An overview of the structural Eurocodes in the construction industry

Denis Camilleri outlines the forthcoming Eurocodes and says it is time for structural engineers to get acquainted with their contents, and for academic institutions to cover them in their courses. As guides are published, he advocates a forum to make the codes more user-friendly.

The structural Eurocodes are an unrivalled set of unified international codes of practice for designing buildings and civil engineering structures. They embody the vast experience and research output of 19 member states. The Eurocodes consist of 10 codes covering basis of design, actions on structures, the main structural materials together with geotechnical and seismic design.

Anyone opening the Eurocodes for the first time may find them complicated as they are not new editions of codes with which the reader has grown up. Also as the Eurocodes refer to 2nd order effects, this may require more than a slide rule or hand-held calculator. They may need programmed support, requiring development of appropriate software. However, with familiarity they should be easier to use than codes they replace, as their consistency of philosophy is evident in the terminology and notation across materials and types of structures.

The common basic rules of structural design follow the requirements for public safety and serviceability of structures based on the principle of risk in terms of reliability conditions. Construction works should be fit for their intended use and offer:

- adequate durability under normal maintenance conditions;
- an economically reasonable working life;
- the structure should also be designed so that it will not sustain damage disproportionate to the original cause.

On the other hand, the Eurocodes give the necessary liberty to the designers whilst allowing innovation in the construction industry.

The process

The idea of Eurocodes dates back to 1974. In May 1990 the European committee for standardisation (CEN) created a new technical committee, CEN/TC 250 'Structural Eurocodes'. The codes have been available as European pre-standards ENVs for some years and are now being converted to full European standards 'ENs'. In October 2001 the head code EN 1990 *Eurocode – basis of structural design* and the first part of EN 1991 Eurocode 1: *Actions on structures* were converted to EN standard.

Each of the following structural Eurocodes, generally consisting of a number of parts, should be released as ENs up to 2005 (all exist at present as ENVs except as noted above):

- ENV 1990 *Basis of design*
- ENV 1991 Eurocode 1: *Actions on structures*
- ENV 1992 Eurocode 2: *Design of concrete structures*
- ENV 1993 Eurocode 3: *Design of steel structures*
- ENV 1994 Eurocode 4: *Design of composite steel and concrete structures*
- ENV 1995 Eurocode 5: *Design of timber structures*
- ENV 1996 Eurocode 6: *Design of masonry structures*
- ENV 1997 Eurocode 7: *Geotechnical design*
- ENV 1998 Eurocode 8: *Design of structures for earthquake resistance*
- ENV 1999 Eurocode 9: *Design of aluminium structures*

After a Eurocode becomes an EN, under CEN rules there will be a period of co-existence,with the appropriate National Code (possibly 5 years), following which the National Code will cease to be maintained. In the final EN Eurocodes will consist of the EN text, produced and approved by CEN as a European standard and a national annex to each Eurocode part containing nationally determined parameters to be used in the relevant member state.

The national annexes are governed by CEN rules. Each national annex may only contain information on parameters that are left open in the Eurocode for national choice, known as 'nationally determined parameters'. These parameters will allow member states to choose the level of safety, serviceability and durability applicable to their territory. Such parameters may include country-specific data such as wind speed and seismic activity. However, other data such as varying variable actions (live loads), values between member states and three approaches to be chosen from for foundation design really touches on the basis in engineering design.

The intended benefits of the Eurocodes are to provide a common understanding of structural design between owners, operators, users, designers, contractors and construction product manufacturer, and to be a common basis for research and development in the construction sector. To achieve their objectives, and for the construction industry to derive maximum benefit, it is now vital for the construction professionals to be trained in their use and for universities to start basing their design courses on the new methodology.

Assistance to facilitate an effective transition to the Eurocodes is being made available in a series of designers' guides to the Eurocodes published by Thomas Telford. These guides, published and forthcoming, are noted in the following sections and will be essential reading for civil and structural engineers, code-drafting committees and students in structural design.

EN 1990 Eurocode – *Basis of structural design*

This was approved in October 2001. It is the world's first 'material-independent' design code. The large number of materials include concrete, steel, masonry, timber and aluminium, whilst the disciplines incorporate fire, geotechnics, earthquake, bridge design etc. This Eurocode introduces the principles and requirements for safety, serviceability and durability, whilst providing an introduction to reliability and risk management and its limit-state design philosophy based on partial safety factors. It also summarises the loading combinations for the assessment of structures.

The principles of partial safety factors were proposed in 1927 by the Dane, Moe. An early example of the result of this work is in a British standard CP 110. The most important innovation in CP 110 was the explicit use of probability theory in the selection of 'characteristic values' of strength which, according to some notional or measured distribution, would be exceeded in at least 95% of standardised samples. In 1978 the Nordic Committee on Building Regulations (1978) issued a report on Limit State Design containing 'Recommendation for loading and safety regulations of structural design' (NKB report No. 36), which introduces a concept of safety class and control class.

In EN 1990 properties of materials including soil and rock and products are represented by characteristics values that correspond to the value of the property having a prescribed probability of not being attained in a hypothetical, unlimited test series. Actions are combined so that they produce the most unfavourable effect on the structure for the limit state being considered. A novel combination value gives the ultimate value for actions that cannot occur simultaneously, such as the proportion of the live load to be considered in combination with seismic forces, the predominant permanent action being established in such cases.

Harmonisation of the Eurocodes is achieved via EN 1990, the head code, as the partial safety factors to be adopted are consistent throughout, whether in the ultimate or serviceability state, whilst static vertical loading may be combined with dynamic seismic action in a consistent partial safety factor format.

This clarifies many of the previous misconceptions of going from a static design to a seismic design as it was difficult to formulate a consistent set of partial safety factors for this design situation. Partial safety factors were often previously referred to as factors of ignorance. Hopefully the Eurocode has helped towards giving more feeling for the 1.4s; or are they 1.35s? By adopting structural reliability theory, included as an annex, the factor of safeties may not be static figures but may change according to the importance of the structure. The aftermath of the 11 September may possibly also require a rethink on these factors of safety.

The design then involves the ultimate foundation design, hence minimising the misuse of the proper design characteristic value to be adopted.

- *Designers' guide to EN1990 Eurocode: basis of structural design,* by Gulvanessian, Calgaro, & Holicky, has been published. Besides giving detailed information on EN 1990, it explains its relationship to Eurocode 1 action on structures, the material Eurocodes 2–6 and 9, Eurocode 7 for geotechnical design and Eurocode 8 for seismic design.

EN 1991 Eurocode: *Actions on structures*

This is in an advanced state of development, forming one of the key documents in the suite of 19 structural Eurocodes. It is in four parts, the first part being divided into sections covering self and imposed loads and actions due to fire, snow, wind, heat, construction and accidents. The remaining three parts cover traffic loads on bridges, actions by cranes and machinery and actions in silos and tanks. For the first time in an international standard, annexes provide models for more realistic calculation of thermal actions.

- *Designers' guide to EN 1991–1.1, 1991–1.3 and 1991-1.5 to 1.7 Eurocode 1: actions on structures,* by Gulvanessain & Calgaro, refers to general rules and actions on building except wind.
- *Designers' guide to EN 1991–2. Eurocode 1: actions on structures',* by Gulvanessain, Calgaro, Tschumi and Shetty, refers to traffic loads and other actions on bridges.

Guidance on wind actions is provided for the structural design of buildings, chimneys and bridges. The data on wind velocity to be provided as a national annex corresponds to the 10 minute wind speed, with an annual probability of exceedence of 0.02 (50 year period), taken at 10.0m above ground.

- *Designers' Guide to EN 1991–1.4 Eurocode 1: actions on structures,* by N. Cook, refers to wind action.

EN 1992 Eurocode 2: *Design of concrete structures*

The first part of the code in plain, reinforced and prestressed concrete, covering common design rules and design requirements for fire is likely to be released in 2003. The second and third parts covering design of bridges and liquid-retaining structures is due in 2005.

All the expressions in the code relate to cylinder strength, not cube strength of concrete. When the first part is published, it will contain national annexes which will deal with matters such as partial factors for material. The items to be covered in the national annex are very limited, with six in the design rules section and three in the fire section.

Other main codes/standards relevant to practicing concrete design engineers are:

- ENV13670 *Execution of concrete structures*
- EN 206-12000 *Concrete: performance, production, placing and compliance criteria*
- prEN10080 *Reinforcement steels*
- prEN10138 *Pre-stressing steels*

Product standards currently in preparation include:

- EN1168-1 *Pre-stressed hollow-core elements*
- EN1168-2 *Reinforced hollow-core elements*
- EN13743 *Precast floor plates* (Parts 1-3)
- EN13224 *Ribbed elements*
- EN13225 *Linear structural elements*
- W1 002 290 10 *Beams and block floor system*
- W1 002 290 04 *Stairs*

- *Designers' Guide to EN 1992–1.1 Eurocode 2: design of concrete structures,* by A. Beeby and N. Naryanan, refers to common rules for buildings and civil engineering structures.
- *Designers' Guide to EN 1992–2. Eurocode 2: Design of concrete bridges,* by Atkins.

EN 1993 Eurocode 3: *Design of steel structures*

This code is wider in scope than most other Eurocodes due to diversity of steel structures, the need to cover both plastic and elastic design, the use of both bolted and welded joints and the possible slenderness of construction.

It codifies semi-rigid joints, sheetpiles, shells, silos and stainless steel structures for the first time. For coldformed steelwork, more advanced methods of design are included. It is also unusual in having a partial material safety factor of 1.0, since a recent survey of European steel products shows they are generally around 20% stronger than their nominal value. Included is the basis of steel design with design procedures for hot-rolled sections.

The best known is Part 1-1, *General rules and rules for buildings*, but is only the first of a total of 18 documents issued as ENVs. Relevant supporting standards include those for steel properties, tolerances on steel sections and plates, ordinary bolts, high-strength friction-grip bolts, welding electrodes and fabrication and erection.

- *Designers' Guide to EN 1993–1.1 Eurocode 3: design of steel structures* refers to common rules for buildings.

- *Designers' Guide to EN 1993–2. Eurocode 3: design of steel bridges,* by Atkins.

EN 1994 Eurocode 4: *Design of composite steel and concrete structures*

This code applies to composite structures and members made of structural steel, and reinforced or prestressed concrete connected together to resist loads. This should lead to the publication of three parts namely:

- Part 1-1: General-common rules and rules for building
- Part 1-2: Structural fire design
- Part 2 : Bridges.

The scope of this code is to be wider than any previous codes. For buildings, web-encased beams, columns joints and frames are included. For bridges, double composite action, trusses, tied arches, filler beam decks and prestressing by tendons or by jacking at supports are included. Further reference is made to partially encased composite beams, high-strength structural steels, composite joints, composite columns and composite slabs.

- *Designers' Guide to EN 1994–1.1 Eurocode 4: design of composite steel & concrete structures*, by Johnson and Anderson, refers to common rules for buildings.
- *Designers' Guide to EN 1994–2. Eurocode 4: design of composite steel and concrete bridges,* by Atkins.
- *Designers' Guide to EN 1991–1.2, 1993–1.2 and 1994–1.2*, by Wang, Bailey, Lennon & Moore, refers to fire engineering actions on steel and composite structures.

EN1995 Eurocode 5: *Design of timber structures*

Unlike BS 5268 based on the permissible stress, this code, to be consistent with the other Eurocodes, adopts the limit state. The limit state leads to more complex equations for joints that ideally require a programmed solution. The code is divided into two parts, with the first part giving general rules for buildings and the second devoted to bridges.

Serviceability is considered in great detail, particularly creep deflection and floor vibrations. A more comprehensive approach is given in relation to strength capacity assessment. Here, bearing stress in a beam at its seating, concentrated load immediately above the beam, and distribution of stress through deep beams is given.

More important is the CE marking given to timber, which has to rely on a Eurocode for validation. If CE markings become compulsory for all products, there would be no point in having national alternative application rules.

- *Designers' Guide to EN 1995–1.1 Eurocode 5: design of timber structures,* by Enjily and Mettem refers to common rules for buildings.

EN 1996 Eurocode 6: *Design of masonry structures*

The first part of this code relates to buildings and other civil engineering works in unreinforced, prestressed and confined masonry. The first part of the code applies to the design of buildings and civil engineering works. Only the requirements for resistance, serviceability and durability of structures are dealt with, including also fire and lateral load design. Other requirements such as thermal or sound insulation are not considered.

The second part of the code deals with the design selection of materials and execution of masonry. Masonry units will in the future conform to the six parts of EN 771 product standard being produced by CEN/TC125, namely:

- EN 771-1: clay units
- EN 771-2: calcium silicate units
- EN 771-3: aggregate concrete units
- EN 771-4: autoclaved aerated units
- EN 771-5: manufactured stone units
- EN 772-6: natural stone units.

The third part relates to simplified and simple rules for masonry structures. Examples include the thickness of basement walls of a certain height, a simplified method for obtaining the eccentricity of walling on unreinforced walls, together with the factors to be used in lateral load design.

- *Designers' Guide to EN 1996 Eurocode 6: Design of masonry structures,* by Morton.

EN 1997 Eurocode 7: *Geotechnical design*

This code aims to bridge the gap between traditional geotechnical calculations relying on highly subjective assessments of design parameters, with greater emphasis on serviceability and how this is satisfied through ultimate-limit-state design. This implies a rectangular soil foundation stress block, instead of the traditional triangular or trapezoidal stress block, doing away with the middle third criteria, thus simplifying bending moment and shear force calculations.

It was a foregone conclusion that the Eurocodes should be written in the limit state design format and that partial safety factors should be used. Consequently it was decided that also those parts of the Eurocodes which will be dealing with geotechnical aspects of design should be written in the limit state format, implying that characteristic values have to be given to soil properties. This creates a common language for structural and geotechnical engineers.

The first class in geotechnical limit state design is the ultimate limit state, in which either a mechanism is formed in the ground or in the structure, or even severe structural damage occurs due to movements in the ground. Five ultimate limit states are to be considered:

- loss of equilibrium of the structure or the ground, considered as a rigid body, in which the strengths of structural materials and the ground are insignificant in providing resistance (EQU);
- internal failure or excessive deformation of the structure or structural elements, including footings, piles, and basement walls, in which the strength of structural materials is significant in providing resistance (STR)
- failure or excessive deformation of the ground, in which the strength of soil or rock is significant in providing resistance (GEO);
- loss of equilibrium of the structure or the ground due to uplift by water pressure (buoyancy) or other vertical actions (UPL);
- hydraulic heave, internal erosion and piping in the ground caused by hydraulic gradients (HYD).

The second class is the serviceability limit state at which deformation in the ground will cause loss of serviceability in the structure. This includes settlements which affect the appearance or efficient use of the structure, or cause damage to finishes or non-structural elements, or vibration which causes discomfort to people or damage to the content of the building.

By dividing geotechnical tasks into various categories the code specifies the various geotechnical risks encountered as related to hazard and vulnerability levels. The low, moderate and high-risk category then goes on to outline the necessary procedure to be adopted.

- *Designers' Guide to EN 1997 Eurocode 7: geotechnical design,* by Frank, Bauduin, Driscoll, Kavvadas, Krebs Ovessen, Orr & Schuppener.

EN 1998 Eurocode 8: *Design of structures for earthquake resistance*

This code has five parts which cover a range of structures including buildings, bridges, towers, tanks and geotechnical structures. The life-safety objective is followed in the code, implying that the structure may be damaged, but it must not collapse in order top prevent loss of life.

Structures are to be designed to resist an earthquake which has a 10% chance of exceedence in 50 years, otherwise known as a 475-year return period. Each state is responsible for defining an appropriate seismic hazard map. The philosophy behind the code is that areas with a design ground acceleration less than 0.1g are treated as regions of low seismicity, with simplified design procedures being implemented. For areas where the design ground acceleration is less than 0.04g the provisions of Eurocode 8 do not need to be observed.

The code provides specific seismic design and detailing rules for various materials in concrete, steel, timber and masonry, whilst the elements covered being beams, columns, walls and braces. These cover the selection of materials on the basis of strength and ductility.

Another part of the code covers seismic strengthening and repair of buildings. This reflects the importance of seismic evaluation and retrofitting of existing structures. The increased awareness of seismic risk to existing structures has increased creating a need to retrofit vulnerable structures.

Something new, not found in many other codes, is the detailed guidance given on seismic design of foundations, retaining structures and geotechnical aspects.

• Designers' Guide to EN 1998–1 Eurocode 8: design provisions for earthquake resistant structures, by Fardis, Carvalho, Elnashai, Faccioli, Pinto and Plumier, refers to general rules, seismic action and rules for buildings.

EN 1999 Eurocode 9: *Design of aluminium structures*

Owing to the increasing use of aluminium alloys in construction this code has been added as an alternative to steel. With only a third of the weight, 2700kg/m^3, together with a comparable strength varying between 150 to 350N/mm^2 and a self-protecting surface, the material has clear advantages over steel but it also behaves very differently. It has a high deflection and buckling tendency due to its Young's modulus also being a third that of steel, 70,000N/mm^2, no yield plateau and complex strain hardening characteristics, with the importance of ductility on local and global behaviour being given.

The code covers several innovations including behavioural cross-section classes and new calculation methods for verification of local buckling depending on effective thickness instead of effective width, evaluation of rotation capacity and design of connections, including welded, bolted, riveted and glued connections.

Fire design included in all Eurocodes is very relevant for aluminium as it is generally less resistant to high temperatures than steel and reinforced concrete. Nevertheless, by introducing rational risk-assessment methods, the analysis of a fire scenario might in some cases, result in a more beneficial time-temperature relationship and thus make aluminium more competitive.

Conclusion

The Eurocodes have managed to set a consistent format for the materials presently outlined. Now it is time for the structural engineers to get acquainted with their contents, and for academic institutions to cover them in their courses. With this hands-on experience, a forum can be created whereby these codes are made more user-friendly with the publication of handbooks. The contents of the Eurocodes may then be extended, to include further materials such as structural glass and fibre-reinforced polymers. Hopefully other composite materials will be added to EN 1994, e.g. timber and concrete composite floor slabs, a sustainable composite material favoured on the continent.

• The contents of the above article draw heavily on the Proceedings of the Institution of Civil Engineers, Special Issue No. 2, in Eurocodes, November 2001 Vol. 144.

• Further information: Report of IABSE Conference, Davos 1992 – Structural Eurocodes;
Eurocodes Expert (email: eurocodes@thomastelford.com).