Department for
Communities and
Local Government

Guide to the use of
EN 1991-1-4 – Wind Actions

September 2006

Department for Communities and Local Government: London

On 5th May 2006 the responsibilities of the Office of the Deputy Prime Minister (ODPM) transferred to the Department for Communities and Local Government (DCLG)

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It should be noted that this guidance has been based on the latest draft at the time (which was close to the publicised Eurocode); together with the draft National Annex.

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CONTENTS

1. Introduction

The project which led to the production of this report arose with the intention of producing a handbook to encourage the safe and consistent adoption of EN 1991-1: Eurocode 1 - Actions on Structures: Part 1: General Actions, in the UK. The project was modified to consider only two specific sections of EN 1991-1, which were:

EN 1991 Actions on structures - Part 1.4: Wind Actions
EN 1991 Actions on structures - Part 1.7: Accidental actions

However, both of these sections require information from EN 1990 Basis of Structural Design , hence EN 1990 also had to be considered.

Although the original intention had been to produce one handbook, it became apparent that the various parts of the Eurocode could not be treated in a consistent manner. For example, parts of EN 1991-1-4 can be compared with BS6399-2, but EN 1991-1-7 has no equivalent UK code; hence, it was felt appropriate to prepare separate reports for each section. This would also allow further parts of EN1991-1 to be considered later. The reports, which have been produced so far, are for EN 1990, EN 1991-1-4 and EN 1991-1-7.

An initial requirement was that the handbook should be concise, user friendly and summarise the major differences between EN1991-1 and existing UK codes. Therefore, information given in EN 1991 that does not conflict with UK codes is simply referenced and no explanation is given about its derivation. For this latter type of information, the reader is referred to the Thomas Telford publications on the Structural Eurocodes (www.eurocodes.co.uk).

Although several parts of EN1991 and their respective National Annexes are complete, others are still being processed. The current state of progress is given in Table 1. A consequence of starting the work before the codes with their National Annexes are published by BSI is that the work can only be based on the latest editions of the code, and some details may change when the Codes are finally issued.

Table 1 Current status of the various sections of EN 1991

Section	Title	Final text released by CEN	Anticipated publication date by BSI along with associated National Annex
EN 1990	Basis of structural design	April 2002	April 2004
EN 1991-1-1	Densities, self-weight and imposed loads	April 2002	April 2004
EN 1991-1-2	Actions of structures exposed to Fire	Nov 2002	~ Nov 2004
EN 1991-1-3	Snow Loads	July 2003	~ Dec 2004
EN 1991-1-4	Wind Actions	~ May 2004	May 2006
EN 1991-1-5	Thermal Actions	Oct 2003	Oct 2005
EN 1991-1-6	Actions during execution	Sep 2004	Sep 2006
EN 1991-1-7	Accidental actions due to impact and explosion	Jun 2005	Dec 2007

Because EN1991-1-4 is not yet finalised, little guidance on its background and usage has been produced. A series of designer s guides on the various Eurocodes is being prepared by Thomas Telford and some user manuals are planned by the Institution of Structural Engineers (www.istructe.org.uk). It is recommended that these web pages be checked to obtain up-to-date information on the available publications

1.1 Eurocode terminology

Most of the definitions given in the Eurocodes derive from

- ISO 2394(1998) General principles on reliability for structures
- ISO 3898 (1997) Bases for design of structures -- Notations -- General symbols
- ISO 8930 (1987) General principles on reliability for structures -- List of equivalent terms

EN 1990 provides a basic list of terms and definitions which are applicable to EN 1990 to EN 1999, thus ensuring a common basis for the Structural Eurocode suite. Sections of EN 1991-1 contain terms and definitions which are specifically related to that section.

Attention is drawn to the following key definitions, which may be different from current national practices:

- *Action* means a load, or an imposed deformation (e.g. temperature effects or settlement)
- *Effects of Actions* or *Action effects* are internal moments and forces, bending moments, shear forces and deformations caused by actions
- *Strength* is a mechanical property of a material, in units of stress
- *Resistance* is a mechanical property of a cross-section of a member, or a member or structure.
- *“Execution”* covers all activities carried out for the physical completion of the work including procurement, the inspection and documentation thereof. The term covers work on site; it may also signify the fabrication of components off site and their subsequent erection on site.

1.2 Eurocode annexes

There are two categories of Annex used by the Structural Eurocodes. One type is labelled ’I’ and is Informative (i.e. for information and not as a mandatory part of the code). The second type I labelled ’N’ and is Normative (i.e. a mandatory part of the code). In their National Annex (NA), a country can choose to make an Informative annex Normative if they so wish.

2 EN 1991 Actions on structures – Part 1.4: Wind Actions

The aim of this section of the report is to review the provision of EN1991-1-4 [1] in comparison with current UK practice and to summarise the major differences. EN1991-1-4 must be used in the UK in conjunction with the UK National Annex. This guidance is based on the December 2004 version of EN1991-1-4 which may not be technically complete. The National Annex gives alternative procedures known as National Determined Parameters (NDPs) for many clauses in EN1991-1-4; this report includes a commentary on the rationale for the choice of these NDPs. The scope of this report is limited mainly to static building structures for which BS6399-2 [2] is the corresponding UK standard. Bridges are excluded and dynamic response of structures has been limited to a brief overview.

2.1 Definitions

Some of the terminology, symbols and definitions used in EN1991-1-4 will be new to UK engineers. This Chapter sets out the major differences between EN1991-1-4 and UK practice. The clause numbers indicate where the term is first mentioned in EN1991-1-4. P indicates that the clause is a Principle. Principles are general statements and definitions for which there is no alternative, as well as requirements and analytical models for which no alternative is permitted unless specifically stated. Clauses without the letter P are known as Application Rules and are generally recognised rules which comply with the Principles and satisfy their requirements.

Background response factor B (6.3.1(1)): accounts for the lack of correlation of the wind gusts over the surface of the structure or element. There is no equivalent value in BS6399-2.

Basic velocity pressure q_b (4.5(1): derived from the basic wind velocity ($q_b = 0.613\ v_b^2$). There is no equivalent value in BS6399-2.

Basic wind velocity v_b (4.2(2)P) : is the fundamental basic wind velocity modified to account for seasonal and directional effects. There is no direct equivalent value in BS6399-2.

Directional factor c_{dir} (4.2(2)P): used to modify the basic wind velocity to produce wind speeds with the same risk of being exceeded in any wind direction. c_{dir} is the same as S_d in BS6399-2.

Exposure factor $c_e(z)$ (4.5(1)): accounts for the effect of terrain, orography and building height. Similar to S_b^2 in BS6399-2. Note: orography is equivalent to topography in BS6399-2

Force coefficient c_f (5.3(2)): the ratio of the force acting on a structure or element to the peak velocity pressure multiplied by an appropriate area. There are no equivalent values in BS6399-2.

Friction coefficient c_{fr} (5.3(2)): the ratio of the frictional drag on surfaces aligned parallel with the wind to the peak velocity pressure multiplied by an appropriate area. Corresponds to C_f in BS6399-2.

Fundamental basic wind velocity $v_{b,0}$ (4.2 (1)P): this is the mean wind velocity for a 10 minute averaging period with an annual risk of being exceeded of 0.02, at a height of 10m above ground level in flat open country terrain (terrain category II). There is no direct equivalent value in the main body of BS6399-2. For use in the UK, $v_{b,0} = v_{b,0}^* \cdot c_{alt}$ where $v_{b,0}^*$ is the mean wind velocity for a 10 minute averaging period with an annual risk of being exceeded of 0.02, at a height of 10m above sea level in terrain category II, c_{alt} is the altitude factor which accounts for the effects of altitude on the fundamental basic wind velocity.

Mean wind velocity $v_m(z)$ (4.2(2)P Note 4): is the basic wind velocity modified to account for terrain roughness category and orography effects (defined below). There is no direct equivalent value in BS6399-2.

Orography factor $c_o(z)$ (4.3.1(1)): used to account for the increase in wind speed due to topographic features such as hills, cliffs and escarpments. $c_o(z)$ is obtained using the same method for calculating topographic effects as included in the S_a factor in BS6300-2.

Pressure coefficients c_{pe} and c_{pi} (5.2(1)): the ratio of the pressure acting on the external or internal surfaces to the peak velocity pressure. Corresponds to C_{pe} and C_{pi} in BS6399-2.

Peak velocity pressure $q_p(z)$ (4.5(1)): is the site wind velocity taking account of the terrain and building size. $q_p(z)$ corresponds to q_s in BS6399-2.

Probability factor c_{prob} (4.2(2)P Note 4): used to modify the basic wind velocity to change the risk of the wind speed being exceeded. c_{prob} is the same as S_p in BS6399-2.

Resonant response factor R (6.3.1(1): accounts for the effects of wind turbulence in resonance with the vibration of the structure in its fundamental mode of vibration. There is no equivalent value in BS6399-2.

Roughness factor $c_r(z)$ (4.3.1(1)): used to modify the mean wind speed to account for the terrain roughness upwind of the site and the height of the building or structure under consideration. $c_r(z)$ corresponds to S_c in the BS6399-2 directional method.

Season factor c_{season} (4.2(2)P): used to modify the basic wind velocity to produce wind speeds with the same risk of being exceeded in any specific sub-annual period. c_{season} is the same as S_s in BS6399-2.

Structural factor $c_s c_d$ (5.3(2)): takes account of the effect of non-simultaneous wind action over the surfaces of the structure or element combined with the effect of dynamic response of the structure or element. c_s and c_d correspond to C_a and (1 +C_r) respectively in BS6399-2.

Turbulence intensity $I_v(z)$ (4.4(1)): is the standard deviation of the wind turbulence divided by the mean wind velocity and is a measure of the gustiness of the wind. $I_v(z)$ corresponds to $S_t T_t$ in the BS6399-2 directional method.

Wind force F_w , $F_{w,e}$, $F_{w,I}$, F_{fr} (5.3(2): the wind force acting on the overall structure or element (F_w), on the external surfaces ($F_{w,e}$), on the internal surfaces ($F_{w,i}$) or due to frictional forces (F_{fr}). Corresponds to P and P_f in BS6399-2.

Wind pressure w_e and w_i (5.2(1)): the wind pressure acting on external and internal building surfaces respectively. Corresponds to p_e and p_i in BS6399-2.

2.2 Scope of EN1991-1-4

EN1991-1-4 is applicable to:

- Building and civil engineering works with heights up to 200m
- Bridges with spans of not more than 200m (subject to certain limitations based on dynamic response criteria)
- Land based structures, their components and appendages

The specific exclusions are:

- Lattice towers with non-parallel chords
- Guyed masts and guyed chimneys
- Cable supported bridges
- Bridge deck vibration from transverse wind turbulence
- Torsional vibrations of buildings
- Modes of vibration higher than the fundamental mode

The scope of EN1991-1-4 is much wider than BS6399-2, it includes wind actions on other structures, which in the UK are given in a number of other British Standards and design guides. In some cases, for example dynamic response of buildings, there is no equivalent UK standard. Table 2 shows the scope of EN1991-1-4 compared with current UK practice, (where no direct equivalent UK current standard is available, the nearest other guidance is shown in brackets).

Table 2 Comparison between EN1991-1-4 and current UK practice

EN1991-1-4	UK Practice
Buildings (static)	BS6399-2
Buildings (mildly dynamic)	BS6399-2
Buildings (dynamic)	**No direct equivalent** (ESDU)
Bridges	Design manuals for roads and bridges, BD49, BD37
Chimneys (Steel)	BS4076, CICIND
Chimneys (concrete)	CICIND (Int. Committee for Industrial Chimneys)
Scaffolding	BS5975, BS5973, BS EN 12811
Structural elements	Limited guidance in BS6399-2 (CP3-V-2)
Lattice structures (not towers)	**No direct equivalent** (CP3-V-2)
Spheres, domes, barrel vaults	**No direct equivalent** (reference books, papers)

2.3 UK National Annex EN1991-1-4

EN1991-1-4 must be used in the UK with the accompanying National Annex. The National Annex (NA) contains information on National Determined Parameters (NDPs) such as:

- Values and/or classes where alternatives are given in the Eurocode
- Values to be used where only a symbol is given in the Eurocode
- Country specific geographical or climatic data
- Procedures to be used where alternative procedures are given in the Eurocode
- Decisions on the application of informative annexes
- References to non-contradictory complementary information to assist the user

A National Annex cannot change or modify the content of the EN text in any way other than where allowed for above.

In EN1991-1-4 there are 61 NDPs; 51 in the main body and 10 in the annexes. In most cases a recommended procedure or value is given, although national choice is allowed. The UK National Annex provides an alternative for a number of these procedures. These are listed in Table 3 with a commentary on the reasons for the alternative procedures (additional alternative procedures are also given in Section 8 Wind actions on bridges and in the annexes, but these are outside of the scope of this report).

Table 3 Clauses where the UK National Annex gives alternative rules or guidance

EN1991-1-4 Clause number	Commentary
4.1(1)	***Peak velocity pressure q_p*** - Procedures for directly obtaining q_p are given in 4.5
4.2(1)P Note 2	***Fundamental value of the basic wind velocity $v_{b,0}$*** — this is the wind velocity at a height of 10m above ground level. The UK wind velocity map is for a height of 10m above sea level (Figure NA1); an expression is given to adjust the UK map velocity using the altitude factor.
4.2(2)P Note 1	***Altitude factor c_{alt}*** — an expression is given for c_{alt} for use in the UK. Note that this is not the same as the factor used in BS6399-2, it now allows a reduction in c_{alt} with height above ground
4.2(2)P Note 2	***Directional factor c_{dir}*** - an expression is given for c_{dir} for use in the UK
4.2(2)P Note 3	***Season factor c_{season}*** - an expression is given for c_{season} for use in the UK
4.3.2(1) Note 1	***Roughness factor $c_r(z)$*** - Expressions 4.4 and 4.5 are replaced by two figures, NA3 and NA4, which directly give $c_r(z)$. These figures account for the upwind distance to sea and for urban sites, the distance to the edge of the urban area. The opportunity has also been taken to simplify the five terrain categories to Sea, Country and Town.
4.4(1) Note 2	***Turbulence factor $k_l/\ln((z-h_{dis})/z_o)$*** — a new turbulence factor has been introduced to account for up wind distances to sea and edge of town, this is given in Figures NA5 and NA6.
4.5(1) Note 1	***Peak velocity pressure q_p*** - Expression 4.8 has been replaced by expression NA3. This was necessary because 4.8 is a linearised form of the equation for q_p which underestimates wind pressures, particularly in Town terrain. NA3 corresponds with the approach used in BS6399-2. A new term, the exposure factor for flat terrain $c_{e,flat}(z)$, has been introduced in Figures NA7 and NA8. This greatly simplifies the determination of $q_p(z)$ for sites on flat terrain or on hilly sites at heights above ground of up to z= 50m.
4.5(1) Note 2	***Air density ρ*** — The value for air density in the UK is 1.226kg/m^2 (as used in BS6399-2)
5.3(5)	***Lack of correlation between windward and leeward faces*** - the recommended procedure only allows the reduction factor in 7.2.2(3) to be applied to walls. In the UK, the reduction will be applied to all horizontal components of the wind force acting on walls and roofs. This will reduce overall wind loads and is similar to the approach used in BS6399-2.
6.6(1)	***Structural factor c_sc_d*** — In the UK c_sc_d may be separated in to a size factor, c_s, and a dynamic factor, c_d, using Table NA3 and Figure NA9. This simple approach avoids the need to use the complex dynamic procedures in 6.3 and can give significant reductions in wind loads on large buildings or elements that are not dynamically sensitive. The c_s and c_d factors correspond to the size effect factor, C_a, and dynamic augmentation factor ,C_r, in BS6399-2.
7.1.2(2)	***Asymmetry*** — No decision has yet been made for the UK National Annex
7.2.1(1) Note 2	***Determining the external pressure coefficient c_{pe}*** — the recommended procedure requires pressure coefficients to be calculated for every loaded area between 1m^2 and 10m^2 using logarithmic interpolation. This would increase the calculation effort significantly in the UK cladding and glazing industry. There is no scientific evidence to support this rule, therefore in the UK, the $c_{pe,1}$ value should be used for all loaded areas † 1m^2 and the $c_{pe,10}$ value for areas >1m^2. This new procedure was developed in consultation with the UK glazing industry.
7.2.2(2) Note 1	***External pressure coefficients for walls*** - Table 7.1 is replaced by Table NA4. This was done to allow the inclusion of net pressure coefficients, which can give significant reductions in overall wind loads. This corresponds with the new Table 5a in BS6399-2.
7.2.8(1)	***Vaulted roofs*** - Figure 7.11 is replaced by Figures NA10 and NA11. These new figures give better estimates of pressure coefficients on vaulted roofs based on recent wind tunnel studies.
7.2.9(2)	***Permeability*** - Table NA5 gives typical permeability values for UK construction
7.2.10(3) Note 2	***Multiskin walls and roofs*** — Experience in the UK has shown that the recommended procedure does not apply to tiled and slated roofs or masonry cavity walls. The EN1991-1-4 procedure should not be used in the UK for these situations. The existing guidance in BS5534 and BS5628-1 should continue to be used.
7.13(2)	***Effective slenderness length*** - Figure 7.16 is replaced by NA6. This is because the values in Figure 7.16 are of uncertain origin and are significantly different from the values currently used in the UK. The revised values given in NA6 correspond with those given in BS6399-2

2.4 Main differences between EN1991-1-4 (with the UK NA) and BS6399-2

When considering wind loads on static building structures there are many similarities between EN1991-1-4 and BS6399-2, there are also a number of obvious differences, such as the change from mean hourly to 10-minute mean wind speeds plus other more subtle differences in the methodologies and expressions used; some of which will not be immediately obvious to the user. The UK National Annex also gives some alternative procedures which change EN1991-1-4 to make it applicable for use in the UK. This Chapter provides an overview of the first seven sections of EN1991-1-4 (excluding section eight on bridges) and identifies and discusses the major differences from BS6399-2. Table 4 shows some of the main differences between EN1991-1-4 and BS6399-2. For a detailed commentary on EN1991-1-4, the reader is referred to Cook [3].

2.4.1 Section 1 General

This section gives the scope, normative references, assumptions, rules for design assisted by testing and measurements, definitions and symbols. The differences in definitions, symbols and scope have already been explained in section 1 of this report. Section 1.5 Design assisted by testing and measurements, allows wind tunnel testing, validated numerical methods or full scale testing to be used to obtain the wind loads and the structural response. This is essentially the same as the guidance given in BS6399-2 which allows other equivalent methods to be used. However, whereas BS6399-2 gives guidance for wind tunnel testing in Annex A, EN1991-1-4 does not give any guidance. It is likely that guidance on this and other parts of BS6399-2 which contain non conflicting complementary information (NCCI), such as wind effects on irregular shape buildings, inset stories, multipitch roofs, etc. will be published as a residual standard.

2.4.2 Section 2 Design situations

The general requirement of this section is that the relevant wind actions be determined for each design situation identified in EN1990 (Basis of Structural Design), such as persistent, transient and accidental design situations. In EN1991-1-4, the following specific design situations should also be taken in to account:

- other actions (such as snow, traffic or ice) which will affect the wind loads
- changes to the structure during construction which modify the wind loads
- where doors and windows that are assumed to be shut are open under storm conditions then they should be treated as accidental actions
- fatigue due to wind actions should be considered for susceptible structures

This section does not have a direct equivalent in BS6399-2. The guidance for doors and windows accidentally left open or which break during a wind storm is different from that given in BS6399-2. In BS6399-2 this is treated as a serviceability limit state and a reduced probability factor of 0.8 used which has the effect of reducing the mean recurrence interval from 50 to about 2 years. In EN1991-1-4 this is treated as an accidental design situation.

2.4.3 Section 3 Modelling of wind actions

This Section describes wind actions and defines characteristic values of wind velocity and velocity pressure according to EN1990. Wind actions are classified according to EN1990 as variable fixed actions; this might seem like a contradiction in terms but it essentially means that for a given structure in a given location the wind action is fixed except where a range of values is given. For example on a pitched roof both positive and negative pressure coefficients are given for many roof zones, both of which should be considered in design. The information given in this section is consistent with BS6399-2, although there is no direct equivalent to this section in BS6399-2. Definitions of fixed and variable actions are given in EN1990.

2.4.4 Section 4 Wind velocity and velocity pressure

This section gives the procedures for determining the wind velocity and the peak velocity pressure. Alternative procedures have been given in the NA for a number of clauses in this section in order to give a more realistic representation of wind conditions for the UK, these are described below.

2.4.4.1 Basic wind velocity

The starting point for the determination of the wind velocity is the map of fundamental basic wind velocity given in Figure NA1 of the NA. This map corresponds to the map of basic wind speed given in BS6399-2, except that it is based on a 10-minute mean velocity instead of the mean-hourly map used in BS6399-2 and a slightly increased terrain roughness (z_0 = 0.05 instead of 0.03). These changes do not account for the major differences between these maps. This is caused by a reanalysis of the meteorological wind speed data which has resulted in slightly higher windspeeds over most of the country except for the Southeast where quite large reductions are seen.

The map wind speed is adjusted using the altitude factor (given in the NA) which differs from that given in BS6399-2 because it now reduces with height above ground. This new altitude factor is based on a study [10] which showed that the old altitude factor in BS6399-2 was very conservative, especially for site altitudes above 200m.

The basic wind velocity is determined from expression (4.1), which is essentially the same as equation (8) in BS6399-2.

$$v_b = c_{dir} \cdot c_{season} \cdot v_{b,0}$$ (4.1) from EN1991-1-4

$$V_s = S_d \cdot S_s \cdot S_a \cdot S_p \cdot V_b$$ (8) from BS6399-2

Where	$v_{b,0}$ = V_b =	map wind speed ($v_{b,0}$ is adjusted for altitude in the NA using c_{alt})
	c_{dir} = S_d =	direction factor (the same procedure is used in both standards)
	c_{season} = S_s =	season factor (the same procedure is used in both standards)
	c_{alt} = S_a =	altitude factor (c_{alt} uses an improved, less conservative, version of the BS6399-2 procedure)
	c_{prob} = S_p =	probability factor (the same procedure is used in both standards) note that c_{prob} is not included in expression 4.1 but is allowed in Note 4 of 4.2 (2)P

2.4.4.2 Mean wind velocity

There is no direct equivalent of the mean wind velocity term in the main body of BS6399-2. However, multiplying S_o, the terrain and building factor for hourly mean windspeeds given in Annex C.2.1 by the site windspeed v_s gives the mean wind velocity corresponding to the EN1991-1-4 value. In EN1991-1-4 the mean windspeed is used extensively in Annexes B, C and E for determining inwind and vortex shedding response. It is also used to determine the peak velocity pressure as described in 4.4.4 below.

The mean wind velocity v_m is given by expression 4.3.

$$v_m(z) = c_r(z) \cdot c_o(z) \cdot v_b$$ (4.3)

where $c_r(z)$ is the roughness factor which accounts for the ground roughness of the upwind terrain

$c_o(z)$ is the orography factor which accounts for the effects of topography at the site

The procedure for determining the orography factor is given in Annex A.3 of EN1991-1-4 and is the same as that used in BS6399-2.

The roughness factor assumes an equilibrium wind velocity profile, which implies that the boundary layer is in equilibrium at all heights and does not change with distance downwind. Such a profile could only be established with an upwind fetch of approximately 200km of flat uniform terrain; such conditions do not occur in the UK. Thus in order to more realistically account for changes in wind speed with terrain, the UK NA gives an alternative procedure for determining $c_r(z)$ using Figures NA3 and NA4. Because of this alternative procedure, expression (4.4) for the roughness factor and (4.5) for the terrain factor are not to be used in the UK.

Other points worth noting in this Section are:

- The terrain categories - Table 4.1 defines five terrain categories ranging from sea 0, to city centre IV. For ease of use, the NA reduces the number of terrain categories to three which approximately correspond to the three terrain categories in BS6399-2. These are Sea (category 0), Country (categories I and II) and Town (categories III and IV).
- Increased wind speeds from surrounding buildings - Section 4.3.4 gives guidance to account for the wind speed-up caused by large and considerably taller neighbouring structures. The recommended procedure, given in Annex A.4, is simple to use and generally conservative. This should prove to be more helpful to the user than the guidance given in BS6399-2 which just gives a warning and suggests that specialist advice should be sought.
- Shelter effects - Section 4.3.5 allows the effects of shelter from closely spaced surrounding buildings to be taken in to account. The recommended procedure, given in Annex A.5, is the same as the procedure used in BS6399-2 and uses the displacement height h_{dis}. However, EN1991-1-4 does not give any guidance on how h_{dis} should be used. In general the building height z may be replaced with $z – h_{dis}$. The new figures for the roughness factor, Figures NA3 and NA4, are both given in terms of $z – h_{dis}$.

2.4.4.3 Wind turbulence

The turbulence intensity given in EN1991-1-4 by expression (4.7) is for equilibrium conditions, which as discussed above do not occur in the UK. The effect of distance to sea and distance to edge of town may be accounted for by the turbulence factor, k_i, which has a recommended value of 1.0. In the UK this recommended value is not used. Instead, the NA gives an alternative procedure for determining k_i. However, to make calculation easier graphs of the factor $k_i/ln((z-h_{dis})/z_o)$ are given, which for terrain where orography is not significant gives the turbulence intensity directly. This factor is given in Figure NA5 for sites in Country terrain with a correction factor for sites in Town terrain given in Figure NA6.

2.4.4.4 Peak velocity pressure

EN1991-1-4 uses a simplified expression for the peak velocity pressure given in expression 4.8

$$q_p = 1/2\ \rho\ v_m^2\ [1 + 7I_v(z)] = c_e(z)\ q_b \qquad (4.8)$$

Where $c_e(z)$ is the exposure factor which corresponds to S_b^2 in BS6399-2; except that in EN1991-1-4 a linearised version is used which disregards second order turbulence effects and consequently can significantly underestimate the wind pressure, particularly in urban terrain where the turbulence is greatest. This additional turbulence term is included in the BS6399-2 method (see box).

For this reason expression 4.8 in EN1991-1-4 is not used in the UK and has been replaced by expression NA3

$$q_p = 1/2\ \rho\ v_m^2\ [1 + 3I_v(z)]^2 = c_e(z)\ q_b \qquad \text{(NA3)}$$

To simplify the calculation of q_p, the NA introduces a new term, $c_{e,flat}$ which is the exposure factor for sites where orography is not significant. $c_{e,flat}$ is obtained directly from Figures NA7 and NA8 and replaces $c_e(z)$ in expression NA3. When orography is significant but the height of the structure is less than 50m then the NA gives a simplified conservative procedure for determining q_p using expression NA4.

Comparison between $c_e(z)$ and S_b^2

In EN1991-1-4 the exposure factor $c_e(z)$ corresponds to the terrain and building factor S_b^2 in BS6399-2

From BS86399-2 equation 28, $S_b^2 = S_c^2 (1 + (g_t S_t) + S_h)^2$ (for Country terrain)

Making the substitution $S_0 = (1 + S_h)$ gives

$$S_b^2 = S_c^2 S_o^2 \left[1 + (\frac{g_t S_t}{S_o})\right]^2$$

$$S_b^2 = S_c^2 S_o^2 \left[1 + \left(\frac{2g_t S_t}{S_o}\right) + \left(\frac{g_t S_t}{S_o}\right)^2\right]$$

Compare this with expression 4.8 in EN1991-1-4, $c_e(z) = c_r^2(z)\, c_o^2(z)\, [(1 + 7I_v(z)]$, where $7I_v(z)$ corresponds with $2g_t S_t/S_o$ and $c_r^2(z)\, c_o^2(z)$ corresponds with $S_c^2 S_o^2$. It can be seen that there is no term equivalent to $(g_t S_t/S_o)^2$. The effect of this missing term is to underestimate the wind pressure. In the worst case of a very low building in category V terrain this could be by up to 30% (depending on the turbulence intensity).

$q_p = [q_b\, c_{e,flat}(z)]\, [(c_o + 0.6)/1.6]$ (NA4)

For structures higher than 50m then expression NA3 should be used.

2.4.4.5 Value for air density

The recommended value for air density, ρ, in EN1991-1-4 is 1.25kg/m^3. The UK has historically used a value of 1.226kg/m^3 since the first metric version of CP3: Chapter V: Part 2 (1970). Therefore the recommended value for air density should not be used in the UK, a value of 1.226kg/m^3 should be used instead.

2.4.5 Section 5 Wind actions

This section gives the rules for determining the wind pressures on internal and external surfaces, the wind forces and frictional forces. The approaches used in EN1991-1-4 to calculate wind pressures, wind forces and friction forces are essentially very similar to those used in BS6399-2. However, there are important differences in each of these approaches as described below:

- ***Wind Pressure -*** Expressions (5.1) and (5.2) for external and internal wind pressures do not include the equivalent of the BS6399-2 size effect factor; this factor, called the size factor in EN1991-1-4, is only allowed for external pressures and is included in the equations for wind force.
- ***Wind Force -*** The 0.85 factor used in BS6399-2 Equation (7) to account for the non-simultaneous effects of wind forces on windward and leeward faces is not included in the EN1991-1-4 expressions for wind force. In EN1991-1-4 this factor is applied directly to the pressure coefficients and varies between 1.0 and 0.85 depending on the slenderness of the building. It is recommended in clause 5.3(5) of EN1991-1-4 that this factor only be applied to vertical walls, however, this decision is left to national choice. The UK has decided that this factor may be applied to the horizontal force component from both walls and roofs. This is the same as the approach used in BS6399-2.
- ***Friction Force -*** The frictional coefficients used in EN1991-1-4 are the same as those used in BS6399-2. An inconsistent approach is used in BS6399-2 whereby the friction effects on the roof are

only considered on those parts of a roof whose length exceeds the smaller of W/2 or H, and for walls on those parts whose length exceeds the smaller of W or 2H. In EN1991-1-4, friction effects on walls and roofs are only considered when the roof or wall length exceeds the smaller of 2W or 4H. EN1991-1-4 also has a simple rule allowing friction effects to be disregarded when the area of the surfaces parallel to the wind (i.e. roof and side walls) is equal to or less than 4 times the area of all surfaces perpendicular to the wind (i.e. windward and leeward walls). The area over which the friction force is assumed to act is smaller in EN1991-1-4 than BS6399-2, however EN1991-1-4 does not allow the use of the size factor when calculating friction forces, these are counteracting effects but there will be differences between friction forces calculated from these two methods.

2.4.6 Section 6 Structural factor c_sc_d

This section gives rules for determining the structural factor c_sc_d which accounts for the effect of non-simultaneous occurrence of peak pressures over the surface of the structure or element combined with the effect of dynamic response of the structure or element due to turbulence. For the majority of traditional low-rise or framed buildings c_sc_d may conservatively be taken as 1.0 . Clause 6.2(1) of EN1991-1-4 gives a list of building and element types for which c_sc_d may be taken as 1.0. For other building types, or where a more precise value is required, c_sc_d must be determined using the detailed procedure given in clause 6.3.1. Two alternative procedures are given in Annexes B and C of EN1991-1-4 for determining the parameters required for the calculation of c_sc_d, the recommended procedure is given in Annex B. The UK NA allows Annex B but not Annex C for use in the UK.

The factor c_sc_d is generally treated as a single factor unless otherwise specified in the NA. In the UK it has been decided to allow c_sc_d to be separated into a size factor c_s and a dynamic factor c_d. This is similar to the approach used in BS6399-2, where the size effect factor, C_a, corresponds to the size factor c_s and the dynamic augmentation factor, $(1 + C_r)$ corresponds to the dynamic factor c_d. The decision to allow c_sc_d to be separated was not taken just to promulgate the BS6399-2 approach but because of the positive benefits to be gained from reduced wind loads and also because the procedure for determining c_s and c_d in Annex B is complex and not suited for hand calculation. The NA gives Table NA3 for determining c_s values and Figure NA9 for determining c_d. These have been derived using the detailed procedure in Annex B. In Figure NA9, graphs are given for four classes of structure which correspond to the classes given in Figure 1 of BS6399-2. The benefits of separating c_s and c_d are greatest for large plan area low-rise buildings. For example consider wind loads on the long face of an office building 10m high with plan dimensions of 60m x 20m in Town terrain, using the NA c_d = 1.0 and c_s = 0.77 giving a c_sc_d value of 0.77. This will give a 23% reduction in wind load on this face compared with the c_sc_d value of 1.0 recommended in clause 6.3.1 of EN1991-1-4.

2.4.7 Section 7 Pressure and force coefficients

This section gives pressure and force coefficients for a wide range of buildings, structures and elements (note that force coefficients for bridges and related structures are given in Section 8).

EN1991-1-4 uses four separate types of aerodynamic coefficient:

- Internal and external pressure coefficients
- Net pressure coefficients
- Friction coefficients
- Force coefficients

The first three will be familiar to users of BS6399-2. Force coefficients give the overall load effect on a structure or element and include friction effects, whereas pressure coefficients do not. Therefore friction coefficients may be applied in conjunction with pressure coefficients but should never be used with force coefficients.

2.4.7.1 Pressure Coefficients

Pressure coefficients are given for buildings in Section 7.2. There are many similarities between the EN1991-1-4 and BS6399-2 pressure coefficients, because they were largely based on those given in the BS6399-2 standard method. The layout of the tables and figures and the size of the roof and wall zones will therefore be familiar to UK engineers. There are some omissions and differences, for example, EN1991-1-4 does not include directional pressure coefficients, information on inset stories, polygonal plan shapes, re-entrant corners, irregular faces or multipitch roofs. The major differences are:

- ***Pressure coefficients***
  Two sets of pressure coefficients, $c_{pe,1}$ and $c_{pe,10}$ are given in EN1991-1-4 for most building forms. $c_{pe,1}$ values are intended to be used for the design of small elements and fixings, and $c_{pe,10}$ values are for design of loaded areas over 10m^2. In general the $c_{pe,10}$ values are similar to those given in BS6399-2. For loaded areas between 1m^2 and 10m^2 EN1991-1-4 recommends that logarithmic interpolation be used using Figure 7.2. After consultation with UK industry it was concluded that this would impose a considerable unnecessary burden in calculation effort. Consequently Figure 7.2 is not to be used in the UK. The NA gives a simplified alternative procedure in which the $c_{pe,1}$ values should be used for all fixings and elements of 1m^2 or less and the $c_{pe,10}$ values should be used for all loaded areas >1m^2.

- ***Division by parts***
  The rule on division by parts has been changed, it may now only be applied to the windward walls; in BS6399-2 it could be applied to all walls but only for determining overall loads

- ***Pressure coefficients for vertical walls***
  In EN1991-1-4 these values depend on d/h ratio, this is the inverse of the ratio used in BS6399-2. The effects of wind funnelling are not included in EN1991-1-4. Also note that Table 7.1 should not be used in the UK. It has been replaced in the NA by Table NA4 which now includes net pressure coefficients for overall load; this corresponds to Table 5a in BS6399-2.

- ***Pressure coefficients for circular (vaulted) roofs***
  Figure 7.11 pressure coefficients for vaulted roofs, should not be used in the UK. This has been replaced in the NA by Figures NA10 and NA11 which provide more reliable data and include the effects of roof length. Pressure coefficients for vaulted roofs are not given in BS6399-2.

- ***Internal pressures***
  In BS6399-2 only two possible values for internal pressure, +0.2 and -0.3 are given for the general case with no dominant openings. It is known that the internal pressure can take values within this range, or even outside of this range in some circumstances. The approach used in EN1991-1-4 is based on the permeability of each wall and roof and allows a more precise value of internal pressure to be calculated depending on the approaching wind direction.

2.4.7.2 Net pressure coefficients

Net pressure coefficients are given for canopy roofs, free-standing walls and parapets. These data are based on BS6399-2, however, there are some differences, for example:

- ***Monopitch canopies***
  Some of the pressure coefficients have been increased and the distance of the centre of pressure from the windward edge has been reduced from 0.3W used in BS6399-2 to 0.25d in EN1991-1-4.

- ***Free-standing walls and parapets***
  In BS6399-2 a reduction factor is given to account for end effects, in En1991-1-4 this factor has been combined with the pressure coefficients. The figure for the effect of shelter from upwind walls has been simplified.

2.4.7.3 Force coefficients

Force coefficients are given for signboards, structural elements, circular cylinders, spheres, lattice structures and flags. BS6399-2 does not give any force coefficients; however' it does give net pressure coefficients for signboards and for a limited range of structural elements, which for these cases can be considered to be equivalent to force coefficients. It should be noted that for slender structures with h/d > 5 the force coefficients for elements may be used. This causes a discontinuity around h/d = 5 because the loads for h/d<5 are derived from pressure coefficients and the loads for h/d>5 are derived from force coefficients. This more likely reflects the uncertainty and lack of information on force/pressure coefficients on tall buildings rather than an aerodynamic effect.

2.4.8 Annexes

There are six informative annexes in EN1991-1-4:

- Annex A - Terrain effects
- Annex B - Procedure 1 for determining the structural factor c_sc_d
- Annex C - Procedure 2 for determining the structural factor c_sc_d
- Annex D - c_sc_d values for different types of structure
- Annex E - Vortex shedding and aeroelastic instabilities
- Annex F — Dynamic characteristics of structures

Of these Annexes C, D and E will not be used in the UK.

Annex A contains five parts of which part A.2 Transition between roughness categories 0, I, II, III and IV, will not be used in the UK because transition effects are contained in Figures NA3 to NA8 in the National Annex.

Annex B gives the recommended procedure for determining c_sc_d and is based on the procedure given in the ENV version of EN1991-2-4.

Annex F gives recommendations for determining the basic structural parameters that are required for determining dynamic response of structures, such as:

- natural frequencies
- modal shapes
- equivalent masses
- logarithmic decrements of damping.

Annex E does not include adequate information on aeroelastic response of bridge decks. For this reason Annex E will not be used in the UK. It will be replaced by a new document based largely on the existing Annex E but with additional information for bridges. This new document will not be part of EN1991-1-4, but is expected to be published as a companion document (NCCI).

2.5 Road map

EN1991-1-4 includes two general procedures for calculating wind loads on buildings and structures, these are:

a) a standard procedure that applies to those structures whose structural properties do not make them susceptible to dynamic excitation. This procedure applies to the following classes of structure:

- Any building of height less than 15m
- Fa ade and roof elements which have natural frequencies > 5Hz
- Framed buildings with structural walls of <100m in height and whose height is also less than 4 times their in-wind depth.
- Circular chimneys with height <60m and whose height is also less than 6.5 times their diameter

b) a detailed procedure that applies to those structures which are likely to be susceptible to dynamic excitation and which fall outside of the scope of the standard procedure.

It is anticipated that the standard procedure will be used for the design of the majority of buildings and structures in the UK, including dwellings, low-rise buildings and medium-rise buildings. The detailed procedure is likely to be used, or at least considered, in the design of tall buildings, chimneys, masts, long-span bridges and other similarly wind sensitive structures.

The number of steps required in EN1991-1-4 to determine wind loads for the majority of buildings and structures is the same as in BS6399-2. In general the 6 steps outlined in Table 4 are required (the equivalent steps in BS6399-2 are also shown in this table for comparison).

Table 4 Summary of calculation steps to calculate wind load using EN1991-1-4 and BS6399-2

EN1991-1-4 Procedure	BS6399-2 Procedure
1. Read $V_{b,map}$ from map, adjust for altitude	1. Read V_b from map
2. $v_b = c_{dir}\ c_{season}\ c_{prob}\ v_{b,0}$	2. $V_s = V_b\ S_s\ S_d\ S_a\ S_p$
3. $q_b = 1/2\ \rho\ v_b^2$	3. $V_e = V_s\ S_b$
4. $q_p = c_{e,flat}(z)\ q_b$	4. $q_s = 1/2\ \rho\ V_e^2$
5. $W_e = q_p(z)\ c_{pe}$	5. $p = q_s\ C_{pe}\ C_a$
6. $F_w = c_s c_d\ \Sigma\ W\ A_{ref}$	6. $P = 0.85\ (\Sigma\ P_{front} - \Sigma\ P_{rear})\ (1 + C_r)$

Table 5 outlines the steps required to determine wind loads on buildings and structures where $z < 50$m and orography is not significant. In other cases the number of steps increases, however the NA has greatly simplified EN1991-1-4 by introducing alternative procedures for determining the design wind load by presenting parameters such as the roughness factor c_r, the turbulence factor $(k_I/\ln((z-h_{dis})/z_o)$, the exposure factor $c_{e,flat}$ and the size and dynamic factors c_s and c_d in a tabular or graphical format. This speeds up the design process, reduces the calculation effort and improves the accuracy over the EN1991-1-4 original procedures, whilst still being fully compatible with the EN1991-1-4 principles. Figure 1 shows the flow chart for determining wind loads using the NA and EN1991-1-4 simplified and general methods.

Figure 1 Flow chart for determining wind loads using the UK NA with EN1991-1-4

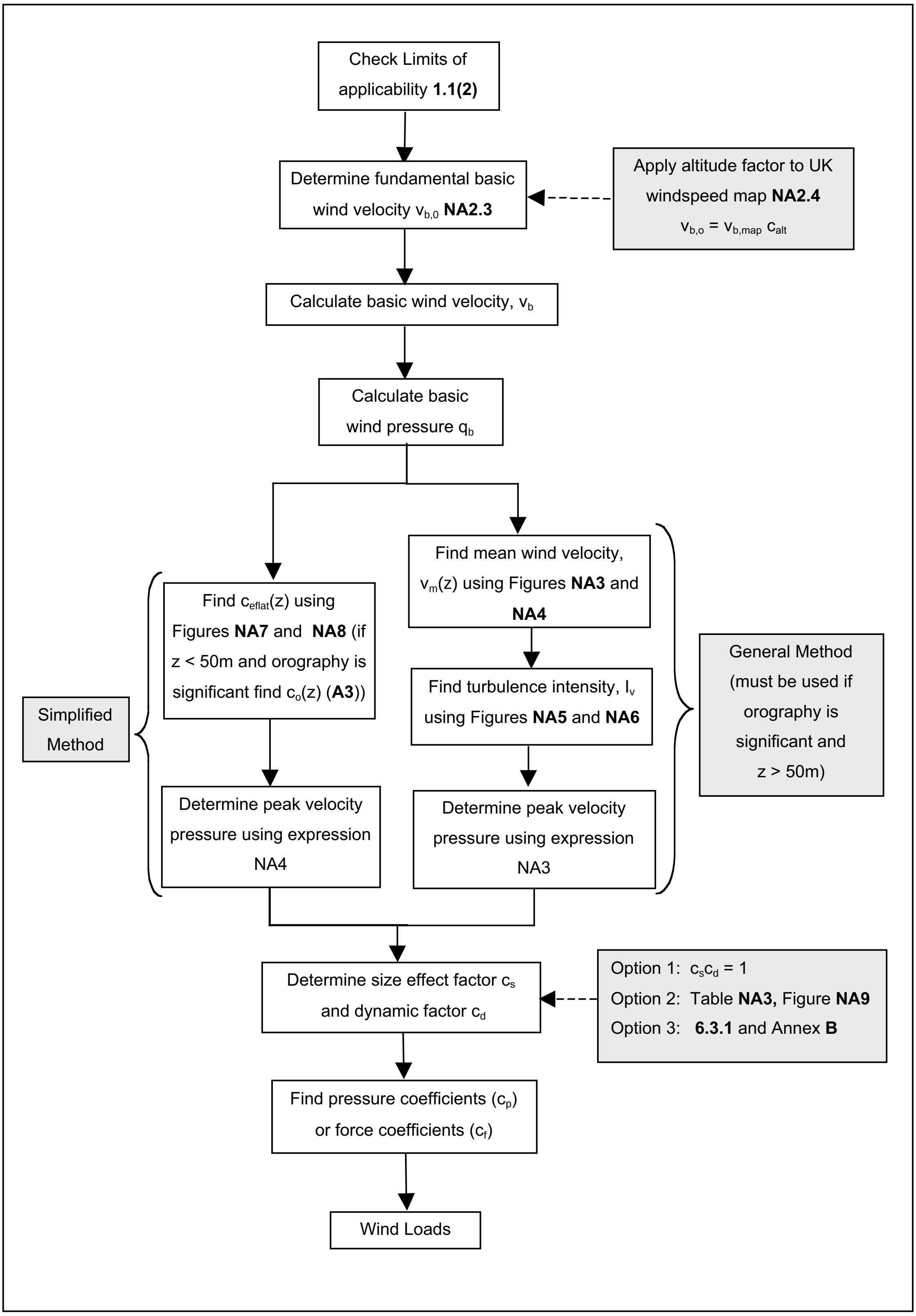

Table 5 Main differences between EN1991-1-4, including the National Annex, and BS6399-2

	EN1991-1-4	BS6399-2	UK National Annex	Commentary
Scope	Buildings and civil eng. works	Buildings and their components	No change	Much wider scope in EN, includes: buildings, bridges, chimneys, masts, towers, lattice structures, etc. but excludes guyed masts, lattice towers, lighting columns
Methods	Standard procedure	Standard method	Modified in NA 2.19	The standard procedure may be used for buildings where H<15m or 100m < H < 4D or for a wider range of buildings using the modified procedure given in the NA
		Directional method		
	Detailed procedure	Hybrid method		The detailed procedure should be used for buildings which have a significant dynamic response
Wind speed	Fundamental basic wind velocity v_b	Basic wind speed V_b .	Map Figure NA1 .	EN1991-1-4 is based on a 10-minute mean wind speed, BS6399-2 is based on a mean hourly wind speed
	Mean wind velocity v_m	No equivalent		Corresponds to v_s S_o in BS6399-2 where it is only used in annex C.2.1
	Basic wind velocity v_b	Site wind speed V_s		The basic wind velocity corresponds to the site wind speed in BS6399-2
				v_b is calculated for the actual building height. V_s is calculated for a 10m reference height
	No equivalent	Effective wind speed V_e		EN1991-1-4 does not directly calculate gust wind speed
	Orography factor c_o	Topography increment S_b		Same as the procedure used in the BS6399-2 directional method
	Altitude factor c_{alt}	Altitude factor S_a	Given in NA 2.4	Similar to BS6399-2 procedure but allows a reduction in c_{alt} with height above ground
	Directional factor c_{dir}	Direction factor S_d	Given in NA 2.5	Same as the BS6399-2 procedure
	Season factor c_{season}	Seasonal factor S_s	Given in NA 2.6	Same as the BS6399-2 procedure
	Roughness factor $c_r(z)$	Fetch factor $S_c T_c$	Modified in NA 2.10	The NA gives a simplified procedure for determining $c_r(z)$ using Figures NA3 and NA4
	Turbulence intensity $I_v(z)$	Turbulence factor S_t T_t	Modified in NA 2.15	The NA gives a simplified procedure for determining $I_u(z)$ using Figures NA5 and NA6
	Exposure factor $c_e(z)$	Terrain & building factor S_b^2	Modified in NA 2.16	The NA gives a simplified procedure for determining $c_e(z)$ in flat terrain using Figures NA7 and NA8
Terrain categories	Five terrain categories 0, I, II, III and IV	Sea, Country Town	Modified in NA 2.10	The NA combines the five EN1991-1-4 terrain categories to give three categories that correspond to those in BS6399-2, Sea (cat 0), Country (cat I & II) and Town (cat III & IV)
Wind Pressure	Peak velocity pressure $q_p(z)$	Dynamic pressure q_s	Modified in NA2.16	The NA gives an alternative procedure for $q_p(z)$ which corresponds to the BS6399-2 procedure, except that the gust factor g_t, which is a variable in BS6399-2, has a fixed value of 3.0
Pressure coefficients	Orthogonal pressure coefficients $c_{pe,1}$ and $c_{pe,10}$	Orthogonal and directional pressure coefficients	Modified in NA 2.24	The NA gives an alternative procedure for determining c_{pe} for areas between 1m^2 and 10m^2. EN1991-1-4 does not include directional pressure coefficients.
Force coefficients	Given for some buildings and elements	No force coefficients given		EN1991-1-4 gives force coefficients for tall slender buildings, lattice frames and elements

3. References

1. EN1991-1-4, Eurocode 1: Actions on structures – General actions – Part 1-4: Wind actions, CEN 2005.

2. BS6399-2: 1997, Loading for buildings – Part 2: Code of practice for wind loads, BSI, June 2002

3. Cook N J, Designers' Guide to EN1991-1-4 Eurocode 1 Part 4 - Wind actions. ISBN 0727731513

4. Rees J, The assessment of site wind speeds at Bilsdale Mast using computational fluid dynamics, IASS Working Group 4 for masts and towers, 21st meeting, Milan, September 2003.