Darko Dujmović / Boris Androić / Ivan Lukačević

Composite Structures according to Eurocode 4

Worked Examples

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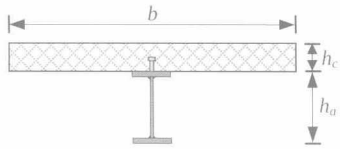
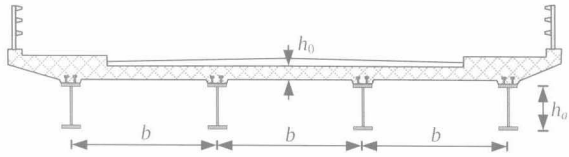
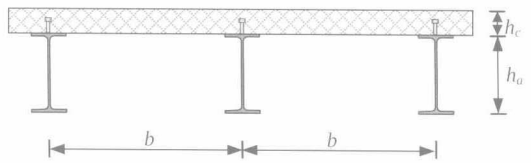
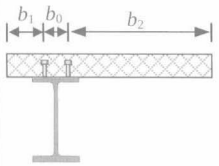
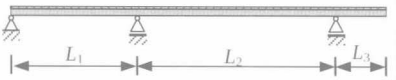
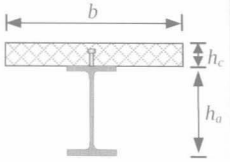
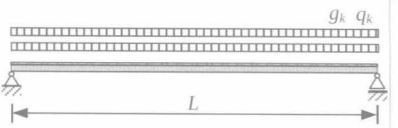
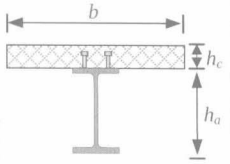
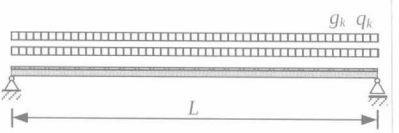
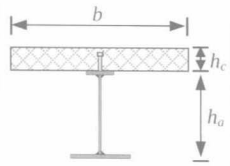
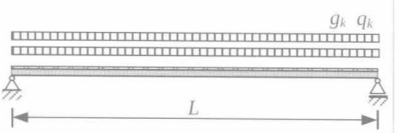
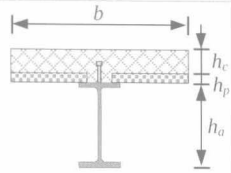
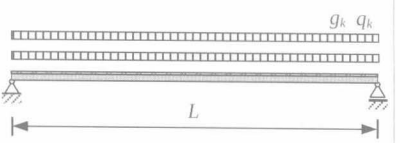
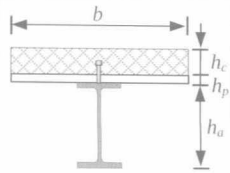
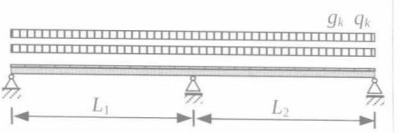
List of examples

A Creep and shrinkage

Example	Cross-section	Page
A1		3
A2		15
A3		27

B Composite beams

Example	Cross-section	Static system and actions	Page
B1			47
B2			53
B3			67
B4			111
B5			151
B6			177

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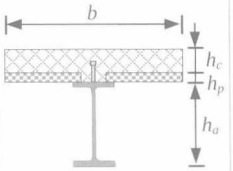
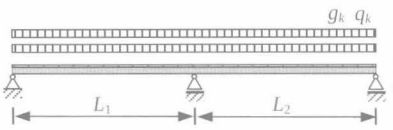
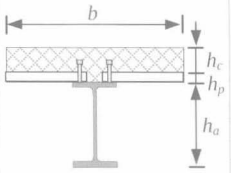
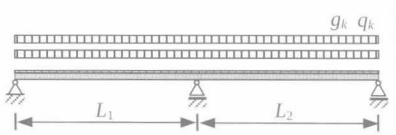
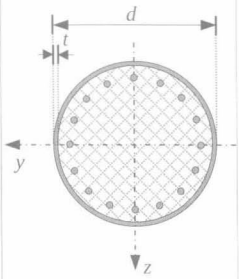
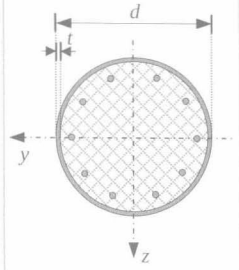
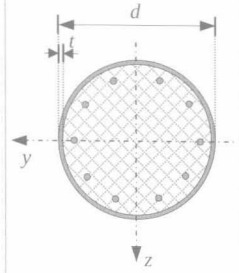
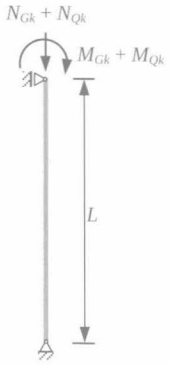
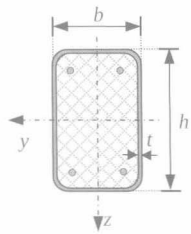
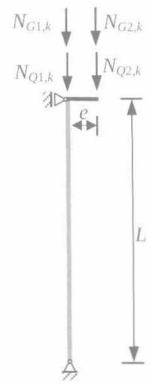
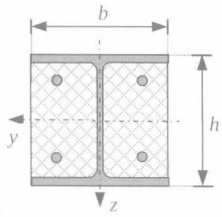
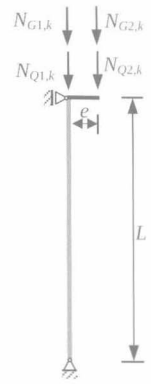
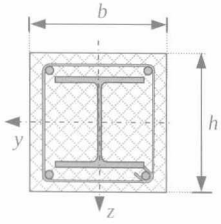
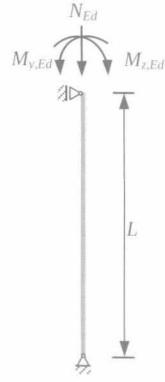
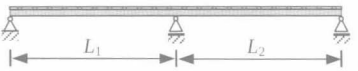
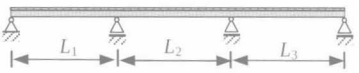
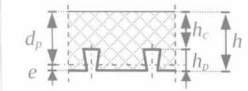
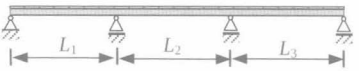
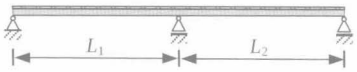
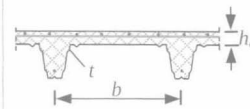
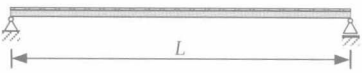
Example	Cross-section	Static system and actions	Page
B7			243
B8			297

C Composite columns

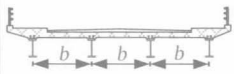
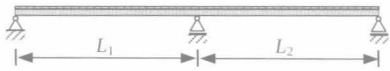
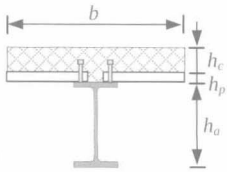
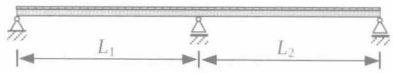
Example	Cross-section	Static system and actions	Page
C1			399
C2			419
C3			445

Example	Cross-section	Static system and actions	Page
C4			487
C5			545
C6			615

D Composite slabs

Example	Cross-section	Static system	Page
D1			673
D2			697
D3			723
D4			765
D5			797

E Fatigue

Example	Cross-section	Static system	Page
E1			827
E2			857

F Types of composite joints

Example		Page
F1	Beam to beam joints	881
F2	Beam to column joints	883

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Introduction

Between the development and the implementation of the Eurocodes that are currently published and in effect in many countries across Europe a number of years have passed. Given the long time of initial adoption of the Eurocodes some of the tests and methods of verification used in the current standards originate from the 1980s or 1990s. As is inherent in any standard, the Eurocodes have no educational character; their purpose is not to explain how they originated or developed. For Eurocode 4, this actually means that EN 1994-2004 no longer represents the state of the art for composite construction in Europe. The current level of scientific knowledge is not represented in the codes and they obviously do not take account of any forms of interaction between steel and concrete that now exist in the European construction markets but where the techniques were developed after adoption of the code. Only the next generation of Eurocode 4 due to come into force in 2018 as EN 1994-2018 will be based on the reactions and comments of the construction industry to the current standard.

In the meantime, we thought it highly necessary for practicing engineers to know well the details of calculation in accordance with the standard EN 1994-2004 that is currently published. This is exactly why we have compiled these fully worked out numerical examples in this book. The examples provided herein are intended for anyone involved in the detailed design of a composite structure of steel and concrete.

The examples listed in Chapter A represent the calculation of the values of the time-dependent concrete deformations due to creep and shrinkage. These values are included in EN 1992 (Design of concrete structures) but are used in EN 1994 as well. The final values of the creep coefficient are determined by means of nomograms in EN 1992. However, EN 1994 does not provide any nomograms for the determination of the final values of shrinkage deformations. For that reason, the nomograms that can be found in literature have not been used in these examples. The values of the time-dependent concrete deformations are given in the examples so as to enable the structural engineers to use them in practice.

The examples given in Chapter B refer to beams composed of steel profiles and concrete flanges. Although these structural elements have been thoroughly discussed in EN 1994, there are still some dilemmas about the calculation of the serviceability limit state. Those dilemmas are pointed out and commented at the end of the examples. It should be expected that they will be solved or better substantiated in the next edition of the Eurocode. Current practice utilises more and more often beams composed of structural steel and concrete with increased

strength, but they are still not adequately represented in the current standard. Similarly, although frequently used, pre-stressed elements are not covered by the rules of EN 1994 at all. The examples given in Chapter B show in a detailed way a set of problems associated with the calculation of the bearing capacity of the shear connectors whose resistance is determined by a push-out test. The present test does not give sufficiently accurate data on ductility, so it will be necessary to present a more accurate, but also a more expensive, test in the future. Steel girders with openings, connected with concrete flanges represent a modern technical solution frequently applied, but there are no corresponding guidelines in EN 1994.

Chapter C provides examples for the calculation of composite columns consisting of structural steel and concrete. The recommendation of EN 1994-1-1 is that the calculation should be performed according to a simplified method. But when it comes to columns with non-uniform or asymmetric cross-sections, the verification can be produced only by a general method. Such a method is not convenient for practical purposes, so the standard does not contain any more detailed guidelines for its application. Even if a computer (software) support is used, it is necessary to know in advance the rules of the simplified method. For that reason, the articles associated with the simplified method are discussed in detail in Chapter C. For columns subjected only to axial pressure, the produced verification is the same for both structural steel and composite columns so the "χ" procedure can be used. However, for columns subjected to axial compression and bending, the verification is produced according to the second-order theory – through the introduction of equivalent imperfection. The imperfection is added only in the plane where a failure is to be expected. If it is not obvious which plane is in question, the verification should be produced for both planes. So, for instance, if the column is subjected to axial compression and uniaxial bending, the verification is frequently produced for axial force and biaxial bending. The modification of the new EN 1994-2018 will comprise the amendment to or correction of some informative Annexes because they have not been accepted by some countries. This refers specifically to the fire resistance of columns of concrete-filled tubes covered by the Annex H, EN 1994-1-1.

In the numerical examples given in Chapter D, the composite slabs consisting of steel profiled sheets and concrete are discussed. They highlight the complexities involved in their calculation, and also some dilemmas, which probably need to be resolved in the future. For the next generation EN 1994-2018 currently being developed, one special interest represents the introduction into the standard of new guidelines for some new types of composite slabs. These new types adhere to the principle that it is desirable to have more "hollow space" within the slab cross-section which reduces the amount of concrete as well as the slab's weight but still results in an effective flexural stiffness.

Fatigue problems are discussed in the examples included in Chapter E. A complete estimation of the fatigue of composite elements consisting of structural steel and

concrete is given by EN 1994 only for headed studs. The fatigue estimation is produced for structural steel (EN 1993), concrete (EN 1992) and reinforcement (EN 1992), from which it can be concluded that such estimation represents a very complex problem.

The final chapter, F, deals with structural solutions for the joints applied most frequently in practice.

In recent years, composite elements consisting of steel and concrete have not, for various reasons, had the chance to be applied to any great extent – certainly not to the extent that they deserve. However, bearing in mind all the previously stated facts and also some of the dilemmas about the further development of the new generation of the Eurocode, we can say that there is now a new opportunity for the application of composite elements.

Zagreb, October 2014 The authors

Chapters

A Creep and shrinkage 1

B Composite beams 45

C Composite columns 397

D Composite slabs 671

E Fatigue 825

F Types of composite joints 879

Literature 887

Contents

Chapters V

List of examples VII

Introduction XXXI

A Creep and shrinkage 1

A1 Determination of creep and shrinkage values 3

1. Purpose of example 3
2. Cross-section 3
3. Input data 3
4. Creep coefficients 4
4.1 Determination of final creep coefficient 4
4.2 Determination of creep coefficient at time t = 90 days 5
5. Shrinkage strains 8
5.1 Determination of final value of shrinkage strain 8
5.2 Determination of shrinkage strain at time t = 90 days 11
6. Commentary 12

A2 Determination of creep and shrinkage values on an example composite highway bridge 15

1. Purpose of example 15
2. Cross-section 15
3. Input data 16
4. Calculation of modular ratio n_L for permanent action constant in time 16
4.1 Calculation of modular ratio n_L for permanent action constant in time at time $t = \infty$ 16
4.2 Calculation of modular ratio n_L for permanent action constant in time at opening to traffic t = 63 days 18
5. Calculation of modular ratio n_L for shrinkage and shrinkage strains 19
5.1 Calculation of modular ratio n_L for shrinkage and shrinkage strains at time $t = \infty$ 19
5.2 Calculation of modular ratio n_L for shrinkage and shrinkage strains at opening to traffic t = 63 days 21
6. Primary effects of shrinkage 23
7. Commentary 26

A3 Determination of creep and shrinkage values and their effects at calculation of bending moments 27

1. Purpose of example 27

2. Static system, cross-section and actions 28
3. Input data 29
4. Creep and shrinkage 29
4.1 Determination of final creep coefficient 29
4.2 Determination of shrinkage strain 31
5. Effective width of the concrete flange 34
5.1 Cross-section at mid-span 34
5.2 Cross-section at support 34
6. Geometrical properties of composite cross-section at mid-span 34
7. Geometrical properties of composite cross-section at support 37
8. Effects of creep and shrinkage 38
8.1 Design bending moment for internal support 38
8.2 Secondary effects of shrinkage 40
9. Commentary 43

B Composite beams 45

B1 Effective width of concrete flange 47

1. Purpose of example 47
2. Static system and cross-section 47
3. Calculation of effective width of the concrete flange 47
3.1 Support A 48
3.2 Mid-region AB 49
3.3 Support region BC 50
3.4 Mid-span region CD 50
3.5 Support region DE 51
4. Recapitulation of results 52
5. Commentary 52

B2 Composite beam – arrangement of shear connectors in solid slab 53

1. Purpose of example 53
2. Static system, cross-section and actions 53
3. Properties of materials 54
4. Ultimate limit state 54
4.1 Design values of combined actions and design values of effects of actions 54
4.2 Effective width of concrete flange 55
4.3 Plastic resistance moment of composite cross-section 55
4.4 Vertical shear resistance 58
4.5 Check of resistance of headed stud connectors 60
4.6 Check of the longitudinal shear resistance of the concrete flange 65
5. Commentary 65

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