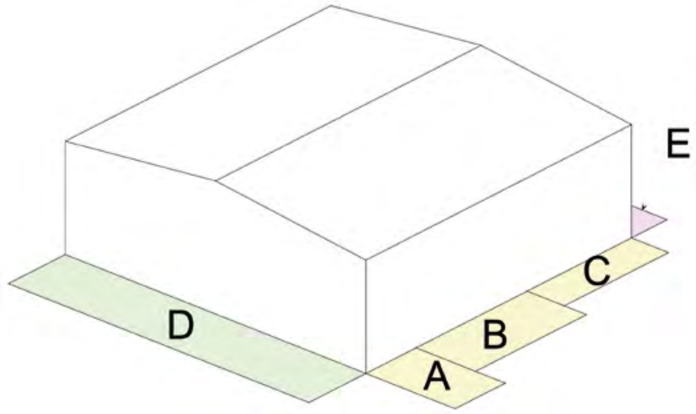

Figure 5: Wall coefficients

Local external pressure coefficients

Where wind flows around a corner, or over the eaves, or over the ridge, increased turbulence leads to higher local suctions. CP3: Chapter V presented coefficients for these zones, but noted in clause 7.2 that "they should not be used for calculating the load on entire structural elements such as roof walls or the structure as a whole". This gave rise to the widespread practice (at that time) of neglecting the local zones for the design of the structure. There is no permission to ignore the local zones in BS 6399-2 or BS EN 1991-1-4.

Further resources

SCI publication P394 contains comprehensive advice on the application of BS EN 1991-1-4 and a worked example. The three parts of both the 1999 and 2015 versions of BRE Digest 436 contain helpful guidance and are recommended reading. ■