

DESIGN AND ANALYSIS OF STEEL-CONCRETE COMPOSITE STRUCTURE

Radomir Folić

Professor Emeritus

Vlastimir Radonjanin,

Associated professor

Mirjana Malešev

Associated professor

University of Novi Sad, Faculty of Technical Sciences, Department of Civil Engineering

Novi Sad, Serbia

folic@uns.ns.ac.yu

1. ABSTRACT

Composite steel/concrete structures are used widely in modern bridge and building construction. The very large amount of theoretical and experimental research, design application and construction work carried out has shown the efficiency and economy solution of composite structure. In this paper is presented the current state of the art related to design and analysis, based on quoted references, in steel-concrete composite structures. Furthermore, it comments some provisions of recently adopted Eurocodes that are being published as EN for structures and their applications in composite construction. The focus is on steel beam-concrete slab and their connections and the effects of their interaction. The concrete slab can be executed as cast in situ or as precast, reinforced and/or prestressed. Various components (beams, slabs and columns) of a structure and their properties are considered. The analysis of time-dependent deformations (creep and shrinkage of concrete) and stress relaxation of prestressing steel are commented. The problems dealing with the designing of buildings and bridges are covered.

Key words: composite structures, steel-concrete, composite action, buildings, bridges composite columns, effective width, creep, shrinkage, relaxation, ductility, repair

2. INTRODUCTION - PROPERTIES OF COMPOSITE STRUCTURES

Composite structures are generally made up with the interaction of different structural elements and may be developed using either different or similar structural materials. This is often referred to as “composite construction” and includes steel-concrete beams, columns and other structural components [29]. The use of steel-concrete composite beams has gained popularity in the last century thanks to its ability to well combine the advantages of both steel and concrete. Composite members exhibit enhanced strength and stiffness when

compared to the contribution of their components acting separately, and represent a competitive structural solution in many civil engineering applications, such as bridges and buildings [28].

It is known that composite structures (CS) are formed by combining different materials under the condition that their joint action – work is provided through structural measures. Still, the most frequent way of composite construction is the combining of steel and concrete which is the subject of this paper. Composite structures have been created for economic reasons i.e. to cut costs regarding form/shuttering and scaffold and to build faster. In the beginning the use of composite structures were based on empirical experiences, and the lack of technical regulations (Codes) and recommendations made its application more difficult and slowed it down. The first bigger CS was built as prefabricated and monolith structures and they unite the advantages of both of them. They have brought the high level of industrialization, saving of material and labour, faster building and more reliable quality control of material and performance. It has contributed to their wider application in bridges, buildings and other structures, as they are executed faster in comparison to those structures built in a classical way. Prefabricated elements change regarding form and scaffold and accept subsequently executed concrete elements. With the appropriate choice of shuttering shape it is possible to eliminate scaffold, which brings significant save. Through the application of CS, good properties of both prefabricated and monolith ways of construction are used.

The connection between the concrete slab and the steel beam is the most important for the obtaining of composite action. Depending on the size of shear forces in the contact plane between the concrete and steel, special mechanical connectors are designed coming out from the steel element into the part of section that is concreted in situ. In designing CS it is required that during service loads there is no partial interaction in the joint and that the bending failure occurs instead of the brittle failure. It is also important to provide adequate usability and durability of the structure. This method of building is often used in repairs and strengthening of elements and structures [5]. During the procedure every change of the cross-section of the beam at any moment must be analysed to prevent the occurrence of limit states of failure and usability.

The paper gives a short survey of the classification of composite structures and their properties. The problems of design, analysis and construction of CS are dealt with. A survey of some important theoretic and experimental investigations of composite concrete structures is given in [17]. As it is known, for service loads, steel has elastic properties, while concrete shows the characteristics of creeping and shrinkage, which significantly affect the state of loads and deformations in the course of time. The change of state in deformations in cross-sections determines general deformations of the element, so that in the course of time, the required properties of elements regarding their usability can be lost. Viscous-elastic behaviour of concrete in CS can cause significant changes in the state of loads and deformations with regard to their elastic state. The influence of creep and shrinkage of concrete is introduced in the analysis of limit states of usability, as well as in the analysis of failure states. Therefore, corresponding procedures of analyses are discussed in this paper. The formation of a general calculating procedure for the analysis of state of loads and deformations in CS is of interest in the course of time, when the slab can be unreinforced, reinforced and prestressed (PS). In PS structures, apart from the influence of shrinkage and creeping of concrete, it is also necessary to cover relaxing of PS

reinforcement and time history of load, as well as geometric change of section in the course of time in case of multiphase construction. When introducing the PS force it is possible to change the static influences in PS beams. The analysis of composite systems is also necessary in designing strengthening and repair works, especially in the application of additional reinforcement, additional concrete parts and/or prestressing, in order to enlarge serviceability properties of composite structures.

The application of composite structures was developed aiming to overcome the property of concrete not to accept greater tensile stress. Approximately equal coefficients of linear thermal strain and the adhesive property of concrete and reinforcement enable the composite construction of these two materials.

According to the method of slab construction there are:

- monolith, prefabricated-monolith, and
- prefabricated (placement of prefabricated elements instead of a monolith slab).

In comparison to the monolith method of construction when prefabricated elements are applied, there are relatively smaller influences than creeping and shrinkage of concrete, for in prefabricated elements one part of these influences has already taken place prior to the composite construction of the elements in the structure.

Composite beams do not need any false work or timber shuttering. This advantage is considered in the following section together with two different construction methods, "propped" and "unpropped". *According to the method of execution*:

- without shoring, and
- with shoring.

There is a significant difference in the behaviour of CS if [17] and [24] are taken into account during execution. If supporting is not applied, the first executed element accepts all loads subsequently applied to the moment it is composed with another element. Other loads that occur afterwards, remaining dead load of the structure and live load, are accepted by the composite action. This case refers to partial composite construction of the structure for live load and a part of dead load. Supporting of the first concrete element till the completion of CS refers to complete composite construction of the structure for its total load. It is applied in:

- continual composite construction, and
- discontinual composite construction.

The classification *according the mode of treatment of composite construction in calculations* is also of interest. There are two *calculation theories* that refer to:

- stiff composite construction (full shear connection between the composed elements), and
- elastic composite construction (when slipping occurs in the contact zone of the composed elements).

Generally, CS is calculated according to the theory of stiff composite construction, for in service loads very small displacements occur at the connection of composed elements. For upper phases of loads the displacements are not insignificant, especially in the area of the

limit state of load of CS. Therefore, CS can be discussed regarding: service influences, and ultimate influences.

Structural steel and reinforced concrete with the composite action are applied in case of composite slabs, beams and columns. The use of composite construction for buildings and bridges shows a few advantages in comparison with structures of steel and concrete used independently. The advantages manifest in fire-resistance, speed of construction, flexibility and final fitting out. These materials are completely compatible and complementary to each other; they have almost the same thermal expansion; they have an ideal combination of strengths with the concrete efficient in compression and the steel in tension; concrete also gives corrosion protection and thermal insulation to steel at elevated temperatures and additionally can restrain slender steel sections from local or lateral-torsional buckling. They can be used in mixed structural systems, for example concrete cores encircled by steel tubes, cased columns, as well as in composite structures where members consisting of steel and concrete act together compositely [15].

3. COMPOSITE BEHAVIOUR & DESIGN CRITERIA

The main philosophy in modern structural design is based on Limit States Design or Load Factor Design. This almost universally adopted procedure was developed during 1970's and 1980's [24]. The two limit states are to be considered for strength and stiffness. The normal strength of the member R_U (which may be its bending, axial or shear strength) is reduced by the capacity reduction factor f to obtain a design strength. In designing it must be provided that Design action \leq Design strength. The serviceability limit state is generally governed by limiting excessive deflections and vibrations. Composite members normally use grade steel and normal strength concrete. High strength concrete must be used particularly in columns, as well as cold-rolled profiled steel sheeting in profiled slabs and beams. Detailed information may be obtained on the behaviour of these materials in Standards which deal with concrete [10], or steel (EN 1993) and in [11].

For buildings in EN 1994-1-1 [11] contents are: (1) General, (2) Basis of design, (3) Materials, (4) Durability, (5) Structural analysis, (6) Ultimate limit states, (7) Serviceability limit states, (8) Composite joints in frames for buildings, (9) Composite slabs with profiled steel sheeting for buildings, and informative Annexes - AA: Stiffness of joint components in buildings; AB Standard tests; AC Shrinkage of concrete for composite structures for buildings. Besides reference standard EN 1990 this document uses together with EN 1992-Part 1-1 [10] and EN 1993 Parts 1-1, 1-3, 1-5, 1-8 and 1-9, and Standard for different materials.

Two commonly-used terms that describe composite behaviour are: partial-shear-connection and partial interaction and these relate to the behaviour of the connection between the steel and concrete components. Partial-shear-connection (PSC) concerns equilibrium of the forces within a composite member, while partial interaction concerns compatibility of deformation at the steel/concrete interface. PSC thus represents a strength criterion, while partial interaction represents a stiffness criterion [24b]. There are three possible stress distributions that can occur for a composite beam at its maximum strength (with different degree of shear connection), and these are shown in Fig. 1.

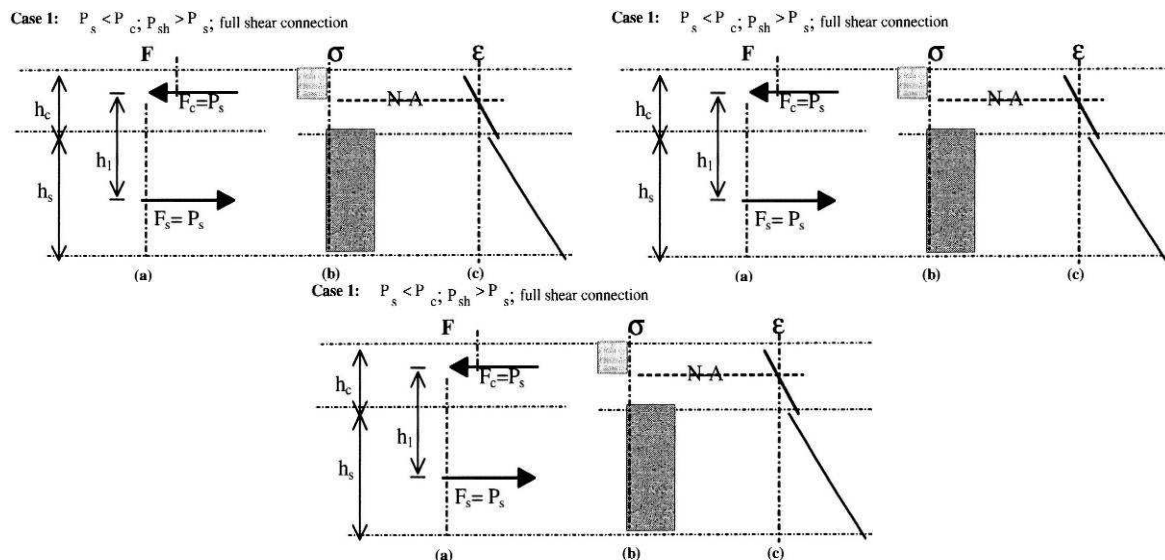


Fig. 1 Degree of shear connection, after [24b]

The behaviour of a composite beam is affected directly by the slip of the shear connection at the steel / concrete interface. The degree of interaction is a stiffness-based property, and is not the same as the degree of shear connection that is based on strength. The degree of shear connections and the degree of interaction are directly related, however, an increase of the number of shear connectors increases both the shear strength at the interface and the shear stiffness at the shear connection. Slip strains in beams with partial shear connection tend to be significantly larger than those in beams with full shear connection [24b].

The application of partial shear connection is of interest in structures in which the cooperation between the steel section and the concrete slab is not fully exploited to get sufficient resistance as in the following cases:

- when the concrete slab is not propped, the dimensions of the beam may be determined by the load during laying of the concrete,
- according to the deflection limitations the stiffness of the composite beam can be critical for the dimensions of the beam,
- for economical and technical reasons a designer may choose a larger steel section and fewer shear connectors instead of a minimum steel section with a large number of shear connection.

The theoretical and experimental results of a research programme on composite beams with partial shear connection in both simply supported and continues beams are presented in [32]. In [28] an analytical model for the analysis of steel-concrete composite beams with partial shear interaction including the shear deformability of the steel component is presented. This model is obtained by coupling an Euler/Bernoulli beam for an RC slab to a Timoshenko beam for the steel beam. The steel of the beam and the steel of the slab reinforcement are modelled by using linear elastic laws, while the time-dependent behaviour of the slab concrete is included by using general viscous-elastic laws. The numerical solution is obtained by means of the finite element method implementing a time-stepping procedure. Based on these results, the effects of shear deformations need to be carefully evaluated for composite steel-concrete systems, particularly in case of continuous beam configurations, to well-depict both shortened long-term responses at service conditions.

For accurate analytical predictions, the structural model must account for the interlayer slip between these two components. In numerous engineering applications (e.g., in the fields of structural optimization, structural reliability analysis and finite element model updating), accurate response sensitivity calculations are needed as much as the corresponding response simulation results. This paper focuses on a procedure for the response sensitivity analysis of steel-concrete composite structures using displacement based locking free frame elements including deformable shear connection with fiber discretization of the cross-section. Realistic cyclic uniaxial constitutive laws are adopted for the steel and concrete materials, as well as for the shear connection [34]. Analytical and experimental investigation of static strength of the shear connectors in steel composite beams is presented in [27].

If slip is free to occur at the interface between the steel section and the concrete slab, each component will act independently, as shown in Fig. 2.

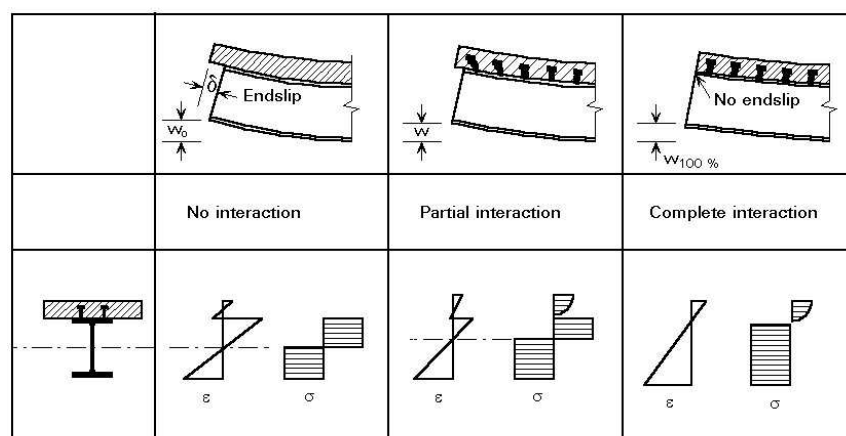


Fig. 2 Composite steel-concrete slab interaction, after [15]

If slip at the interface is eliminated, or at least reduced, the slab and the steel member will act together as a composite unit. The resulting increase in resistance will depend on the extent to which slip is prevented. It should be noted that Fig. 2 refers to the use of headed stud shear connectors. The degree of interaction depends mainly on the degree of shear connection used. The use of composite action has certain advantages. In particular, a composite beam has greater stiffness and usually a higher load resistance than its non-composite counterpart. Consequently, a smaller steel section is usually required. The result is a saving of material and depth of construction. In turn, the latter leads to lower storey heights in buildings and lower embankments for bridges.

In case of elastic analysis geometric properties of the cross-section are determined through the values of the equivalent section in which the area of the concrete part of the section A_c is replaced by the equivalent area of the steel A_s/n , where n is the nominal relation of the elasticity moduli of steel E_s and concrete E_c ($n = E_s/E_c$). This modulus is variable during time, for the modulus of elasticity for concrete changes due to creeping and shrinkage of concrete. The calculation of composite beams depends on the class of cross-sections, which are defined in EN1993. The section is classified according to the least favourable class of the compressed components of the steel section (flange or rib). Four classes of cross-

sections are determined depending on the capacity of rotation of the section and local buckling.

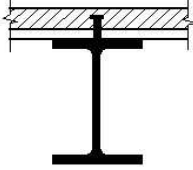
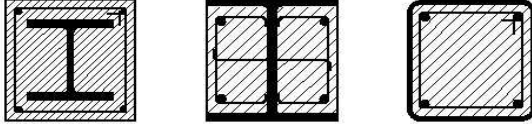

Composite girder		Steel-beam composite slab or RC-slab
Composite column		Steel profiles embedded in or filled with concrete
Composite slab		Holorib [®] sheeting + concrete

Fig. 3 Typical composite elements for buildings [15]

Depending on the cross-section class in the calculation of the bearing capacity of the section, the distribution of stresses in the section is defined either by the theory of elasticity or by the theory of plasticity. The theory of plasticity can be used only for sections of classes 1 and 2, while for sections of classes 3 and 4 the theory of elasticity is applied. For sections of class 3 the assumption is the reaching of yield in the end compressed fibre of the steel part of the section, and for sections of class 4 the reduction of bearing capacity caused by local buckling. In this case the effective width can be applied. When calculating stress and strain for the serviceability limit state we should apply elastic analysis for all cross-section classes. Where bending moments determined by elastic global analysis may be modified by redistribution of hogging moments (M), per cent of the initial value of the M to be reduced (Cl. 5.4.4 in [11]).

The disadvantage of a steel element subjected to compression is that it is prone to buckle. In composite members, there are two modes of buckling known as local and lateral distortional. Buckling must not occur if a composite beam is analysed by using rigid plastic assumptions.

4. FLOOR MEMBER DESIGN

Action effects may be calculated by elastic global analysis, even where the resistance of a cross-section is based on its plastic or non-linear resistance. Elastic global analysis should be used for serviceability limit states, with appropriate corrections for non-linear effects such as cracking of concrete, as well as for verifications of the limit state of fatigue. The effects of shear lag and of local buckling shall be taken into account if these significantly influence the global analysis. Linear elastic analysis allowance should be made for the effects of cracking of concrete, creep and shrinkage of concrete, sequence of construction and pre-stressing. The effective width of concrete flanges should be determined in accordance with the provisions from [11] and [12]. When elastic global analysis is used in [11] and [16], a constant effective width may be assumed over the whole of each span. This value may be taken as the value $b_{eff,1}$ at mid-span for a span supported at both ends, and the

value $b_{eff, 2}$ at the support for a cantilever. At mid-span or an internal support, the total effective width b_{eff} , see Fig. 4, may be determined as:

$$b_{eff} = b_0 + \Sigma b_{ei} \tag{1}$$

where:

b_0 - is the distance between the centres of the outstand shear connectors;

b_{ei} - is the value of the effective width of the concrete flange on each side of the web and taken as $L_e/8$ but not greater than the geometric width b_i . The value b_i should be taken as the distance from the outstand shear connector to a point mid-way between adjacent webs, measured at mid-depth of the concrete flange, except that at a free edge b_i is the distance to the free edge. The length L_e should be taken as the approximate distance between points of zero bending moment. For typical continuous composite beams, where a moment envelope from various load arrangements governs the design, and for cantilevers, L_e may be assumed to be as shown in Fig. 4. The same is in the analysis of bridges.

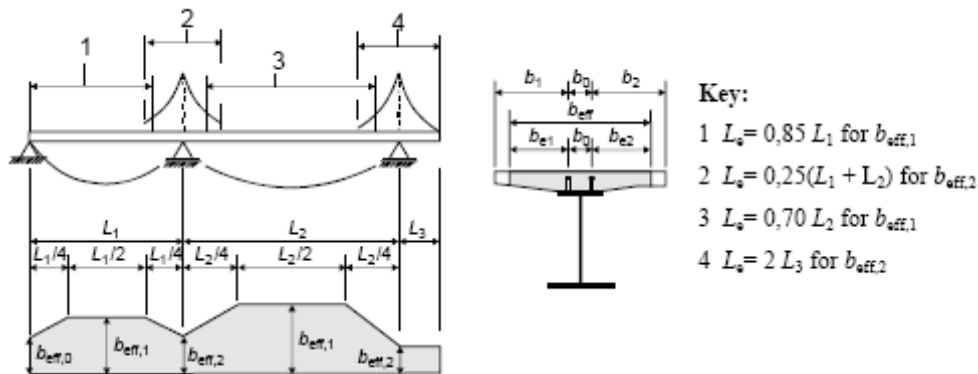


Fig. 4 Equivalent spans for effective width of concrete flange

In composite flexural beams the two materials are interconnected by means of mechanical shear connectors. To achieve this connection in practice are mostly used headed studs, semi-automatically welded to the steel flange. Fig. 5 shows several composite beam cross-sections in which the wet concrete has been cast in situ on timber shuttering. For single span beams, positive bending moments, due to vertical loads, cause tensile forces in the steel section and compression in the concrete deck thereby makes optimum use of each material. Therefore, composite beams, even with small steel sections, have high stiffness and can carry heavy loads on long spans [15].

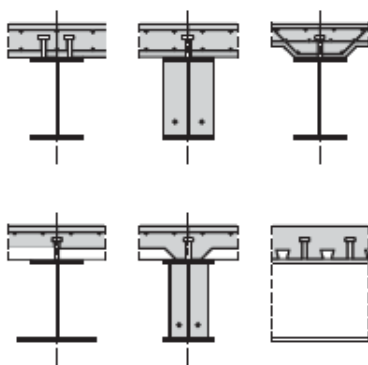


Fig. 5 Typical cross-section of composite beams, after [11]

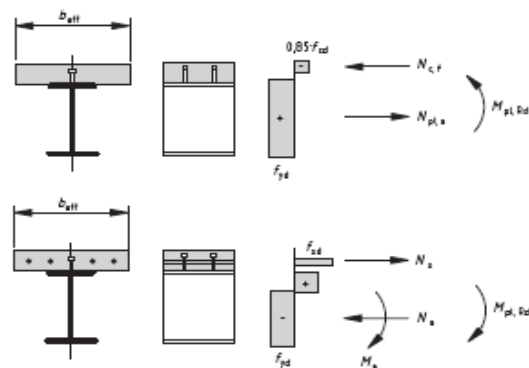


Fig. 6 Examples of plastic stress distributions for a composite beam with a solid slab and full shear connection in sagging and hogging bending, [11]

In multi-storey buildings, structural steelwork is typically used together with concrete; for example, steel beams with concrete floor slabs. The same applies to road bridges, where concrete decks are normally preferred (Fig.6). It is a way to provide adequate resistance for earthquake action, which requires a high amount of resistance and ductility.

The composite floor construction is highly competitive if spans are increased to 12, 15 or even 20 m. There is, of course, a demand for larger column-free spans in buildings to facilitate open planning or greater flexibility in office layout. It is important that the use of rolled steel sections, profiled metal decking, and/or prefabricated composite unit speeds erection. For high efficiency and economy the joints should be cheap to fabricate and straightforward to erect on site. For buildings have been developed composite floor systems like in [8] published by the Canadian Institute of Steel Construction, and [11] dealing with multi-storey buildings. They make the use of Codes easier in designing these structures.

5. COMPOSITE AND CASED STEEL COLUMNS

The steel columns are sometimes cased in concrete for fire protection. However, the concrete also increases the strength of the section and buckling resistance. The columns can be exposed for axially load, and to axially load and bending [4].

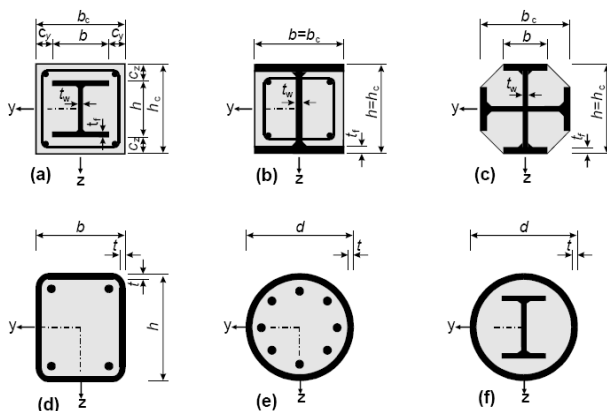


Fig. 7 Typical cross-sections of columns and notation, after [12]

Provision [12] related to isolated columns and columns and composite compression members in framed structures (Fig. 7). The steel contribution ratio δ should fulfil the following condition:

$$0.2 \leq \delta \leq 0.9; \text{ where } \delta = \frac{A_a f_{yd}}{N_{pl,Rd}}, \text{ and}$$

$N_{pl,Rd}$ is the plastic resistance to compression.

Composite columns or compression members of any cross-section should be checked for:

- resistance of the member in accordance with 6.7.2 or 6.7.3;
- resistance to local buckling (LB), the influence of LB of the steel section shall be considered in design, but may be neglected for a steel section fully encased,
- introduction of loads in accordance with 6.7.4.2 [12], and
- resistance to shear between steel and concrete elements.

Two methods of design are given:

- a general method in 6.7.2 whose scope includes members with non-symmetrical or non-uniform cross-sections over the column length and
- a simplified method in 6.7.3 for members of doubly symmetrical and uniform cross-section over the member length [12].

Design for structural stability shall take account of second-order effects including residual stresses, geometrical imperfections, local instability, cracking of concrete, creep and shrinkage of concrete and yielding of structural steel and of reinforcement. Internal forces shall be determined by elasto-plastic analysis. Full composite action up to failure may be assumed between the steel and concrete components of the member. The tensile strength of concrete shall be neglected. Shrinkage and creep effects shall be considered if they are likely to reduce the structural stability significantly. The scope of this simplified method is limited to members of doubly symmetrical and uniform cross-section over the member length with rolled, cold-formed or welded steel sections. The simplified method is not applicable if the structural steel component consists of two or more unconnected sections. The longitudinal reinforcement that may be used in calculation should not exceed 6% of the concrete area. This clause applies to columns and compression members with steel grades S235 to S460 and normal weight concrete of strength classes C20/25 to C50/60.

In paper [33] the stability and ductility characteristics of concrete filled columns using high performance steels (HPS) are investigated. When such steel sections are filled with concrete the stability characteristics for both short and slender columns' behaviour need to be modified to take account of the potential advantages for both local and overall buckling. In addition, the concrete infill will also play a role in improving the post-peak behaviour of both short and slender columns and it needs to be considered.

6. CONNECTIONS IN SEISMIC AREAS

The stiffness of composite sections in which the concrete is in compression is computed using a modular ratio $n=E_a/E_c$. Where the concrete is in tension the stiffness of the composite section is computed assuming that the concrete is cracked and that the steel parts of the section are active [12]. The connections of floor structures with the beam, and the beam with columns (Fig. 8) are of great importance, as well.

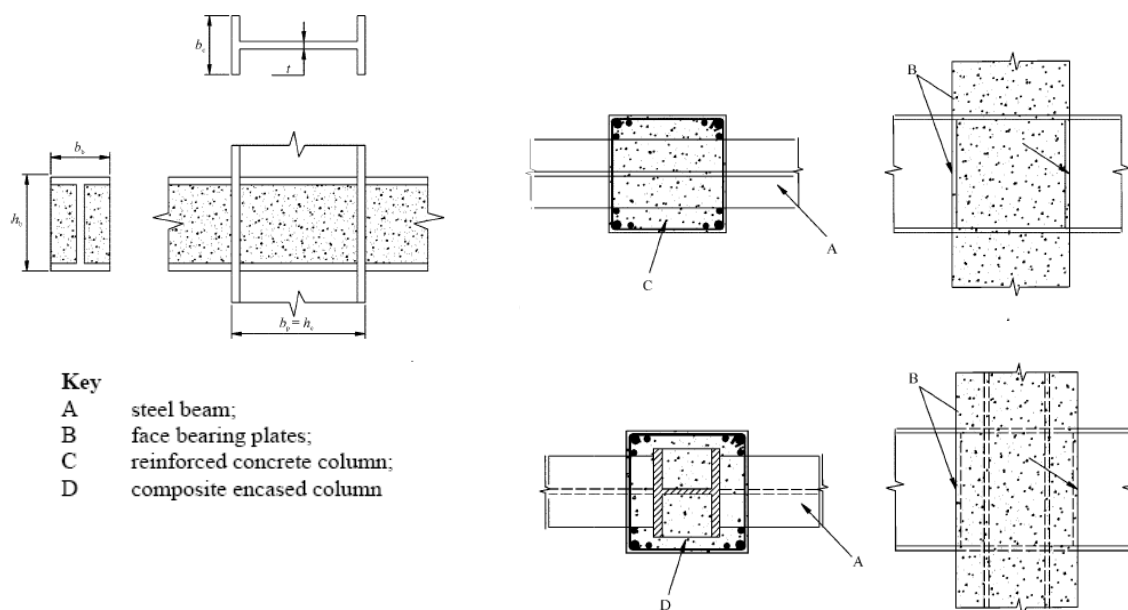


Fig. 8 Beam-column connections, after [13]

The design composite connections shall limit the localization of plastic hinge residual stresses and prevent fabrication defects. The integrity of the concrete in compression shall be maintained during the seismic event and yielding shall be limited to the steel sections. For ductility class of structure DCM and DCH with behaviour factor for different elements see Ch. 7 [13]. In the design of all types of composite columns, the resistance of the steel section alone or the combined resistances of the steel section and the concrete encasement or infill (partially and fully encased H or I section, and filled rectangular and circular section) may be taken into account. For fully encased columns with composite behaviour, the minimum cross-sectional dimensions b , h or d should not be less than 250 mm. The resistance, including shear resistance, of non-dissipative composite columns should be determined in accordance with the rules of [11].

In paper [6] a new type of joints (plug and play for easy in situ construction) aiming to reduce the cost of steel frame, is presented.

7. BRIDGES

The basis of design shall be in accordance with the general rules given in EN 1990: 2002 (resistances, durability and serviceability). The supplementary provisions for composite bridges given in EN 1994- 2 [12], include relevant stages in the sequence of construction. The following subjects are dealt with in this document: (1) General, (2) Basis of design, (3) Materials, (4) Durability, (5) Structural analysis, (6) Ultimate limit states, (7) Serviceability limit states, (8) Decks with precast concrete slabs, (9) Composite plates in bridges, and informative Annex C: Headed studs that cause splitting forces in the direction of the slab thickness (C.1 - Design resistance and detailing; C.2 - Fatigue strength).

With an appropriate combination of structural steel and concrete more efficient bridge construction can be realized. The concrete deck plate utilized as a carrying element with big stiffness which reduces considerably the number of transversal bracing. The use of self-supporting steel systems allows the easy execution on site. Essentially, the principal advantages of composite bridges in comparison with concrete systems are given in [14] and [21]:

- smaller constructive depths and self-weight,
- greater simplicity and ease of execution,
- minimization of environmental problems during execution,
- reduced foundation,
- favourable and simple use of continuous systems, including bottom concrete slabs in support regions (double composite bridges).

In comparison to steel systems the advantages of CS are:

- increased stiffness and better functional response,
- better maintenance and durability characteristics,
- reduction of secondary bracing systems.

Another suite of advantages of this type of bridges are:

- low labour costs because of the work conditions, the manufacturing in workshops is at lower price than in situ works,

- using the new generation of steel grades, plates with variable thickness, the structure can be easily optimized (the European industry offers a wide range of products, like the thermo-mechanically rolled steel with yield stress grades up to 460MPa),
- the concrete plate distributes and reduces the loads from fatigue and attenuates the vibrations,
- using of the Computer Aided Manufacturing procedures makes possible the adaptation of the sections with variable depth,
- possibility of the future enlarging of the structure,
- easy dismantling of the structure (ecological aspect),
- decrease of the accidents due to frozen carriageway.

The development of modern highway networks increased the rate of construction of different types of bridges and necessitated the further development of the exact science of bridge construction. Composite structures were introduced to serve as a highly competitive type of concrete and prestressed concrete bridge due to their reduced weight and quick and cost-effective erection. In the development of the hybrid bridges, it can be seen that the direction being taken by research studies focuses on [1]:

- analysis and design methods of composite bridge structures,
- connections between composite bridge components (steel girder-concrete deck connection),
- performance of composite bridges with the overall structure life (reliability and life cycle of bridges),
- establishment of new concrete-steel bridge systems, and
- the development of alternative materials to be used in composite bridges.

Typical components of composite bridges are I-girder and box-girder. In practice several codes are available to support the design of composite bridges AASHTO-LRFD [36], AISC specifications, Chinese code, etc. The methods of analysis of composite bridges are: adoptive and analytical method to calculate structural stress; computation of a response of a section to different load histories using numerical methods as the finite element method (FEM), as well as design methods depending on the use of numerical methods or adopting the method stated by specific building codes, mostly based on experiments.

The load-carrying capacity (LCC) of composite bridges is an important factor that affects the overall and nonlinear bridge behaviour, which is investigated by using different FEM models such as ADINE code, the ABAQUS software, and by different models and using different types of elements. LCC depends on the interaction between the steel girder and the concrete deck (see Fig. 9).

Classification of cross-sections defined in EN 1993 applies to cross-sections of composite beams. A composite section should be classified according to the least favourable class of its steel elements in compression, which depends on the direction of the bending moment at that section. A steel compression element restrained by attaching it to a reinforced concrete element may be placed in a more favourable class. For classification, the plastic stress distribution should be used except at the boundary between Classes 3 and 4, where the elastic stress distribution should be used taking into account sequence of construction and the effects of creep and shrinkage.

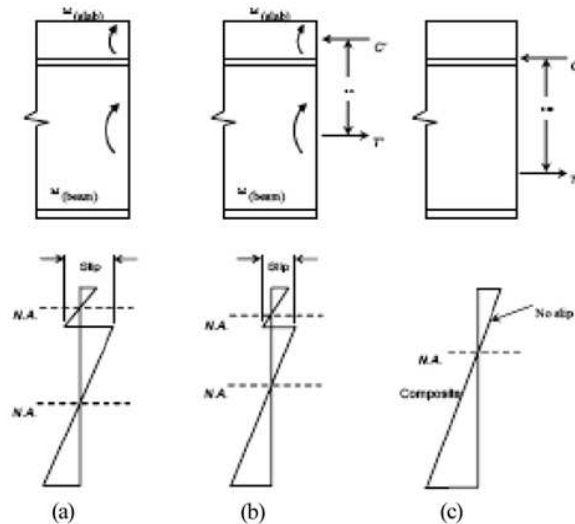


Fig. 9 Strain variation in composite beam
a) no interaction, b) partial interaction, and c) composite interaction [1]

For cross-sections in Class 1 and 2 with bars in tension, reinforcement used within the effective width should have a ductility Class B or C [10]. The classification of sections of filler beam decks for bridges is given in [11] and [12]. A steel outstand flange of a composite section should be classified in accordance with Table 1.

Beams in bridges should be checked for:

- resistance of cross-sections,
- resistance to lateral-torsional buckling,
- resistance to shear buckling and in-plane forces applied to webs,
- resistance to longitudinal shear, and
- resistance to fatigue.

rolled section		welded section		<p>Stress distribution (compression positive)</p>
Class	Type	Limit max (c/t)		
1	Rolled or welded	$c/t \leq 9\varepsilon$		$\varepsilon = \sqrt{\frac{235}{f_y}}$ with f_y in N/mm ²
2		$c/t \leq 14\varepsilon$		
3		$c/t \leq 20\varepsilon$		

Table 1 Maximum value c/t for steel flanges of filler beams

8. TIME DEPENDENT ANALYSIS

The long-term behaviour of the concrete deck slab was investigated with an aim to understand the full behaviour of a composite steel-concrete system. Procedures based on the application of integral relationship are used in all cases where high accuracy of

obtained results is required, and in complex cases of load history. The creep and shrinkage effects for composite box girder with sequencing were investigated by developing a numerical model that adopted layer approach, as well as through experiments and field examinations for actual bridges under construction [22]. Very often engineers in practice use some simplifications.

The application of the *method of effective module* in incremental form is translated in a numerical procedure that corresponds to the application of the rectangular rule of numerical integration of the integral method. In the method of mean stress, while acknowledging the change for E_c in the observed interval, it turns into the *method of mean module of deformation*, and in the incremental form corresponds to the application of trapezoid rule of numerical integration of integral connection. Also *AAEM method* in incremental form is translated into a strict formulation of AAEM method, developed in paper [26] and in another form in [7], and it is by approximations brought to incremental form of AAEM method, which is most frequently used.

All algebraic methods in their complex forms are translated in the incremental form of the integral method. When the incremental connection is taken only in one interval of time (first step of the analysis), the basic algebraic connection of stress and deformation of concrete is obtained. In this way as a parameter in calculations is used the organization of the time interval, that is the number of steps of the analysis. For higher phases of load, the nonlinear analysis is required. When prestressing is used, it should be provided that stresses in reinforcement for PS do not exceed the permitted limits. Nonlinear viscous deformations (occurrence of relaxation) occur in this reinforcement also in the area of operating stresses.

In the model of regulations CEB-FIP MC 90 [15], it is pointed out that in the use of algebraic methods (AAEM method and method of effective module-EM) one must take care when using concrete of different age and different rheological properties. Therefore, the application of this method has been checked and is justified in calculations for composite beams. AAEM method is in the analysis of CB used in its incremental form, where every step of the analysis corresponds to a time interval that follows from a set of characteristic moments of time corresponding to the chronology of load application and execution.

The paper [18] analyses a numeric procedure of determining the stress and strain state due to creeping and shrinkage of concrete and relaxation of high-quality prestressing steel in composite structures. Through the finite element method (FEM) a general calculating procedure is formed to compute stress and strain independent of the statically indeterminate composite structure. The matrix of stiffness is derived by using the method of layers, while the shrinkage and creping of concrete are introduced through the fictive load. The procedure gradually includes particular segments of the composite cross-section into the stress active cross-section. The application of this methodology is shown in paper [19], and it is proved it can be used not only in investigations but also in everyday engineering practice. The analysis included statically determinate and indeterminate structures. In [25] for statically determined composite beam the mathematical model includes an elastic law for the steel part and an integral-type creep law for the concrete part. They used the creep function given in CEB-FIP Model-Code 1990 [7]. Paper [26] presents an analysis of the loss in prestressing force under time-dependent effect and long duration of loading.

9. CONCLUDING REMARKS

The research studies aimed at providing a better understanding of bridge behaviour and developing good and efficient methods (mathematical model) for obtaining the most accurate results. Using of the hollow core slab brings the following advantages: reduces the weight of concrete; reduces the quantities of required concrete; reduces the creep and shrinkage effects of the concrete slab; uses of precast elements connected together at site reduce the erection time. Connecting of precast elements with the steel beam is an important and complex task, as it involves several factors such as types of connectors, support conditions, added reinforcement and grouting materials.

Composite columns are also used widely in practice to resist predominantly compressive loading and appear in different form including concrete-filled section, recently using high strength-high performance concrete. Many experts feel that the further development of steel framed buildings depends largely on the use of composite construction. Unfortunately, these two important building materials, steel and concrete, are promoted by two different industries. Since these industries are in direct competition with each other, it is sometimes difficult to promote the best use of the two materials.

The load-carrying capacity of composite bridges is an important factor that affects the overall and nonlinear bridge behaviour, which is investigated by using different FEM models such as ADINE code, the ABAQUS software, and by different models and using different types of elements. Nonlinear analysis is presented in more detail in paper [19], a performance of CS in fire in [35]. In recent years for the rehabilitation of composite girders are used elements on the basis of FRP. In papers [2] and [30] this problem is discussed more widely. The use of precast concrete for new bridge construction and for the rehabilitation of deteriorated bridge decks is described in [5].

In [15] are detailed the following chapters: Composite construction-general; The behaviour of beam (single span and continuous), Design for serviceability, Shear connection, Composite slabs, Composite columns, Composite buildings and Composite bridges. These materials and Eurocodes, particularly EN 1994 [11] and [12] can be of great use in designing, analysis and building of composite structures. It is also important to mention [3] with a large number of valuable papers such as Partial-Interaction Behaviour of Steel-Concrete Bridge Deck; Numerical Investigation of Moment Redistribution in Continuous Beams; Influence of Concrete Cracking on Composite Bridge Behaviour; A True Innovation: Steel Plates with a Structural Elastomer Core; Vibration Characteristics of Modern Composite Floor System; The Effects of Partial Shear Connection in Hogging Moment Regions of Composite Beams and Joints; and Damage Assessment for Performance-Based Design of Rectangular Concrete-Filled Steel Tubes, etc.

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