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EC 4: Composite Structures of Steel and Concrete

EC 4: Structures mixtes en acier et béton

EC 4: Verbundtragwerke aus Stahl und Beton

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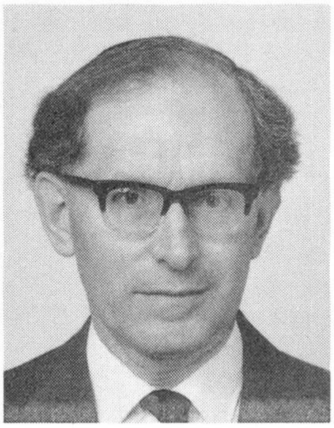

SUMMARY

The history and current plans for the three Parts of Eurocode 4 are explained, and also the relationships between them and Eurocodes 2 and 3. The scope and main features of the original «Eurocode 4», now Part 1.1, are outlined, including the treatment of materials, products, and their testing; the need for simplification and where it has been achieved; the reasons for differences from Eurocodes 2 and 3; the choice of partial safety factors; and statistical calibration based on test data.

RESUME

L'historique et l'organisation des trois parties de l'Eurocode 4 sont expliqués ainsi que leurs liens avec les Eurocodes 2 et 3. On présente l'étendue des activités et les caractéristiques principales du premier «Eurocode 4», maintenant la partie 1.1, ainsi que le traitement des matériaux, les produits et les essais à effectuer, la simplification nécessaire dans certains cas; les différences entre l'Eurocode 4 et les Eurocodes 2 et 3; le choix des coefficients partiels de résistance; et la calibration statistique basée sur des essais.

ZUSAMMENFASSUNG

Der Werdegang und die laufende Planung der drei Teile von EC 4 werden erklärt, ebenso ihre Beziehung untereinander und zu EC 2 und 3. Der Beitrag skizziert Umfang und Hauptmerkmale des ursprünglichen «EC 4» (jetzt Teil 1.1), einschliesslich der Abhandlung von Werkstoffen, Produkten und Prüfverfahren. Dabei zeigt er erforderliche und teilweise erreichte Vereinfachungen auf, bespricht die Wahl des Widerstandteilbeiwerts und erörtert die statistische Kalibrierung aufgrund von Versuchsergebnissen.

1. BACKGROUND AND PLANNING

Eurocode 4, "Design of composite steel and concrete structures", will eventually be a Euronorm numbered EN 1994. It is expected to consist of three documents, each drafted by its own project team:

- Part 1.1, General rules and rules for buildings
- Part 1.2, Structural fire design
- Part 2, Bridges

The histories and future plans for these Parts are as follows.

Part 1.1. This was first drafted in 1983/4, based on a Model Code [1] prepared between 1971 and 1980 by the IABSE/CEB/ECCS/FIP Joint Committee for Composite Structures, chaired by Dr. D. Sfintesco. It was published as "Eurocode 4" [2] and studied for 18 months (1985-87) in the twelve Member States of the European Economic Community. They did trial designs and submitted many comments and proposals for revision. A commentary on this draft was prepared [3] and papers were presented at an IABSE-ECCS Symposium [4, 5]. Since then, much research has been done on problems evident from this draft, and papers have been presented at several conferences, especially the IABSE Symposium at Brussels in 1990 [6].

Eurocodes 2 and 3 have been substantially revised and extended since 1984, and the current draft Eurocode on Actions has been written since then. Eurocode 4 has to be consistent with these three codes, so the project team that has been revising it since 1987 has made many changes and additions, to take account of the national comments and of the progress of other codes, of research, and of practice.

Eurocode 4: Part 1.1 was issued as a prENV document, under the CEN system, in 1992. If it is accepted by CEN Committee TC 250/SC4, it will be translated into French and German and published as ENV 1994: Part 1.1, for trial use over a period of three years. It will be the first Part of any Eurocode to follow this route, as Parts 1.1 of Eurocodes 2 and 3 were approved by the European Commission, before the transfer of responsibility to CEN.

Design manuals (commentaries) on Part 1.1 are being published [7, 8].

Part 1.2. Structural fire design. Until 1992, this code was numbered Eurocode 4: Part 10. Drafting began in 1987, in parallel with work on Parts 10 of Eurocodes 2, 3, 5, and 6. It was issued for national comment in 1990, [9] and is now being revised. It should be issued as a prENV in 1993, for approval by CEN before publication as ENV 1994: Part 1.2.

Part 2. Bridges. It was the intention of the Sfintesco Committee, and of the Commission of the European Communities, that the original "Eurocode 4" should be applicable to bridges, as well as to structures for buildings. The scope of the 1985 draft [2] states that it is " ... concerned with buildings and civil engineering structures. The basic principles apply to all types of composite structures or elements ..... However, they do not cover all aspects relevant to special structures, such as ..... certain types of bridges ....."

The 1985 draft could not cover all aspects of the design of composite highway or railway bridges. It became evident that it would not be feasible to design simple bridges to Part 1.1 and more complex ones using supplementary rules to be given in Part 2. But it is still stated in the latest Part 1.1 that it " .... gives a general basis for the design of composite structures and members for buildings and civil engineering works" (i.e., including bridges).

This led to the addition of the words "for buildings" to the titles of some of the chapters and sections of Part 1.1, to make clear that they are intended to be replaced, rather than supplemented, by material in Part 2.

It is also stated in Parts 1.1 of Eurocodes 2 and 3 that they give "a general basis for the design of ..... civil engineering works ...", but few of the titles of their chapters or sections carry the exclusion "... for buildings".

It is not yet known in what way the Parts 2 of Eurocodes 2 and 3 will be related to their Parts 1.1. At one extreme, they could be comprehensive stand-alone documents. At the other, they could be limited to supplementary rules for specific types of structure (e.g., box girders).

This uncertainty, and lack of funding, have caused the drafting of Eurocode 4: Part 2 to be delayed until substantial progress has been made on Parts 2 of Eurocodes 2 and 3. It has been proposed to CEN that work should begin in January 1993, with a target date, for approval by CEN for publication as an ENV 1994: Part 2, about a year after that stage has been reached by Parts 2 of Eurocodes 2 and 3.

There is little further reference to Eurocode 4: Part 2 in this paper, or in the other five papers on Eurocode 4. Four of them are on Part 1.1 (i.e., the original "Eurocode 4"), and one is on Part 1.2, Fire. In the present paper, all cross-references to chapters or clauses are to the prENV draft of Eurocode 4: Part 1.1, unless noted otherwise.

2. SCOPE OF EUROCODE 4: PART 1.1

Eurocode 4 applies to composite structures and members "... made of structural steel and reinforced or prestressed concrete connected together to resist loads", but prestressed structures are not included in Part 1.1. It is "... only concerned with requirements for resistance, serviceability, and durability ...", but excluding seismic design and resistance to fire, and to actions liable to result in fatigue.

Execution (known as "construction" in the U.K.) is covered only to the extent that it is necessary to indicate the quality of construction materials and workmanship on site needed to comply with the assumptions of the design rules. This subject is elaborated in another paper.

Detailed application rules, mainly applicable to ordinary buildings, are given for composite slabs, beams, columns, and frames. These may be constructed using the full range of materials covered by Parts 1.1 of Eurocodes 2 and 3, except structural steel of Grade Fe E 460 (yield strength 460 N/mm^2), and concretes with cylinder strength less than 20 N/mm^2. Rules are given for the use of lightweight concrete, pending the completion of Eurocode 2: Part 1C.

The scope is wider than that of any equivalent national code known to the Project Team, but there are many aspects of current practice for which no application rules are given. These include:

- certain new or developing types of shear connector,
- use of large holes in the webs of beams, and stub girder construction,
- base plates beneath composite columns,
- framed structures with "semi-rigid" connections; i.e. connections that are neither "rigid" nor "nominally pinned", using terms defined in Eurocode 3,
- members where the structural steel component has cross-sections with no axis of symmetry parallel to the plane of its web.

Application rules for these situations are not yet well established, and their provision at too early a stage of development can stifle innovation. Other subjects (e.g., sway frames) are omitted because they are rarely used in composite structures, and would require complex design rules.

Beams and columns consisting of steel I or H sections with concrete-encased webs are included, as are concrete-filled and fully-encased steel sections used as columns. No application rules are given for steel beams that are either fully encased or have encased flanges. The former are widely used in bridges; and also in seismic areas, such as Japan, where they are designed by superposition of the resistances of the structural steel and reinforced concrete components.

Fully-encased beams without shear connectors are not included in Part 1.1 because:

- it is not known to what extent other rules (e.g., for moment-shear interaction and redistribution of moments) would be applicable;
- no satisfactory model has been found for resistance to longitudinal shear.

The applicability of codes may be limited by the unstated assumptions commonly made during drafting; for example, that members in frames are orthogonal and concrete slabs are horizontal. In Eurocode 4 it is assumed (e.g. in the rules for redistribution of moments) that the steel member of a composite beam is below the concrete slab; but this is not stated. The design of unconventional structures requires wider knowledge than can be found in a code.

3. RELATIONSHIP TO PARTS 1.1 OF EUROCODES 2 AND 3

Eurocode 4 is unusual in not being the principal source of information for design in any structural material. Why does it not consist solely of one chapter, "Shear connection" and the instruction "Follow Eurocodes 2 and 3"?

Design would then be found to be more complex than it is either for structural steel or for reinforced concrete. For example, cracking, creep, and shrinkage of concrete and slip at the steel-concrete interface create uncertainties about stress levels in slender steelwork that may influence buckling loads. The need for economy and simplicity has led to design methods that sometimes differ in detail from those for structural steel or for concrete. But the differences are not so extensive that Eurocode 4 could be self-contained. That could treble its length.

The policy has been to cross-refer to Eurocodes 2 and 3 wherever practicable. For example, the three pages on vertical shear in beams give only the main requirements and the few modifications needed to the 14 pages that the subject requires in Eurocode 3.

There are two exceptions to this practice. Chapters 1 (Introduction) and Chapter 2 (Basis of design) are as far as possible identical with those in Eurocodes 2 and 3, to ensure harmonisation. Also, information from Eurocodes 2 and 3 that is both concise and frequently needed is repeated in Eurocode 4. This applies mainly to the properties of materials, given in Chapter 3.

There are many differences of sequence and presentation between Parts 1.1 of Eurocodes 2 and 3, and a few inconsistencies of technical content. Eurocode 4, as applied to buildings, is based on the concept of the initial erection of a steel frame, perhaps including precast composite members. So Eurocode 4 relates closely to steel construction, and in presentation and content, it is more like Eurocode 3 than Eurocode 2; but in one respect its sequence follows the latter: "ultimate limit states" precede "serviceability limit states", as this is the usual sequence in design. Many aspects of a composite structure are covered in both Eurocodes 2 and 3 (e.g., lateral instability of a multi-storey frame). The policy for Eurocode 4 has been to use as a basis the more appropriate of the two methods, and modify it as little as possible.

4. MATERIALS, PRODUCTS, AND TESTING

The Structural Eurocodes are intended for use with a full set of international standards for materials, products, and their testing. These will either be Euronorms from CEN, or ISO Standards. For steel components and for concrete, Eurocode 4 gives basic information in Chapter 3, but otherwise refers to Euronorms or to Eurocodes 2 and 3, both of which include Provisional Guides, for use until the relevant CEN or ISO standards are available.

For shear connectors, there are four distinct situations.

(a) For connectors that consist of steel blocks, bars, sections, or reinforcement, attached by welding, the materials and welding should be in accordance with Eurocodes 2 or 3, as appropriate.

(b) For welded stud connectors, international standards are needed both for tests on the material and for the automatic welding process. Provisional guidance is given in clauses 3.5.2 and 9.4.3 of Eurocode 4.

(c) For friction-grip bolts, the relevant clauses of Eurocode 3 are supplemented, in Section 6.5.

(d) New types of connector continue to be developed. Those based on the use of shot-fired steel pins, for example, are not covered by any of items (a) to (c), above. New types of connector should be the subject of European technical approvals, and should comply with the Principles of Eurocode 4 (e.g. in Section 3.5 and clause 9.4.3).

Design assisted by testing is treated in general terms in Chapter 8 of Eurocode 3, supplemented by the Provisional Guide in Annex Y. These are applicable also to the two types of product for which design to Eurocode 4 is closely related to results of tests: shear connectors, and profiled steel sheeting used in composite floor slabs.

For both types of product, extensive supplementary requirements are given in Eurocode 4

(Chapter 10 and Annexes E and F). These include details of test specimens and procedures, interpretation and recording of results, and calculation of values for use in design.

5. SIGNIFICANT FEATURES OF COMPOSITE CONSTRUCTION

Reference was made in Section 3 (above) of the need for a Eurocode 4 to supplement Eurocodes 2 and 3. The main characteristics of composite construction that influenced the content of Eurocode 4 are now summarised. Some have equivalents within the scope of Eurocode 2 and/or Eurocode 3, but they are more significant in a composite structure.

(a) The use of unpropped construction is general, both for beams and for composite slabs. It has a potential influence on all aspects of subsequent response to loading, and is referred to in clause 2.2.1.2(2), "design situations", and in many other places.

(b) A continuous beam of uniform section may have a resistance to hogging bending as low as one-third of its resistance to sagging bending. The use of slab reinforcement to strengthen the hogging region is limited to material of high ductility, because of the large extensions caused by the flexibility of common types of steel beam-to-column connections, and the economic need for the use of redistribution of moments in design. Reinforcement worsens the Class of the steel section, with adverse consequences for design.

(c) Shear connectors apply concentrated forces to the concrete slab, that must be resisted without local failure. The ductility required of a shear connection can be large, and the effects of its flexibility are complex and not always negligible.

(d) It is necessary to ensure that a composite slab fails in a ductile manner. This depends on the type of profiled sheeting used, and influenced the specification of the tests needed to determine resistance to longitudinal shear.

(e) The Class (relevant to local buckling) of a rolled section forming a steel beam is the same in hogging and sagging bending. A typical composite beam may be Class 3 in hogging bending, but is usually Class 1 at midspan.

(f) For steel beams, design methods are needed to ensure that non-distortional lateral buckling does not occur. It cannot occur in composite beams, which have to be checked for distortional lateral buckling, using different methods.

(g) Uniform change of temperature and shrinkage of concrete can both, in theory, alter the curvature, as well as the length, of a composite beam; and the relevant calculations are complex.

(h) Significant economy can be achieved in the design of some concrete-filled steel tubes, as columns, by taking account of triaxial stress effects.

(i) There are many potential combinations of situations. For example, in any framed structure that has composite members, the possibilities include:

- composite beams, propped or unpropped, or steel or reinforced or prestressed concrete,
- concrete, normal density or lightweight,
- steel beam section in Class 1, 2, 3, or 4,
- shear connection partial or full,
- shear connectors ductile or not,
- web of steel beam encased or not,
- profiled sheeting spans longitudinally, transversely, or is absent,
- beam-to-column connections nominally pinned, semi-rigid, or rigid,
- frame braced or unbraced,
- columns steel, concrete, or composite.

There are over 15000 combinations from this list, and most of them are practicable.

The preceding list illustrates the need to specify simple design methods wherever possible. This has been done in Eurocode 4: Part 1.1:

- in the treatment of creep of concrete by the use of modular ratios;
- by enabling the local effects of temperature and shrinkage of concrete in buildings to be neglected, in almost all situations;

- by simplification of the rectangular stress block for concrete in compression;
- by the use of a polygonal interaction diagram for the resistances of a cross-section of a column;
- by allowing global analyses that neglect shrinkage and cracking of concrete, shear lag, and in some structures, the effects of unpropped construction and creep of concrete;
- by defining situations where no check on lateral buckling need be made and providing simplified methods, where checks are needed.

One of the targets originally proposed for Eurocodes was that there should be a unique design procedure for each problem. Eurocodes were not to be collections of different methods customary in various countries. This objective has been achieved. It was also hoped that designers of the same structure, in different offices, would have to use the same methods. This has not been achieved; and should not be, because simplicity, so often needed for composite structures, usually implies some loss of economy. The conflict between these aims is better resolved by the designers of particular structures, than in a code with wide applicability.

Another target was that the Eurocodes should be suitable for contractual use, under the European Public Works Directive, No. 89440. This led to the presentation of some clauses in the form "Unless differently specified, ...".

6. PARTIAL SAFETY FACTORS, AND CALIBRATION

All γ factors in Eurocode 4: Part 1.1 are "boxed". This is to enable the authorities in member countries of CEN to assign other values, if they so decide. All the values for actions given in Eurocode 4 are as in Eurocodes 2 and 3. They will be supplemented by, and aligned with, values to be given in Eurocode 1 in due course.

Since Eurocode 4 copied the values γ_M given in Eurocodes 2 and 3, most of its calibrations were, in effect, checks on the coefficients used in the design formulae. There was also much reliance on existing practice, because the extent of reliable test data is far less than for structural members of steel or reinforced concrete.

Statistical calibrations have been done for the plastic moments of resistance of composite beams in sagging bending, for both full and partial shear connection, and in hogging bending [10]. The results appear to confirm the values γ_M given in Part 1.1. They also show the sensitivities of probabilities of failure to reductions in γ_a (for structural steel) below the current value, 1.1. Reference is made in another paper to the calibration work for shear connectors.

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