Eurocode 5 (EC5): Design of Timber Structures

An Overview & Comparison with the BS 5268-2 Method

Effective from late 2006
Compulsory from 2009 / 2010

1 Introduction

The development of a structural building code is an immensely important matter because human safety is involved. This was so, even as early as the 18th century BC. Article 229 in the Code of Hammurabi, reads: "The builder has built a house for a man and his work is not strong: if the house he has built falls in and kills a householder, that builder shall be slain." Interestingly, the death penalty did not apply if the cause of the collapse was a hurricane or an earthquake, because such extraordinary events were not considered to be under the control of the designer or builder.

Fig 1 Saville Building, Windsor Great Park - designed using Eurocode 5: External decking

The Eurocode process started in the 1970s. The then European Economic Community issued a Construction Products Directive (CPD), which declared that the existence of different national codes and standards constituted "a barrier to trade". It was decided to produce, by consensus, a new set of unified design codes and supporting material standards to cover all the major building materials – a hugely ambitious project, but now largely completed.

A design code like Eurocode 5 is a rule book for structural engineers. It sets out agreed calculation methods for checking the strength, stiffness and stability of buildings and other structures. EC5 is a design code for timber structures and currently co-exists with BS 5268-2, which it will fully replace in 2009 /10. It has already been used to design a number of beautiful buildings in the UK, including the Sheffield Winter Garden (See Fig 3). This indoor park was opened in 2003 and has won four major awards. The glulam arches for the roof were designed to EC5. The roof of the Saville Building in Windsor Great Park (See Figs 1, 5 & 6) was also designed using EC5.

2 Scope of briefing

This briefing is aimed at the semi-technical reader who wants to better understand the changes that lie ahead for timber as we make the transition from the current system (largely to BS 5268-2 for timber) to the new system of Eurocodes. The briefing concentrates, therefore, on Eurocode 5 (BS EN 1995) and in particular Part 1-1: General – Common rules and rules for building. There are two further significant parts, which are not within the scope of this briefing:

- Part 1-2: General – Structures and fire design
- Part 2: Bridges

At a technical level the subject is vast. TRADA recognises that thousands of design professionals and suppliers will need in-depth technical guidance to work to the new rules and make the transition. To this end, TRADA is publishing in conjunction with the Institution of Structural Engineers (IStructE) a comprehensive technical guide to EC5 (Design of timber structures) in Autumn 2007.

This briefing covers the following topics:

- Purpose of the new Eurocode system
- Timescales for implementation
- An overview of the Eurocode documents / standards
- Limit state design philosophy
- Comparison of approach: EC5 vs BS 5268-2
- Advantages and disadvantages of the EC5 approach
- Further help

3 Purpose of the Eurocodes

The Eurocodes are to become the new rule books for structural engineers. But what is wrong with the old / current codes for structural design? Are they technically inadequate for our current needs?

Although the new rules are technically very different in approach, the purpose for introducing them is not primarily because of technical concerns over our current codes. The reason is linked to the raison d'être for the European Union. In particular the goals for the Eurocodes are to:

- Remove obstacles to the free movement of goods and services within the European Union by providing common rules for calculation and design;
- Serve as a basis for reference in contracts both within and outside the European Union; and
- Improve the competitiveness of the European construction industry by offering advanced concepts of calculation and design.

4 Timescales for implementation

4.1 General

It has formally been possible to design using EC5 since the end of 2006 and informally some considerable time before that. It has equally been possible to design to the Eurocodes in other materials. The formal requirement, set by the Department for Communities and Local Government (DCLG), formerly ODPM, is for both the specific Eurocode standard (eg EC5) and the National Annex to be published. These two criteria were reached for timber at the end of 2006. The National Annex is an important document, which provides the necessary data allowing each member state to calculate certain parameters where particular geographical conditions (eg weather), serviceability requirements or levels of workmanship may be taken into account.

Fig 2 shows the sequence of events and timescales set by DCLG for introducing each Eurocode (ie relating to each material sector).

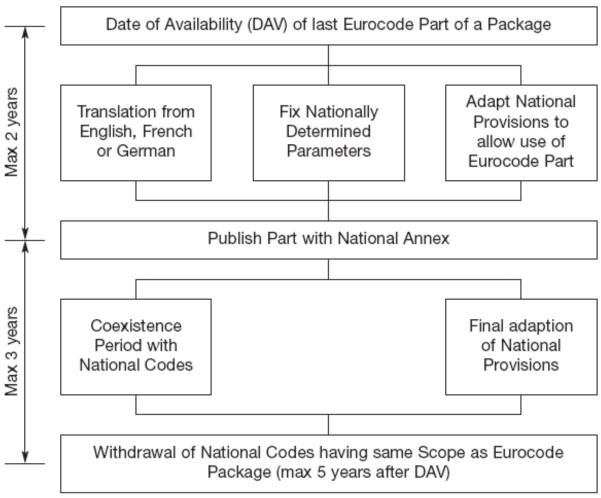

Fig 2 Illustration of general timetable from Date of Availability of Eurocode to withdrawal of National Codes. Taken from 'Implementation of structural Eurocodes in the UK', by ODPM, Feb 2003.

4.2 The Building Regulations

The regulations in England & Wales (Part A) and Scotland (Section 1) have all been amended to allow structural design requirements to be calculated to the Eurocodes. In other words we are formally in the period of co-existence shown in Fig 2.

Section 1 of the Technical Handbook to the Scottish Regulations, which was amended in May 2007, clearly states the period of co-existence will end in Scotland by 2010 at the latest.

Given that EC5 and the National Annex had both been published by the end of 2006, and that there is a maximum three-year transition period, we should see the withdrawal of the British Standards for timber design by the end of 2009.

4.3 Making the transition

Although it is fairly obvious, it is probably worth making the point that it is very easy to make the transition from using only the old system to being able to use both. Those who wish to grapple with the new rule book on certain projects can, while those who do not wish to do so are under no compulsion to change. However, moving from voluntary adoption of the new to compulsory use is a different matter altogether!

5 An overview of the Eurocode documents

Four tables / charts are provided as follows:

Table 5.1	This is a list of all the top level documents. Those required in order to design in timber are shown in bold.
Table 5.2	Contents of the UK National Annex to EC5.
Table 5.3	This provides a list of the sections within EC5 with some explanatory commentary.
Fig 4	This shows the hierarchy of documents relevant to timber design.

Fig 2 Sheffield Winter Gardens, courtesy of Buro Happold, Structural Engineers: Internal view

Table 5.1 List of Eurocodes (those relevant to timber are shown in bold)

Standard	Title
EN 1990[1]	**Eurocode - Basis of structural design ("Eurocode 0")**
EN 1991[2]	**Eurocode 1 - Actions (loads) on structures**
EN 1992	Eurocode 2 - Design of concrete structures
EN 1993	Eurocode 3 - Design of steel structures
EN 1994	Eurocode 4 - Design of composite steel & concrete structures
EN 1995	**Eurocode 5 - Design of timber structures**
EN 1996	Eurocode 6 - Design of masonry structures
EN 1997	Eurocode 7 - Geotechnic design
EN 1998	Eurocode 8 - Design of structures for earthquake resistance
EN 1999	Eurocode 9 - Design of aluminium structures
	National Annex for the UK

Notes:

[1] EN 1990 sets out the design principles for all the structural building materials. It is usually referred to as "Eurocode 0", even though its correct title is simply "Eurocode".

[2] EN 1991 is the loading code, equivalent to BS 6399. It includes snow and wind loads and a vast array of self-weights. These include dry chicken manure, raspberries and mercury at 133kN/m^3 – so it should be possible to design structures for virtually every purpose!

6 Limit state design philosophy

A structure must be designed to sustain safely the loads and deformations which may occur during construction and in use, and should have adequate durability during the life of the structure. The design method aims at guaranteeing adequate safety against the structure being rendered unfit for use. A structure, or part of a structure, is rendered unfit for use when it reaches a limit state, defined as a particular state in which it ceases to fulfil the function or to satisfy the condition for which it was designed. There are two categories of limit states:

- An ultimate limit state is reached when the structure (or part of it) collapses. Collapse may arise from the rupture of one or more critical sections, from the transformation of the structure into a mechanism, from elastic or inelastic instability, or from loss of equilibrium as a rigid body, and so on.
- The serviceability limit states are those of excessive deflection, cracking, vibration and so on.

Normally, three limit states only are considered in design: the ultimate limit state and the serviceability limit states of excessive deflection and cracking under service loads. The structure is usually designed for the ultimate limit state and checked for the serviceability limit states. Structural collapses often have serious consequences; therefore in design the probability of reaching the ultimate limit state is made very low, say, 10^{-6}. Since the loss resulting from unserviceability is generally much less than that from collapse, a probability much higher than 10^{-6}, of reaching a serviceability limit state may still be acceptable. In limit state design, the engineer's aim is that the probability of each limit state being reached is about the same for all the members in a structure and is appropriate to that limit state.

Table 5.2 Contents of the UK National Annex to EC5

Contents of National Annex
• Assignment of loads to load duration classes
• Assignment of timber constructions to service classes
• Partial factors for material properties
• Limiting values for deflections
• Limiting values for vibrations
• Design method for domestic floor vibrations
• Advice on nailed timber-to-timber connections
• Choice of method for design of wall diaphragms
• Modification factors for bracing of beam and truss systems

In contrast to timber, other material types (eg concrete and steel) have been designing using the 'limit state design' approach for many years. For concrete and steel the Eurocodes represent a significant change in detail but not a change in philosophy.

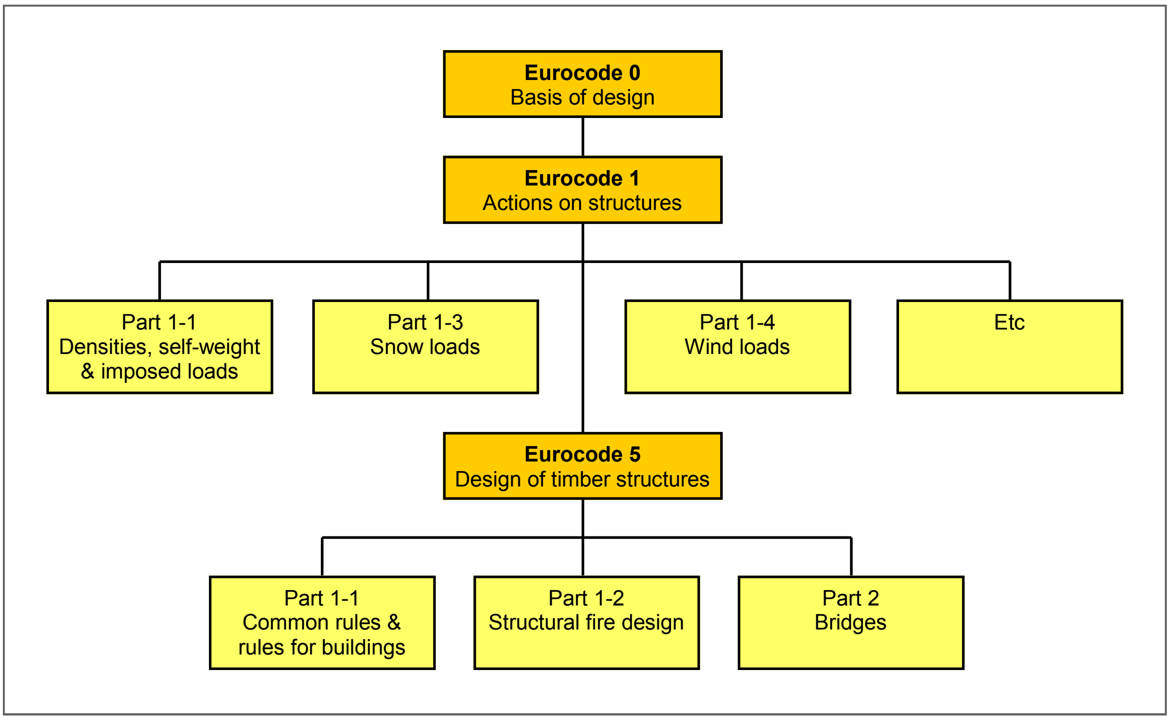

Fig 4 Hierarchy of Eurocode documents relevant to timber design.

Table 5.3 List of the sections within EC5 (EN 1995) Part 1-1

EN 1995-1-1 is the largest part of EC5 and is itself divided into the 10 sections described below. EC5 assumes a knowledge of EC0 which sets out the general design principles which apply to all structural building materials.

Section of Part 1-1	Commentary on the contents
1 General	Consists mainly of definitions.
2 Basis of design	Supplements Eurocode 0 with timber-specific matters – service classes, load duration classes, creep and slip, plus partial safety factors for different timber based materials.
3 Material properties	This section does not include properties as such – these have to be sought in various materials standards which are published separately – but gives tables of values to allow for the effects of service class, load duration and creep.
4 Durability	This is a one-page chapter on durability which includes a very useful table of specifications for the corrosion protection of metal fasteners.
5 Basis of structural analysis	This section is also short, covering mainly the analysis of assemblies including frames and arches.
6 Ultimate limit states	An important section covering the design of beams and columns, and tapered, pitched and curved beams.
7 Serviceability limit states	An explanation on how to calculate the initial and final slip in mechanically fastened joints, and how to check the vibration of domestic floors – the satisfactory vibration performance of floors is a requirement for floor design in Eurocode 5.
8 Connections with metal fasteners	The longest chapter in the code - a reminder that the design of connections is one of the most important, and most difficult, aspects of timber design. Much of this chapter has already been incorporated into BS 5268, but in Eurocode 5 only the formulae are provided: there are no pre-calculated tables of basic loads which a designer can look up for a quick first design.
9 Components and assemblies	Very useful guidance for the design of items such as I-joists, stressed skin panels and bracing. It also contains the biggest problem area for Eurocode 5 - two methods for designing wall panels to resist racking loads, neither of which is very helpful for conventional UK timber framing. Fortunately an international group, including UK experts, has almost completed a third Eurocode 5-compatible approach which will meet our national needs and which we hope will be included or referenced in the EC5 National Annex as an acceptable alternative.
10 Structural detailing and control	Like its counterpart in BS 5268, this is fairly short, and includes quite a bit on connections.

Fig 5 Saville Building, Windsor Great Park: External roofline

7 Comparison of approach: EC5 vs BS 5268-2

There are many differences in approach between the two codes. In fact the only area where there is not a great deal of difference is the resulting designs! The main attributes of the codes are compared in the table below.

Attribute (including definitions)	EC5	BS 5268
1 General philosophy	**'Limit state design'.** Largely formulaic with very few tables of results. Broadly speaking the design process is the same irrespective of the material type used.	**'Permissible stress design'.** Mainly calculated using tables with few formulae. The approach differs depending on the material type used for the structure.
2 Presentation of the strength properties of materials *The inherent strength performance of individual species / materials when tested under load.*	The properties are presented as 'characteristic test values'. These are simply test values, giving the low 5^{th} percentile value, with no in-built safety factors – these must be added by the designer.	The properties are presented as 'grade stresses'. These have built-in long-term duration factors required for service classes 1 and 2 (see item 7 below).
3 Load durations *Factors applied to take account of how well a material performs under load over longer periods of time.*	The characteristic values referred to above are based on 5-minute duration tests. Because timber's resistance to load is affected by duration, a reduction factor must be applied by the EC5 designer. As an example, in the case of long-term or permanent loads, a reduction factor of 0.6 for solid timber is required for service classes 1 and 2 (see item 7 below).	The long-term effect of load is already taken into account in the tabulated values.
4 Stiffness properties (elastic moduli) *The measured extent to which a material will bend under a load.*	Defines a mean (E_{mean}) and a characteristic value (E_x). Uses the E_x for column stability (strength) and E_{mean} value for member deflection calculations.	Defines a mean (E_{mean}) and minimum value (E_{min}). E_{min} is equivalent to E_x in EC5. Uses E_{min} for column stability and single member deflection calculations and E_{mean} for deflection calculations in load sharing systems.
5 Inclusion of safety factors *Factors applied to allow for margins of error elsewhere.*	Specified factors are applied both to loads and material properties, increasing the loads and decreasing the characteristic materials properties. Timber-based materials which are manufactured to produce less variability eg LVL, are given a lower (or better) safety factor.	All the safety factors are built into the tabulated grade stresses. One consequence of this is that it is difficult to establish what the factors are.

Attribute (including definitions)	EC5	BS5268
6 Load duration classes *A factor which takes account of the period of time that loads are likely to be imposed. Structures taking a load for long periods need to be designed to higher levels of performance.*	EC5 distinguishes between 'permanent loads', nominally having a duration of 50 years (eg self-weight) and long-term loads, corresponding to a duration up to 10 years (eg storage). EC5 combines the result of the load duration class and service class (see below) in a single combined strength factor.	Load duration is calculated as a separate factor.
7 Service classes *This refers to the environmental conditions, which affect the moisture content, which in turn affects the strength and stiffness of timber. Class 1 = heated indoors, Class 2 = unheated indoors / covered outdoors, Class 3 = exposed outdoors.*	EC5 combines the result of the load duration class (see above) and service class in a single combined strength factor.	BS5268 adopted the EC5 service classes in a previous revision. Service class is calculated as a separate factor.
8 Creep *Additional deflection (bending) to that experienced initially and which occurs after a period of time (eg a bookshelf with heavy books after one year).*	Creep must be calculated separately and added to the figure for initial deflection to provide a value for total deflection.	Generally it is considered unnecessary to calculate for creep. Annex K does provide a method of calculating creep deflection in beams, for information only.
9 Limit states *Limits placed on what is considered acceptable in terms of safety (eg risk of collapse) and comfort / appearance (eg risk of plasterboard cracking).*	Ultimate Limit States (ULS): Addresses strength and stability issues critical to the safety of the building. Beyond these limits the building may fail. Serviceability Limit States (SLS): Addresses such issues as deflection, joint slip and vibration, critical to the comfort / appearance / functioning of the building.	BS 5268 addresses ULS with regard to strength in a similar manner to EC5 (with the exception that safety factors have already been added). With regard to seviceability, BS 5268 only addresses initial deflections (without creep). In a simplistic manner, it also sets an upper limit of 14mm for static deflection to avoid too much vibration in floors.
10 Deflection limits *The design limit set on the acceptable deflection distances for any structural member.*	These are advisory in EC5 on the basis that deflection is not normally a safety issue. EC5 provides suggested ranges for deflection limits. The UK National Annex provides some recommendations. TRADA and other bodies may provide others. The client and designer must agree on what is appropriate.	Deflection limits are mandatory for floors.

Attribute (including definitions)	EC5	BS 5268
10 Combinational values of variable loads *When two or more variable loads (eg snow and wind) act on a member, it is unlikely that both will be at their full characteristic value simultaneously.*	EC5 allows for a non-conservative approach to calculate the optimal value of the design load by: • taking each factor and assuming it is at its full characteristic value; and then • taking all other factor(s) and applying a given reduced factor for each. As the number of simultaneous variable loads increases, so the number of permutations multiplies geometrically. In the case of trussed rafter design there can be well over 100 combinations and load cases to consider – making it necessary to use spread sheets to keep time to a minimum.	Typically all the loading factors are added up to give a conservative result.
11 Irreversible vs reversible limit states	EC5 makes the following distinctions: An **irreversible limit state** involves irreversible damage when it is exceeded – eg excessive deflection on a plasterboard ceiling causing it to crack. A **reversible limit state** involves no permanent change – when the load is removed components return to their original state – eg snow on a rafter. Since the consequences of breaching a reversible state limit are less serious, it is 'safe' to reduce the accompanying variable loads. Psi factor values for this are given in the UK National Annex to EC0.	No such distinction is made. BS 5268 provides little guidance on this. A static deflection limit of 0.003 times the span is given as guidance to prevent irreversible limit state (which is the worst of the two cases).
13 Vibration response of floors to impact loading In other words, does the floor vibrate when you walk over it?	EC5 provides formulae but they are complicated to use.	BS 5268 does not cover vibration calculations. Instead it sets a maximum deflection limit of 14mm to address the problem.
14 Beam and column formulae	The EC5 method for dealing with beams allows for an effective reduction in the bending strength to allow for lateral-torsional instability. The method for columns allows for bending moments in both directions as well as the axial forces.	BS 5268 does not allow for lateral-torsional instability. BS 5268 only gives formulae for combining axial load with bending in one direction.
15 Tables for fastener loads	No tables are provided in EC5 – the approach is entirely based on formulae. For timber to timber constructions the formulae are the same as those given in Annex G of BS 5268. Special formulae are also given for steel to timber connections.	Tables of values are provided for a range of fasteners. Some formulae are provided for timber to timber connections in Annex G. Only a "rough and ready" method is provided for steel to timber connections.

8 Advantages and disadvantages of the EC5 approach

The advantages

The same design basis is used for all materials including timber.
Once designers become familiar with Eurocodes it should become much easier to switch between designing in timber and other materials. At present, a relatively small percentage of engineers are experienced in designing in timber and there is an in-built inertia to develop one's knowledge in this area.
Note: In contrast to timber, other materials have been using a form of limit state design for many years.

The safety factors are transparent.
Because the safety factors are all kept separate, it is easy to modify them when there is reason to do so. Sometimes this will yield more efficient material solutions.

The levels of reliability are more logical and consistent.

Designs can sometimes be more economical.
This is because all the required factors are built up separately, rather than sometimes including them unnecessarily in a conservative approach.

Some aspects are handled in a better way.
For example the approaches to beams and columns, creep and steel to timber connections.

The formulaic approach is ideal for spreadsheets and software.
Once you have developed the necessary formulae within a spreadsheet, it is much easier to iterate towards optimum solutions.

EC5 Part 2 is the first design code for timber bridges in the UK.
This could provide the impetus for choosing timber for smaller access bridges as well as for footbridges in parks and leisure centres.

The disadvantages

It is more complicated to use than BS 5268.
This is because all issues are addressed separately. No issues / factors are built into tabulated values. From a commercial point of view it is impossible to design without the efficient use of a computer.

More additional documents are required.
For example, documents covering strength properties of timber, plywood and glulam etc.

No tables are given for permissible fastener loads.
The tables in BS 5268 can make calculations very quick in comparison.

Some areas lack practical guidance.
Areas that need more practical guidance include:

- lateral restraint for beams
- trussed rafter bracing
- masonry wind shielding
- methods of calculating spans for domestic members

Some subjects are missing.
For example there is nothing on the design of glued joints or glued in rods.

Fig 6 Saville Building, Windsor Great Park: Underside of roof in gift shop

9 Further help

TRADA Wood Information Sheet: Eurocode 5 – An introduction
Further introductory guidance available at:
www.trada.co.uk

IStructE / TRADA EC5 Design Manual
Comprehensive practical guidance on designing to EC5 with plenty of tables. Available from TRADA bookshop from Autumn 2007.

BS PD 6693 – A 'rump standard'
UK timber professionals have agreed to produce a publication to include all the practical information in the various parts of BS 5268 which would otherwise be lost.

Software to assist in designing to EC5
Various companies will be producing software design tools. A working trial version of TRADA's 'Actions pre-processor' is available at:
http://research.ttlchiltern.co.uk/pii304 (click on 'outputs')

Timber Design Knowledge
Free downloadable general guidance on designing in timber including case studies, is available at:
http://research.ttlchiltern.co.uk/pif294

Fig 7 Sheffield Winter Gardens, courtesy of Buro Happold, Structural Engineers: Internal view

Further help

TRADA members may contact the Members' Helpline for free on t: 01494 569601.

Other useful websites

Eurocode website:
www.eurocodes.co.uk

Institute of Structural Engineers (IStructE):
www.istructe.org

TRADA Construction Briefings

This document is part of a series of briefings for TRADA members on the key elements of building regulations and codes and how they relate to timber construction. Copies of all briefings are available at www.trada.co.uk.

Feedback

We welcome feedback from readers and if you have any comments on the content of this briefing please contact Rupert Scott on rscott@trada.co.uk.

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