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Composite structures of steel and concrete

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For Part 1.1, drafting has been in progress since the early 1980's - and this built on earlier work from the 70's. The first draft was presented to the European Commission in 1985. The length of time is mainly due to three factors:

- An initial uncertainty on the relationship between the Eurocodes and national regulatory frameworks for construction. How were the Eurocodes to be implemented? This eventually caused the European Commission, around 1990, to hand over the development of the Eurocodes to the European Standards organisation, CEN. This organisation, through its established procedures, can provide the means to introduce the Euroco-des in replacement of national standards. However, transfer to CEN introduced a further cycle of comment and re-drafting in the process. This was because it was decided that the Eurocodes should be published first as ENVs.
- Secondly, there is the need to put in place provisions for funding. Such support is essential, not least because there is substantial input from university staff, to provide knowledge of the basic research on which the Eurocodes are based.
- Thirdly, there is the essential need to take account of comments on the work so far. It is important that views of representative users are heard and, if possible, acted upon. The ENV for Part 1.1 was published in 1992 (CEN, 1992). Substantial comments were received from users, on both the 1985 draft and the 1992 ENV.

The European Commission has long recognised the need for common rules to ensure safety, serviceability and durability. For this reason they have been willing to provide financial support. The Eurocodes are seen as an effective means to share good practice across Europe, to the mutual benefit of all.

The drafting work is carried out by Project Teams composed on European experts. In converting an ENV, each Project Team is working closely with National Technical Contacts (NTCs) – engineers who monitor and advise on the work. The first draft of EN 1994-1-1 was presented to NTCs in December 1999 and to CEN in April 2000.

Composite structures have of course an erection phase as a steel structure and indeed some components, commonly the column and the connections, remain as steel. Eurocode 4 therefore refers to the corresponding code for steel structures, Eurocode 3. Similarly there is a need to consider some parts as concrete elements, which are dealt with by Eurocode 2. The completion of Eurocode 4 is therefore dependant on both Eurocode 2 and Eurocode 3.

The final draft of EN 1994-1-1 has been presented to CEN in February 2002.

Voting will take place later that year. If positive, the code will become available as a full European standard as part of a package of Eurocodes for building structures. It is intended that national design codes for composite construction will be withdrawn by 2008.

In the CEN system, development of the Eurocodes is overseen by Technical Committee 250. The following guidelines are an important feature, intended to avoid delays:

- Provisions should reflect existing practice
- Provisions should not be based on last-minute research
- There should be a coherent set of Principles
- In case of unresolved technical disagreement, the corresponding Rule should be omitted

This paper describes work to finalise Eurocode 4 as a full European Standard for composite construction. The document has three Parts:

1. Part 1.1 General rules and rules for buildings

2. Part 1.2 Structural fire design

3. Part 2 Bridges.

Each Part has been published previously as an "ENV" (in English, a "Draft for Development"). In practice it means that the code is suitable for use on a trial basis. The work now in progress is referred to as "conversion to EN". Conversion is taking place on all three Parts, but this paper concentrates on Part 1.1 as this is of general interest. Eurocode 4 is designated as EN 1994 and Part 1.1 will therefore be EN 1994-1-1.

During conversion, account is being taken of national comments on the ENV but in practice recent developments in composite construction cannot be ignored. This paper describes how three developments are influencing the conversion:

• Steels up to Grade 460

• Beam-to-column joints with composite action

• Innovative forms of composite beam.

Strutture composte acciaio-calcestruzzo

Nella presente trattazione viene analizzato il processo di conversione dell'Eurocodice 4 "Strutture composte acciaio-calcestruzzo" da norma sperimentale (prENV) a norma definitiva.

Il documento si compone di tre parti:

1. Parte 1.1 Regole generali e regole per edifici

2. Parte 1.2 Progettazione contro l'incendio

3. Parte 2 Ponti

Ciascuna parte è stata preventivamente pubblicata come norma sperimentale (in inglese, come "Draft for development"). Ciò significa che la norma poteva essere utilizzata su base sperimentale. Il lavoro qui descritto riguarda la fase di conversione a norma definitiva, ma benché la conversione comprenda tutte e tre le parti, la presente trattazione si riferisce solo alla Parte 1.1 in quanto di interesse generale. L'Eurocodice 4 è designato come EN 1994 e pertanto la parte 1.1 è designata come EN 1994-1-1.

Nella fase di conversione si è tenuto conto dei commenti nazionali riguardanti la norma sperimentale, ma non possono essere ignorati i recenti sviluppi della costruzione composta.

L'articolo descrive tre particolari aspetti riguardanti la conversione:

• Acciai fino al grado 460

• Collegamenti trave-colonna ad azione composta

• Forme innovative delle colonne composte

• Text-book material should not be included.

In practice though, Project Teams have to use their own judgement. For example, recent research cannot be ignored if it casts doubt on the safety of current provisions. What is "text book" material can be difficult to define as engineering curricula vary from country to country. So Project Teams are trying to strike a balance, with provisions that:

• are safe (but not uneconomic)
• are unambiguous and sufficiently detailed, to avoid disputes and to permit fair international competition, and
• permit innovation.

This is a challenging set of aims, so perhaps it is not surprising that the work has occupied many years.

CONTENTS OF THE PRESENT DRAFT

Many readers will have seen the ENV Eurocodes and some will be very familiar with one or more of them. In the EN though, there will be some changes in both the content and the sequence of provisions. Many have arisen from the sensible wish to harmonise presentation of design rules across different structural materials, and to avoid duplicating provisions. The most recent (third) draft of EN 1994-1-1 has the following sections:

Section 1: General
Section 2: Basis of design
Section 3: Materials
Section 4: Durability
Section 5: Structural analysis
Section 6: Ultimate limit states
Section 7: Serviceability limit states
Section 8: Composite joints in frames for buildings
Section 9: Composite slabs with profiled steel sheeting for buildings
Section 10: Execution
Section 11: Standard tests.

Compared to the ENV, Sections 2, 3 and 4 are now short, as reference is made to other Eurocodes. Arguably the most significant change is to provide in each Eurocode a separate Section 5 on Structural Analysis. Efforts have been made to unify approaches to structural analysis in Eurocodes 2, 3 and 4. In general terms, Eurocode 4 follows Eurocode 3 but gives provisions to allow for the action of concrete under load, including cracking, creep and shrinkage.

There is now no separate section on shear connection. This topic is treated within Section 6. ECCS Technical Committee 11 conducted a survey in 2000 to determine what kinds of shear connector are used in Europe. This showed that very little use is made of forms other than headed studs. The draft EN therefore treats only these. In contrast, the ENV gave rules for block connectors, hoops, angles and friction-grip bolts.

Studs may be welded through steel decking, to provide the "fast-track" construction common in multi-storey buildings in several parts of the world. The resistance of a stud may be reduced though if the decking is particularly thin (less than 1 millimetre) or if holes are cut in the sheeting to allow shop-welding of studs to the beam section. This is an example of a rule being revised in the light of recent research, in order not to lessen safety margins.

Note that there is a new Section 8, devoted to composite joints, to which further reference is made later in this paper.

The last section gives standard tests to determine the resistance of shear connectors and the horizontal shear strength in composite slabs. National comments show some concern about these provisions:

• Testing should not be a basis for increasing the agreed resistance values given in Section 6.
• The provisions on testing of composite slabs could result in manufacturers being required to re-test their products.

Eurocode 4 is alone in proposing to include specification of standard tests as normative provisions in what is a document for designers. For these reasons it is likely that Section 11 will be re-presented as an informative annex, which can be adopted, or not, by national authorities. The ultimate solution is for standard methods of testing to be covered by European Technical Approvals, initiated by appropriate manufacturers.

Finally, it is important to remember that this Part should include all the general rules applicable to both bridges and buildings. This has influenced the contents of Part 1.1. The most significant example concerns Fatigue, included in Section 6 of Part 1.1. Although mainly of concern to bridge designers, it is also relevant to some building structures and is therefore a general matter.

Bridge design is also characterised by greater concern for the effects of creep and shrinkage of concrete. This affects the provisions in Section 5. However, care is being taken to retain simplified methods for common building structures, which are clearly marked as such within the Eurocode.

DEVELOPMENTS IN COMPOSITE CONSTRUCTION

An aim in conversion is to permit innovation.

Three examples demonstrate how Eurocode 4 is treating technical developments.

High-strength structural steels

Developments in steel production have led to the availability of grades S460 and S420 as structural materials. During the ENV period, the scope of Eurocode 3 was extended to these steels (CEN, 1994). National comments showed a wish to extend the scope of Eurocode 4 similarly.

Tests on composite beams had previously demonstrated that bending resistance could still be based on a plastic method, despite the higher strains needed to develop yield in the steel (Bode and Kunzel, 1990). However, some restriction is needed if the neutral axis in sagging bending becomes low, because of loss of strength in concrete at high strains. The present draft for EN 1994-1-1 therefore applies a reduction factor β to the plastic moment of resistance if the depth of the neutral axis exceeds 15% of the total depth of the composite section (Figure 1) (Bergmann, 1999). For a similar reason, the moment resistance of a composite column will be more

limited, compared to design in lower grade steels.
For hogging regions in beams, there is need for a minimum amount of slab reinforcement in tension, to ensure sufficient rotation capacity. To avoid this becoming too onerous, redistribution of moment is restricted, compared to beams with lower grade structural steel. A higher minimum degree of shear connection is also required, as a further consequence of the high strains needed to reach yield in the steel section.
These additional requirements have been easily included during the conversion of the code.

Composite joints

For other developments, it is not proving so easy to give comprehensive design provisions within the draft EN. Composite joints are an example. Within the context of Eurocode 4, a composite joint is one in which slab reinforcement is deliberately designed to contribute to the properties of the connection. Examples are shown in Figures 2 and 3. Little additional site work is required in return for greater load capacity and stiffness (or reductions in the steel section) and greater control of cracking.
Limited provisions for such joints were included in the ENV and considerable discussion has taken place on the extent to which such joints should be treated in the EN. As the benefits of composite action in joints are significant, it would seem desirable to treat them within the Eurocode by providing detailed rules. Such rules are already available as a result of testing and other research carried out over the last twenty years (e.g. Johnson and Law, 1981; Leon and Zandonini, 1992; Anderson, 1997; Steel Construction Institute, 1998; ECCS, 1999).
As can be seen from Figures 2 and 3, many forms of composite joint include a steelwork connection and it is therefore necessary for Eurocode 4 to refer to Eurocode 3. Joints are complex elements and to codify their design takes many pages of provisions. Perhaps this why so few national codes have attempted this task? But trial drafts have shown that for Eurocode 4 to give a list of amendments to the detailed rules of Eurocode 3 results in provisions that are very difficult to follow. The draft EN 1994-1-1 therefore concentrates on giving agreed structural properties for joint components specific to composite construction, the reinforcement and possible encasement.
Depending on the method of frame analysis being used, the designer needs to be able to predict the moment resistance, possibly the stiffness and perhaps the rotation capacity of the joint. Eurocode 3 treats a joint as an assembly of components and the response is determined by following the code's rules for the assembly (Jaspart, 1999). For a composite joint, the reinforcement may be treated as analogous to a bolt row in tension, but Eurocode 4 will not give detailed rules for assembly (Figure 3). It is assumed that reference will be made to other literature if the designer is in doubt (e.g. ECCS, 1999). In practice the designer is certain to use published tables or appropriate software for joint properties, because of the length of calculation usually required.
The key properties of a joint are its moment resistance, stiffness and rotation capacity. Composite joints tend to be very stiff and the calculation of this

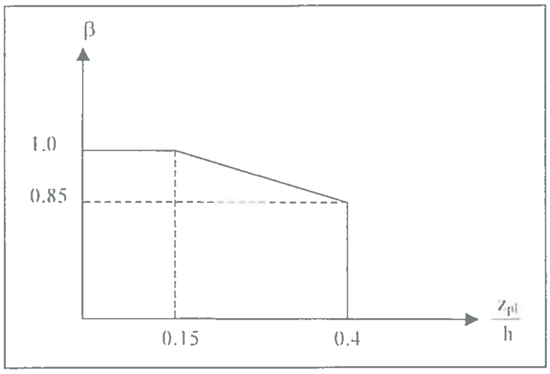

Figure 1
Reduction factor
β for $M_{pl\,Rd}$

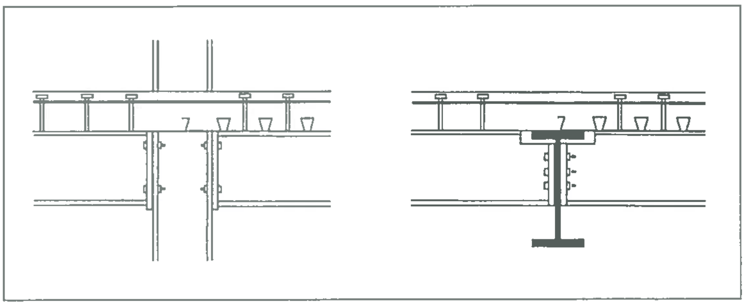

Figure 2
Composite joints
with end plates

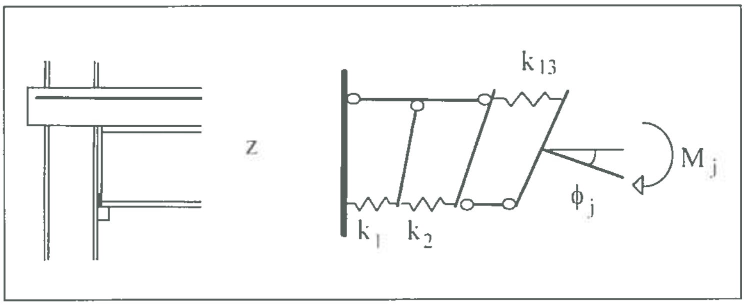

Figure 3
Spring model
for a composite
joint with
a contact plate

property is therefore likely to be of less importance – the joint can be assumed to be rigid. The main text of the code therefore treats moment resistance, with rules for stiffness being given in an annex.
Rotation capacity may also be needed if plastic analysis is used for the frame. Its accurate calculation is though very much a specialist task, to be determined by software. This is because rotation may be limited by fracture of the reinforcement, which is influenced by tension stiffening in the cracked concrete slab (Anderson et al, 2000).

Innovative floor systems

Slim-floor construction has become established practice since ENV 1994-1-1 was published (CEN, 1992). With much of the floor slab within the depth of the steel section, depth of construction and so building height are minimised. If stud shear connectors are used, the rules of Eurocode 4 apply to the design of the beam.
This is not the case though with the latest innovation from Corus. Advances in rolling technology enable an asymmetric beam to be manufactured specially for use with deep decking (Lawson, Mullett and Rackham, 1997). The bottom flange is wider than the top, to provide seating for the decking without welding the additional plate shown in Figure 4. The top flange has a rib pattern rolled into it, which enhances composite action between the steel section and the concrete. No shear connectors are provided, thereby placing such

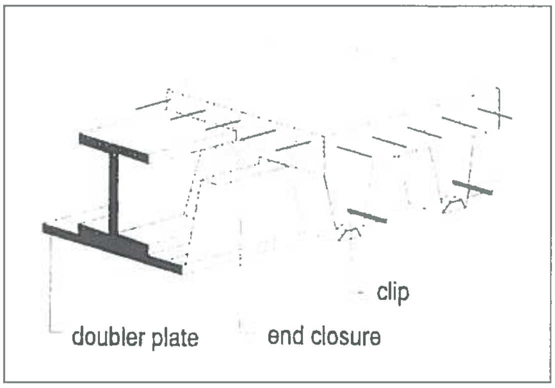

Figure 4 Integrated steel beam and deep composite slab

beams outside the scope of the rules of the draft EN, but still within the principles. Composite action is developed instead by longitudinal shear bond between the steel beam and the concrete encasement. The design value is taken as 0.6 N/mm^2, as justified by full-scale tests on the Corus product (Lawson et al, 1999).

CONCLUSION

Eurocode 4 will provide comprehensive design rules for common composite elements, using modern limit-states format. Through its international nature of its development it should receive wide acceptance in Europe and also in other regions of the world.
Where it does not provide detailed rules, it nevertheless provides a basis for design. It is hoped that this document, so long in preparation, will extend the use of steel in construction.

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REFERENCES

Anderson, D. (ed) "Composite Steel-Concrete Joints in Braced Frames for Buildings", COST-C1 Semi-rigid behaviour of civil engineering structural connections, 1997, European Commission, Luxembourg.

Anderson, D, Aribert, J.-M., Bode, H. and Kronenberger, H.-J. "Design Rotation Capacity of Composite Joints", 2000, The Structural Engineer, Vol. 78, No. 6, p. 25 - 29.

Bergmann, R. "Steel Concrete Composite Beams and Columns" in "Steel and Composite Structures: International Conference: Proceedings", Brekelmans, J. and Tomà, T. (ed), 1999, TNO Building and Construction Research, Delft, p.3.1-3.9.

Bode, H. and Künzel. R., "Composite Beams of St E 460 Quality", 1990, Research Report 2/90, University of Kaiserslautern, Kaiserslautern.

CEN, "ENV 1994-1-1 Eurocode 4: Part 1.1 Design of Composite Steel and Concrete Structures : General rules and rules for buildings", 1992, Brussels.

CEN, "ENV 1993-1-1/A1 Eurocode 3: Part 1.1 Design of Steel Structures : General rules and rules for buildings: Annex D: The Use of Steel Grades S460 and S420", 1994, Brussels.

ECCS, "Design of Composite Joints for Buildings", Publication No. 109, 1999, Brussels.

Leon, R.T. and Zandonini, R. "Composite Connections" in "Constructional Steel Design – An International Guide", Dowling, P.J., Harding, J.E. and Bjorhovde, R. (ed), 1992, Elsevier Applied Science, London, p. 501 – 522.

Jaspart, J.-P., "On the Way to a Unified Design Approach for Joints in Structural Systems" in "Steel and Composite Structures: International Conference: Proceedings", Brekelmans, J. and Tomà, T. (ed), 1999, TNO Building and Construction Research, Delft, p. 16.1-16.8.

Johnson, R.P. and Law, C.L.C. "Semi-rigid Joints for Composite Frames" in "Joints in Structural Steelwork", Howlett, J.H., Jenkins, W.M. and Stainsby, R. (ed.), 1981, Pentech Press, London, p.3.3-3.19.

Lawson, R.M., Mullett, D.L. and Rackham, J.W. "Design of Asymmetric Slimflor Beams using Deep Composite Decking", 1997, Publication 175, The Steel Construction Institute, Ascot.

Lawson, R.M. et al "Slimflor and Slimdek Construction: European Developments", 1999, The Structural Engineer, Vol. 77, No. 8, p. 22-30.

Steel Construction Institute, "Joints in Steel Construction - Composite Joints", 1998, Ascot.

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