

STANDARDISATION OF STRUCTURAL DESIGN: A SHIFT FROM BRITISH STANDARDS TO EUROCODES

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Abstract. The background, objectives and mechanics of producing Eurocodes for structural design in concrete, steel and masonry are described. Comparisons are made between the approaches recommended by existing British Standards structural codes and corresponding Eurocodes. Eurocodes, together with some of the factors which influence its use, is discussed in the hope that it might be helpful to professionals in deciding its future applications in Malaysia. Existing knowledge based on British Standards is examined, as is the ability of Eurocodes to transfer technology in codes of practice and materials standards indirectly from one country to another.

Key words: Structural Design, British Standards, Eurocodes, Standardisation.

1.0 INTRODUCTION

The idea to develop a set of harmonised and common structural design codes for European countries started in 1974, originated in 1957 at the Treaty of Rome through the European Economic Community (EEC). The presence of the common codes amongst European member states has been seen advantageous particularly in lowering trade barriers between them and enables engineers, contractors and consultants from the member states to practice within all European countries (EC) and to compete fairly for works within Europe. The use of a common code is also expected to lead to a pooling of resources and sharing of expertise, thereby lowering the production costs.

In the seventies, the international technical and scientific organisations in Europe agreed to prepare works in coordinating the design principles, formulating rules and establishing the state-of-the-art technical reports. Thereafter, the Commission of European Communities (CEC) took the initiative to elaborate these preparatory works by establishing five working expert groups, including one on "Stability of Structures" which listed the main design codes, latter became known as Structural Eurocodes. However, at that time there was no legal obligations in using the codes for the codes are only to facilitate commercial exchanges between EEC countries

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and promoting the use of a single European standard for construction methods, materials, types of buildings and civil engineering works. The formation of the Single European Act in 1986 was the one which provides impetus to tackle the legal issues to the process of harmonisation. This Act provides directives in which no legislation can stop the exchange of European construction products. Each Eurocode has been drafted by a small group of experts from various member states. These groups were formerly under contract to the EC Commission but are now under the direct control of CEN (Comite Europeen de Normalisation), the European Standards Organisation. A liaison engineer from each member state has been involved in evaluating the final document and discussing with the drafting group on the acceptability of the Eurocode in relation to the national standard from the country which they present.

The Commission of the European Committee (CEC) initiated the work of establishing a set of harmonised technical rules for the design of buildings and civil engineering works which would initially serve as an alternative to the different rules in force in the various member states. These technical rules then became known as the Structural Eurocodes which serve as the European standards for structural design.

In 1990, after consulting with the respective member states, the CEC transferred the work of further development, issue and updating the Structural Eurocodes to CEN, and EFTA secretariat agreed to support the CEN work [1]. CEN Technical Committee CEN/TC250 is responsible for all Structural Eurocodes. The proposed Eurocodes currently under preparation are as follows:

- EN 1991 - EC 1: Basis of Design and Actions on Structures
- EN 1992 - EC 2: Design of Concrete Structures
- EN 1993 - EC 3: Design of Steel Structures
- EN 1994 - EC 4: Design of Composite Steel and Concrete Structures
- EN 1995 - EC 5: Design of Timber Structures
- EN 1996 - EC 6: Design of Masonry Structures
- EN 1997 - EC 7: Geotechnical Design
- EN 1998 - EC 8: Design of Structures for Earthquake Resistance
- EN 1999 - EC 9: Design of Aluminium Alloy Structures.

The steps brought about by the developments of Eurocodes have significant impacts on British Standard users as considerations must be made in keeping abreast with developments and technologies in current practices. This article aims to provide some fundamental background of the European Structural Codes (Eurocodes), and some introductory aspects particularly on design principles and the differences

brought about by the harmonised codes.

2.0 STAGES OF DEVELOPMENTS AND LAYOUT OF EUROCODES

Each structural Eurocode is established in a number of parts, covering a range of applications. These documents are at various stages of developments. Eventually, Eurocodes will have the same legal standing as the national equivalent design standards or codes of practice. Initially, Eurocodes are published as preliminary standards, ENV (Prenorme Europeenne); equivalent to BSI's Draft for Development. ENVs are optional, and have a life of three years, with a possible extension of two years. They will then be revised and reissued as European Standards, EN (Norme Europeene) which are mandatory in the sense that conflicting national standards must be withdrawn. All Eurocodes are published in conjunction with a National Application Document (NAD), containing supplementary information specific to each member state. The NAD takes precedence over corresponding provisions in the Eurocode [1].

At this stage several Eurocodes have been completed and majority of them are still issued as ENVs. Specifically, the main problems faced by the drafting panels for Eurocodes included agreeing to a common terminology acceptable to all the member states, resolving differing opinions on technical issues, taking into account national differences in materials and design and construction practices, and regional differences in climatic conditions.

The terminology used in the Eurocode is generally similar to that already used in the equivalent UK documents with some minor differences. For example, loads are now called actions while dead and imposed loads are now termed permanent and variable actions, respectively. Similarly, bending moments and axial loads are now called internal moments and internal forces, respectively. It is anticipated that these changes are unlikely to present any major problems, especially to UK engineers and those familiarised with British Standards.

A distinct feature of the Eurocodes is that it is concise, as yet it describes the overall aims of design and provides specific guidance on how to achieve these aims in practice. For these purposes the materials in Eurocodes were divided into principles and *application rules*.

The principles, designated *P*, are general statements, definitions, analytical methods, etc. for which no alternative is permitted. The application rules are offset to the right of the page and generally are recognised rules which follow the principles and satisfy their requirements. Usually, an application rule provides one suggested method for satisfying the corresponding principle. Eurocodes are quite flexible in a way that it permits the use of alternative design rules provided that it can be shown to satisfy the relevant principles, and not negating other aspects for example, serviceability

and durability of the structure.

A further point to be noted in using the code is that a number of numerical values, e.g. partial safety factors, minimum concrete covers and coefficients in equations, are shown boxed. This signifies that the values are meant to be for guidance only and that other values may be adopted by individual member states. In Eurocode 3 only safety elements, e.g. partial safety factors have been boxed whilst in EC 6, materials strength appear in boxes. The actual values to be used in each country or member states are given in the National Application Document (NAD).

This system of identifying certain parameters provides Eurocodes the flexibility to account for national differences in material properties, design and construction practices, climatic conditions and other significant factors. However, it is anticipated that the unification of manufacturing and construction practices throughout EC should see to the gradual disappearance of most of these boxed values from the Eurocodes.

In general, Eurocodes are designed to be as user-friendly as possible. The material in the appendices and the 'normative' annexes has the same status as the rest of the Eurocode but appears in the appendices in order to produce a convenient referenced document. The material in the informative annexes, however, does not have any status but has been included merely for information.

3.0 COMPARISON BETWEEN STRUCTURAL EUROCODES AND BRITISH STANDARDS

3.1 Eurocode 2 - Design for Concrete Structures

Eurocode 2 or in short EC2 is the European proposed standard for the structural design of concrete structures. The British Standards Institution (BSI) has planned to publish 9 separate documents related to concrete design under EC2. The publications, known as European Prestandards (ENV) are listed as follows:

DD ENV 1992-1-1:	1992 General rules for buildings.
DD ENV 1992-1-2:	1996 Structural fire design
DD ENV 1992-1-3:	1996 Precast concrete elements and structure
DD ENV 1992-1-4:	1996 Lightweight aggregate concrete
DD ENV 1992-1-5:	1996 Structures with unbonded and prestressing tendons
DD ENV 1992-1-6:	1996 Plain concrete structures
ENV 1992-2 :	1996 Concrete bridges
ENV 1992-3 :	1998 Concrete foundations
ENV 1992-4 :	1998 Liquid retaining and containment structures.

Publications with DD notation have been adopted in the UK and accompanied by its corresponding National Application Document (NAD). The NAD provides operational guidance for each country. There are other documents under EC2, apart from those listed, yet to be published. Generally, EC2: Part 1 is broadly comparable to the existing British Standard, BS 8110 Part 1 and 2 [2–3]. Whilst BS 8110 is basically applicable to buildings, EC2 comprised of various parts and covers on the different types of structures. Building is generally covered by EC2: Part I.

EC 2: Part 1 can be distinguished easily from BS 8110 in the way the chapters are described. The former contained chapters dealing with beams, slabs, columns, etc. whereas, EC2: Part 1 has chapters on bending, shear, torsion, buckling etc. The arrangement of chapters in EC2 is basically based on phenomena whilst BS 8110 uses element types.

Typical of any Eurocodes, the Principles stated in EC2 does not allow for alternatives and all designs should comply with them. Application Rules allows for alternative methods provided that it can be demonstrated that they comply with the principles. As stated earlier some of the terms used in Eurocodes are different from British Standards, in that it tries to cover a wide variety of situations. In EC2 the terminology for 'loading' has been replaced by 'actions'. Changes are made on the dead loads definition in EC2. EC2 draws a distinction between loads with small and large variations. If the variations between lower and upper loads is less than 20% of the mean value, then the mean value is used as the characteristic value. If the variation exceeds 20%, then both the lower and upper loads should be considered as characteristic values. BS 8110 does not make such an explicit distinction in the definition of the characteristic value of dead loads. Such considerations are relevant when dealing for example, with the weight of a slab and a wall cast against earth. Other modifications with regard to loads are made to the load combinations and the values of corresponding partial safety factors both at serviceability and ultimate limit states. The partial safety factor for reinforcement does not change. For concrete, EC2 adopt a single value of 1.5 throughout, as oppose to BS 8110 which is using different values for bending, shear and bond. With regard to durability considerations, EC2 does not permit the 'trade-off' between cover and concrete quality as BS 8110 does.

In general, EC2 provides only the basic information required, whereas BS 8110 gives considerably more detailed information. With BS 8110 one can use the coefficients given for various load effects such as bending moments and shear coefficients for continuous beams and slabs. EC2 expects the designer to obtain these from textbooks or manuals. In EC2, design formulae are generally related to the cylinder strength. This is one of important changes that must be noted. As an approximation the cylinder strength can be taken as 80% of the cube strength. Another difference between EC2 and BS 8110 is the load arrangements for buildings

Both EC2 and BS 8110 permit redistribution of bending moments in continuous

beams. The difference lie in the rules given to cover the ductility and detailing requirements in the two documents. For EC2, 30% redistribution is permitted for high ductility steel, and 15% for normal ductility. EC2 does not permit any redistribution in sway frames, whereas up to 10% redistribution is allowed by BS 8110. Flexural design of sections using EC2 is rather complicated as compared to BS 8110. EC2 permits the use of stress-strain curve for the reinforcement which is identical to that in BS 8110. EC2 also allows the use of a relationship with a sloping upper branch, which takes strain hardening into account. For stress-strain curve of concrete, EC2 uses the same basic diagram as BS 8110, but slightly simpler to use. EC2 allows the use of simplified stress block. It permits the use of both a rectangular and a bilinear diagram. The expression of shear strength of concrete in EC2 contains all the parameters as in BS 8110. There are some differences with regard to limitations. In BS 8110 f_{cu} should not be taken as greater than 40 N/mm². There is no limit on the concrete strength in EC2. The values for α_m are 1.25 and 1.5 in BS 8110 and EC2, respectively. EC2 provides alternative in designing the shear links. It allows the use of the method as in BS 8110 which is based on 45° strut. EC2 also allows the use of variable strut inclination method leading to increased consumption in the requirement of shear links.

The differences between BS 8110 and EC2 could also be seen in the serviceability limit state design. For example, EC2 includes the provision to check the stress level in reinforced concrete, whilst this is not required by BS 8110. In contrast to BS 8110 which uses the characteristic loads for serviceability check, EC2 requires three levels of loading, depending on the nature of the particular check being carried out.

From the brief discussions above, certainly there need to be a clear understanding on the background of the new codes, particularly the differences, before a designer could use it effectively in practice.

3.2 Eurocode 3 - Design for Steel Structures

Eurocode 3 was first published in draft in 1984, then in a pre-standard reference form known as ENV 1993-Design of steel structures. The code is based on limit state principles similar to the BS 5950 [4] and applies to the design of buildings and civil engineering works in steel. In the UK, BSI has published EC3 in 9 separate documents.

DD ENV 1993-1-1	:	1992 General rules for building
ENV 1993-1-2	:	1995 Structural fire design
ENV 1993-1-3	:	1996 Supplementary rules for cold formed thin gauge members and sheeting
ENV 1993-1-4	:	1996 Supplementary rules for stainless steels
ENV 1993-1-5	:	1997 Supplementary rules for planar plated structures

		without transverse loading.
ENV 1993-2	:	1997 Steel bridges
ENV 1993-3-1	:	1997 Tower and masts
ENV 1993-3-2	:	1997 Chimneys
ENV 1993-5	:	1998 Piling.

The organisation of the content in EC3 is to some extent, quite different from those of BS 5950 [3]. EC3 contains numerous comprehensive rules and information and exceeds twice in length than BS 5950. Understandably it is not surprising that, due to this sophistication as well as to minimise difficulties faced by designers who are familiarised with BS 5950, a concise version referred to as Concise-EC3 (C-EC3) was published in the UK. However, C-EC3 does not cover all the topics dealt in EC3. Instead it covers only the types of steel commonly used. The code is being regarded as an adequate standing-alone design standard for building constructions. Many of the tables and charts in C-EC3 have been reorganised and the Principles and Application Rules presented in the same format.

The use of subscripts for symbols is self-defining which helps to interpret clauses easier. The use of symbols is self-defining however, the symbols are found to be completely different for four terms from those used in BS 5950. They are the elastic and plastic section modulus, axial load, and radius of gyration. Another notable difference between the two codes is the notation used in reference to member axes. Specifically, EC3 defines the axis for the longitudinal member of an element as xx , the major axis of the cross-section as yy and minor axis as zz , which conforms with the standard convention used in common computer programs.

As for the characteristic yield and ultimate steel strength is concerned, only the equivalents of steel grade 43 and 50 steel are given in EC3. In addition the lower grade steel, Fe 360, is specified because of its common application in the Continent. The equivalent characteristic strength values for high-yield steel grade 55 are included in Annex D, of EC3. A direct comparison of partial safety factors for both cases is not possible as the factors used in EC3 apply to structures and components, whereas the factors specified in BS 5950 are with reference to strength.

'Actions' in EC3 refers to load and imposed deformation in BS 5950, whereas permanent and variable actions refer to dead and imposed loads. The NAD for United Kingdom (UK), specifies the use of BS 6399: Part 1 [5] and CP3: Chapter 5: Part 2 [6] for characteristic values of 'actions'. In a design, the main objective is to ensure that the design values, S_d , due to the effects of these 'actions' are lesser than the design resistance, R_d . For simple, continuous or semi-continuous type frames, S_d is obtained using the methods of analyses given in EC3. Other references could also be used to analyse these structures, depending on the types of connections.

In addition to the elastic and plastic analysis given in BS 5950 [4], EC3 incorporates theories in the first-order and second order which consider the effects of defor-

mations. A comprehensive information on the elastic-perfectly plastic and elasto-plastic methods for continuous and semi-continuous steel framing is also included in the new code. The information on frame stability is presented in detailed whilst the terms braced and unbraced, sway and non-sway frames are clearly defined. On this basis, EC3 is a more comprehensive code than the former BS 5950.

For a typical design of an element, a section is initially classified in accordance to control of local buckling of web and flange of the structural elements. EC3 classifies it as class 1, 2, 3 and 4 while BS 5950 classified it as plastic, compact, semi-compact and slender, respectively. The design rules in EC3 are categorised under cross-section resistance, member buckling resistance, shear buckling resistance and web crippling which is somewhat different from BS 5950 where the design rules are grouped accordingly to member types such as beams, compression members and plate girders.

Basically, the main differences of the two design rules are only in the symbols, terms, safety factors and limits adopted. The principles of design, concept and formulation are generally similar. This is only a brief discussion on EC3 and certainly there are other aspects that have not been covered where EC3 and BS 5950 may differ.

The above overview of EC3 allows some significant remarks to be made especially on the governing rules for design and practicality. EC3 incorporates rules covering innovative modern and advanced information on analyses and design of structural steel elements which are significant developments for future design practices. EC3 also permits the use of alternative methods of analysis and design thus giving options to designers whether to choose a detailed or simple comprehensive approach whilst lending to a more accurate solution than existing design rules.

Eurocode 6 - Design for Masonry Structures

Eurocode 6 is the new structural European standard for the design of masonry structures. It was published in draft form in 1988 and following an lengthy process of comment and review, the first part was issued in 1995 as a pre-standard or ENV under the title Part 1.1: General rules for buildings: Rules for reinforced and unreinforced masonry.

Eurocode 6 (EC 6) is similar in scope to BS 5628 Part 1 and part 2 [7-8], which it eventually replace. It is known that the developments of EC 6 is far advanced now, however details on the stages of developments and contents have not been publicised yet. In general, EC 6 is based on limit state principles and to be published in several parts as follows:

Part 1.1 : General rules - rules for reinforced and unreinforced masonry; crack and deflection control.

- Part 1.2 : Detailed rules on lateral loading
- Part 1.3 : Complex shapes in masonry structures
- Part 2: Other aspects of masonry
- Part 3: Simplified and simple rules for masonry structures.
- Part 4: Constructions with lesser requirements for reliability and durability.
- Part 10: Fire design of masonry structures.

At the early stage, the drafting panel of EC6, CEN Technical Committee 250, Sub-Committee SC6 has faced various difficulties in drafting the document. These are principally due to the diversified range of masonry units produced throughout Europe and national differences in design methodologies. There is a wide variety of masonry units used throughout Europe. The units differ in many respects including appearance, size, strength and disposition and percentage of perforations. The Eurocode aims to create no barriers to trade and hence been interpreted as design rules which must not disadvantage available products from EC countries. Therefore, the EC drafting has had to develop design methods which enable the majority of masonry products currently available throughout Europe to be used in design.

In solving this problem CEN TC 125 has to reach an agreement for the adoption of a common European specification for masonry units. The European standard for clay masonry units, prEN 777-1, uses a declaration system for specifying product characteristics; somewhat similar to that already adopted in BS3921 [9] which can be assessed by means of standard tests.

The contents of EC 6 differs from BS 5628 over certain aspects of compressive design, *e.g.* slender members, shear resistance and concentrated load design. As reported the design of flexural members (laterally loaded panels) is expected to be difficult. In UK the design of panel walls for lateral loading is based on yield line principles, where it assumes that the wall behaves plastically on subjecting to lateral load. This assumption correlates well with available test data based on BS 5628 panel design range. However, many continental standards do not provide any method of flexural design since their walls tend to be much thicker or either the designs are based on alternative principles. The increased thickness of the wall would mean an increased in cost of masonry construction.

In some aspects the design procedures in EC 6 are a little more conservative than BS 5628. Although there are dissimilarities between EC 6 and BS 5628, it is anticipated that it shouldn't take long for engineers to become proficient with the design techniques in EC 6. Majority of the design principles have been based on the present UK codes, partly due to high participation of UK designers in the drafting of the code.

CONCLUSIONS

There are several differences between Eurocodes and the national codes. For UK engineers these changes are fairly minor, largely due to work put by in by UK members of the various drafting panels. It is envisaged that it will not take very much time for engineers in UK to become familiar with the contents of the Eurocodes and subsequently to use them. However, of greater concern is that many of the European standards which are needed to support the Eurocodes have yet to be drafted. Therefore, in the mean time, reference will have to be made to the appropriate national standards. These, however may cause difficulties especially for consultants bidding for work within EC countries. The strategy devised when the structural Eurocodes were initiated was to produce design standards first and allow these to generate the demand for relevant supporting standards.

The benefits of structural Eurocodes, particularly to the construction industry, ensures standard workmanship to be achieved in a particular design therefore, enhancing quality control. To a considerable extent, the implementation of structural Eurocodes in Europe would have great implications on nations based on British practices. Eventually, a choice has to be made whether to accept the new approach or to remain unchanged. Undeniably, for the developing countries there is a need to keep abreast with new technologies at the international level. The selection of Eurocode is beneficial for this purpose however, requires effort in familiarising with the new requirements and additionally, the transfer of technology to conform to local design and structural requirements.

In general, the applications of Eurocode allows flexibility for its adoption to local needs. The National Application Document plays a big role in the transferring of one national standard to another. Irrespective of the material properties or design conditions, Eurocode can be used reliably for the structural design of engineering materials in any country as long as it is used in conjunction with the national standard. It is this transfer of knowledge and standard which should be considered in deciding the future direction of Malaysian practices for codes of structural design.

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