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COMPOSITE STEEL-CONCRETE STRUCTURES

- CURS 1b -

Introduction

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INTRODUCTION

- **Composite Construction** has developed significantly since its origins approximately 100 years ago when the idea that the concrete fire protection around columns might be able to serve some structural purpose or that the concrete bridge deck might, with advantage, be made to act in conjunction with the supporting steel beams was first proposed. Take-up in practice began in earnest shortly after the end of the Second World War and progress has been particularly rapid during the past 25 years.

- Nowadays, in those countries where steelwork enjoys a particularly high market share e.g. for high-rise buildings, the extensive use of composite construction is a major factor.

INTRODUCTION

- Early approaches to the design of composite structures generally amounted to little more than the application of basic mechanics to this new system. However, it was soon realised that this particular medium possessed features and subtleties of its own and that effective usage required that these be properly understood and allowed for. Composite construction is now generally regarded as a structural type in its own right, with the attendant set of design codes and guidance documents.

- The most comprehensive and up to date of these is the set of Eurocodes—specifically **EUROCODE 4** that deals exclusively with composite construction.

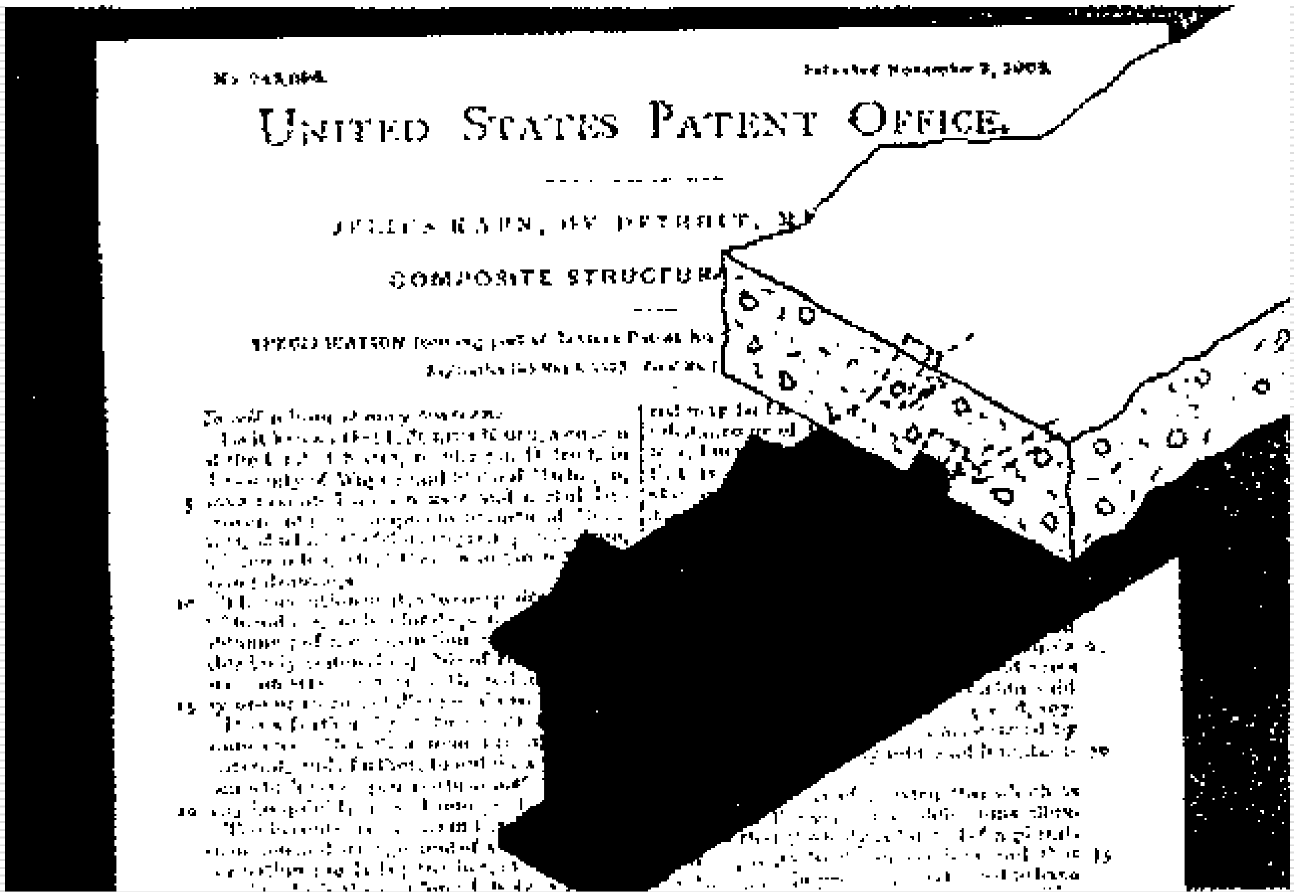
CHAPTER I - FUNDAMENTALS

- The term **"composite construction"** is normally understood within the context of buildings and other civil engineering structures to imply the use of steel and concrete formed together into a component in such a way that the resulting arrangement functions as a single item.
- The aim is to achieve a higher level of performance than would have been the case had the two materials functioned separately. Thus the design must recognise inherent differences in properties and ensure that the structural system properly accommodates these. Some form of interconnection is clearly necessary.
- Since its introduction, the utilisation of composite action has been recognised as an effective way of enhancing structural performance. In several parts of the world a high proportion of steel structures are therefore designed compositely.

§ 1.1 History

- The year 1894 is stated as the period in which concrete encased beams were first used in a bridge in Iowa and a building in Pittsburgh. The earliest laboratory tests on encased columns took place at Columbia University in 1908, whilst composite beams were first tested at the Dominion Bridge Works in Canada in 1922.
- By 1930 the New York City building code recognised some benefit of concrete encasement to steelwork by permitting higher extreme fibre stresses in the steel parts of the encased members. Welded shear studs were first tested at the University of Illinois in 1954, leading to publication of a design formula in 1956 and first use for both bridge and building projects the same year.
- In 1926 the technique of linking the steel beam with the concrete slab was firstly patented by Kahn, and soon after appears the first written books on using composite constructions.

§ 1.1 History



Kahn Patent of 1926

§ 1.1 History

- Early usage in Japan has been recorded by Wakabayashi, who refers to the use of concrete encasement to improve both fire and earthquake resistance, dating from about 1910. Termed “steel reinforced concrete” or SRC, this form of construction quickly became popular for buildings of more than 6 storeys. Its integrity was demonstrated by the good performance of structures of this type in the great Kanto earthquake of 1923.

§ 1.1 History

- A full set of Rules covering the design of composite beams was provided in the 1961 American Institute of Steel Construction (AISC) Buildings Specification.

- Parallel developments had been taking place in Europe - especially as part of the post-war reconstruction in Germany. Reporting on this in 1957, eng. Godfrey refers to "research in Germany, Switzerland and elsewhere" providing the basis for their "Provisional Regulations for the Design of Girders in Composite Construction" published in July 1958. Four years later the topic was addressed more formally in DIN 1078.

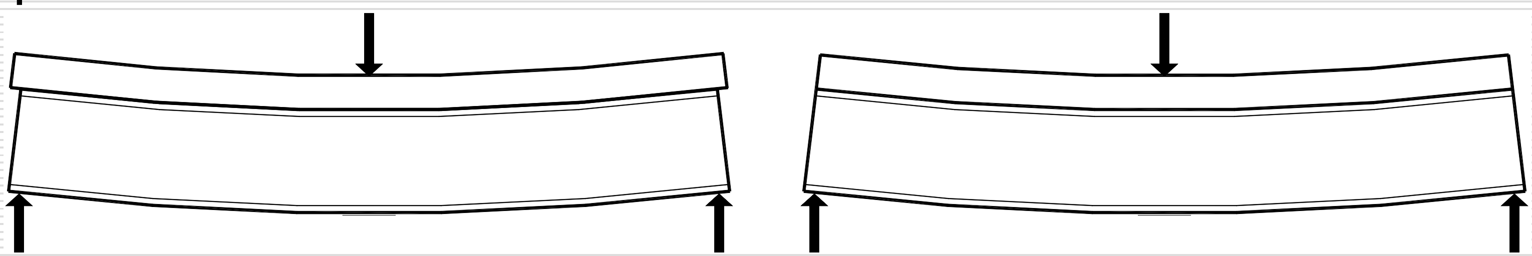
§ 1.1 History

- By the mid 1960s the structural engineering community in the UK was appreciative of the merits of composite construction. It had for example been employed for a number of Government designed buildings, essentially in the form of composite beams but with the novel feature that these utilised precast lightweight aggregate concrete panels and planks.

- Much of this British work was then brought together into the first comprehensive composite code, CP 117, published in 3 parts, covering: simply supported beams in buildings, beams for bridges and composite columns.

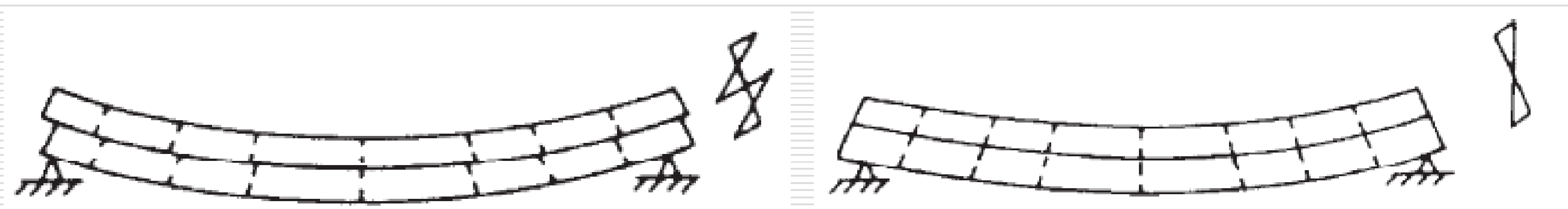
§ 1.2 Basic Concepts

- The essence of composite construction is most readily appreciated by considering its most commonly used application, the composite beam.



- **non-composite action (a)**
- **composite action (b)**

- To begin with a very simple illustration, consider the beam consisting of two identical parts shown in figure below.

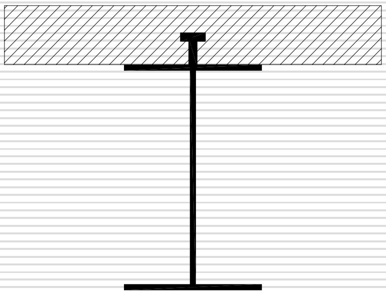


§ 1.2 Basic Concepts

- In the case of figure *a*, both parts behave separately and move freely relative to each other at the interface, whilst in the case of figure *b* both parts are constrained to act together.
- For case *a* longitudinal slip occurs as indicated by the movement at the ends, whereas in case *b* plane sections remain plane. It is readily demonstrated using elastic bending theory that case *b* is twice as strong and four times as stiff as case *a*.

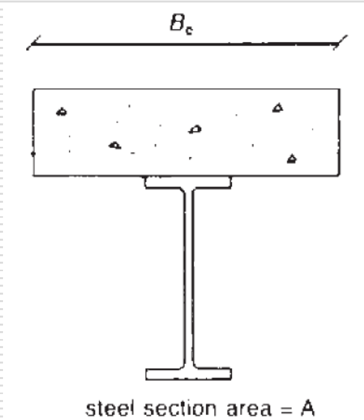
§ 1.2 Basic Concepts

- Now consider the steel/concrete arrangement of the figure below:

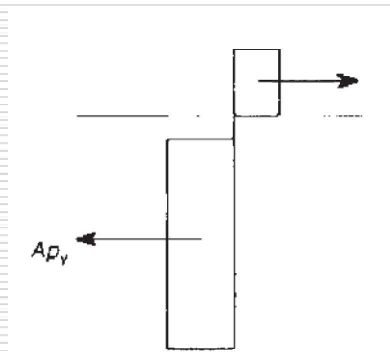


- The two parts are now of different sizes and possess different stress–strain characteristics. Assuming (as example) that the neutral axis of the composite section is located at the concrete/steel interface and that full interaction is ensured so that no slip occurs, the distributions of strain and a corresponding stress block representation of stresses at the assumed ultimate condition will be as shown in figures below:

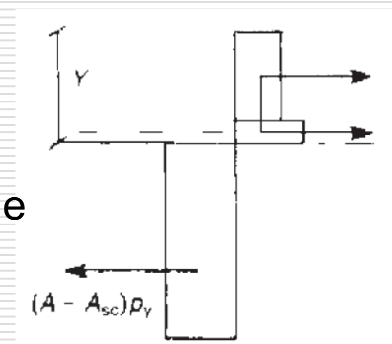
a) cross-section



b) Neutral axis in the slab



c) Neutral axis in the steel profile



§ 1.2 Basic Concepts

- The considerations of cross-sectional equilibrium permit the moment of resistance to be computed. Although the member's neutral axis will clearly not always fall at the interface, good design will attempt to locate it close to this position as representing the most efficient use of the strengths of the two different materials (concrete acting in compression and steel acting in tension).
- For such cases the resulting equilibrium calculations to determine the moment of resistance are only slightly modified.

Obs: The use of plastic methods to determine strength, as employed in the above illustration, are now commonplace when dealing with composite construction.

Although extensive elastic approaches exist, it has been found that, providing certain rules are observed e.g. relating to potential instability in parts of the steel section, the ability of the shear connection to resist the interface slip etc., then a relatively simple plastic approach is both easier to use and leads to higher resistances.

§ 1.3 Material Properties

- When designing composite elements it is usual to adopt the same properties for steel and for concrete as would be the case when designing structural steelwork or reinforced concrete. Thus codes of practice covering composite construction, such as EC4, normally simply summarise the relevant sections from the steelwork and concrete documents - EC3 and EC2 in the case of EC4.

CONCRETE

- Concrete is specified in terms of its compressive strength, as measured in a cylinder test, f_{ck}. Grades between 20/25 and 50/60 are permitted. Characteristic tensile strengths are also provided; for lightweight concretes tensile values should be modified by a correction factor (see EC2 for details).

§ 1.3 Material Properties

CONCRETE

Strength class of concrete	f_{ck} N/mm^2	f_{ctm} N/mm^2	$f_{ctk\ 0,05}$ N/mm^2	$f_{ctk\ 0,95}$ N/mm^2	E_{cm} kN/mm^2
C20/25	20	2,2	1,5	2,9	29,0
C25/30	25	2,6	1,8	3,3	30,5
C30/37	30	2,9	2,0	3,8	32,0
C35/45	35	3,2	2,2	4,2	33,5
C40/50	40	3,5	2,5	4,6	35,0
C45/55	45	3,8	2,7	4,9	36,0
C50/60	50	4,1	2,9	5,3	37,0

Notations : f_{ck} is the characteristic compressive cylinder strength measured at age 28 days,

f_{ctm} is the mean tensile strength,

$f_{ctk\ 0,05}$ is the lower value of the characteristic tensile strength (fractile 5%),

$f_{ctk\ 0,95}$ is the upper value of the characteristic tensile strength (fractile 95%),

E_{cm} is the mean secant modulus of elasticity for short term loading.

§ 1.3 Material Properties

STRUCTURAL STEEL

- The nominal values of the yield strength f_y for hot-rolled steel are given in table below for steel grades S235, S275 and S355 in accordance with EN 10025 and for steel grades S235, S275, S420 and S460 in accordance with EN 10113. Those **nominal** values may be adopted as **characteristic** (unfactored) values in design calculations.

§ 1.3 Material Properties

STRUCTURAL STEEL

Nominal steel grade		Nominal values of f_y (N/ mm^2)					
		Nominal thickness t (mm)*)					
EN 10027-1 Designation	EN 10025 Standard	≤ 16	> 16 ≤ 40	> 40 ≤ 63	> 63 ≤ 80	> 80 ≤ 100	> 100 ≤ 150
S 235 ***S 275*** ***S 355***	***S 235*** ***S 275*** ***S 355***	235 275 355	225 265 345	215 255 335	215 245 325	215 235 315	195 225 295
	EN 10113 Standard						
S 275 ***S 355*** ***S 420*** ***S 460***	***S 275*** ***S 355*** ***S 420*** ***S 460***	275 355 420 460	265 345 400 440	255 335 390 430	245 325 370 410	235 315 360 400	225 295 340 -

Notes:

*) t is the nominal thickness of the element :
- of the flange of rolled sections ($t = t_f$)
- of the particular elements of the welded sections

For other characteristics of steel, see Eurocode 3-1

§ 1.3 Material Properties

REINFORCING STEEL

- In reference to EN 10080 specifications, different types of reinforcing steels are covered by Eurocode 4, differentiating:
  - according to ductility characteristics: high (H) ductility class and normal (N) ductility class.
  - according to surface characteristics: plain smooth bars or ribbed bars or wires (including welded mesh).

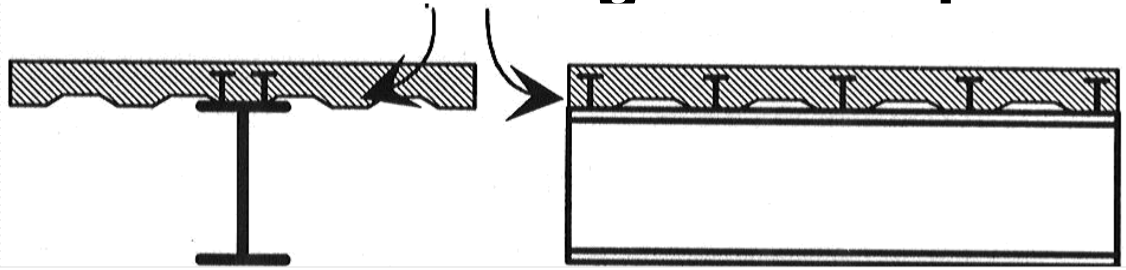
Yielding strength f_{sk} for reinforcing steel:

Reinforcing steel grades	S 220	S 420	S 500
f_{sk} [N/mm^2]	220	420	500

The material coefficients (E_s, G_s, α_T, ρ_s, ν_s) adopted in calculations for reinforcing steel are similar to those of structural steel.

§ 1.3 Material Properties

Profiled steel decking for composite slabs



- The nominal values of f_{yb} of yielding strengths for steel sheeting are given in the following table:

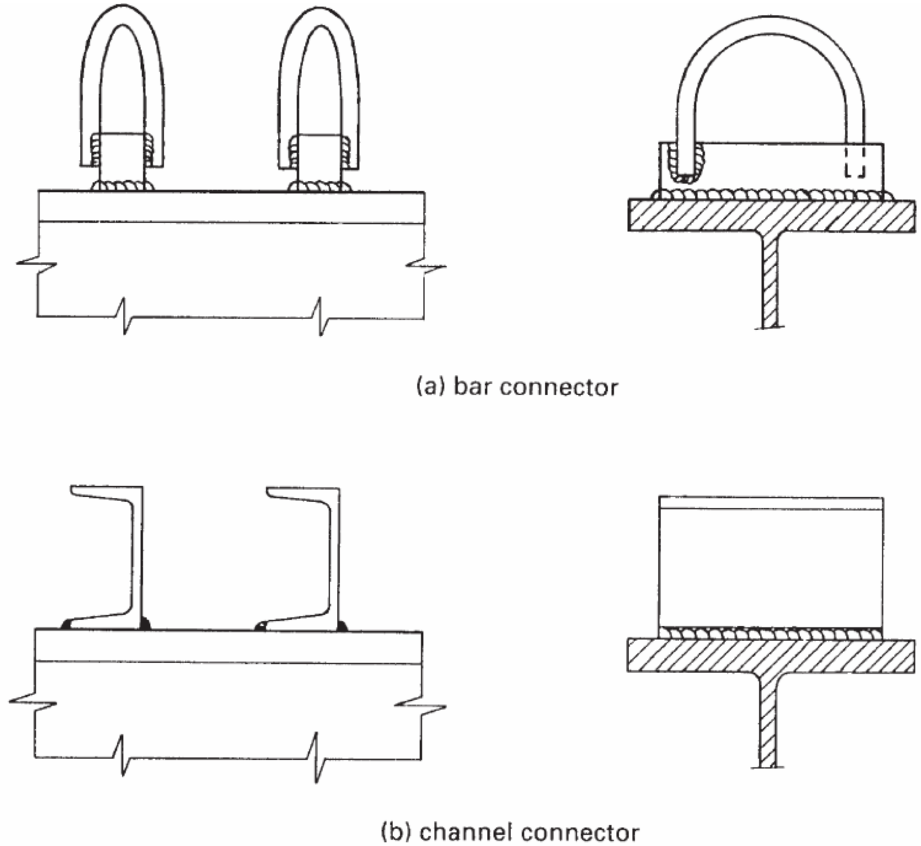
Standard	Grade	f_{yb} (= f_{yp}) [N/mm^2]
EN 10 147	FeE 220 G	220
	FeE 250 G	250
	FeE 280 G	280
	FeE 320 G	320
	FeE 350 G	350

The material coefficients (E_s, G_s, α_T, ρ_s, v_s) adopted in calculations for decking steel are similar to those of structural steel.

§ 1.3 Material Properties

Shear connectors (connecting devices)

- Several early forms of shear connector, used principally for bridges are given figures below:



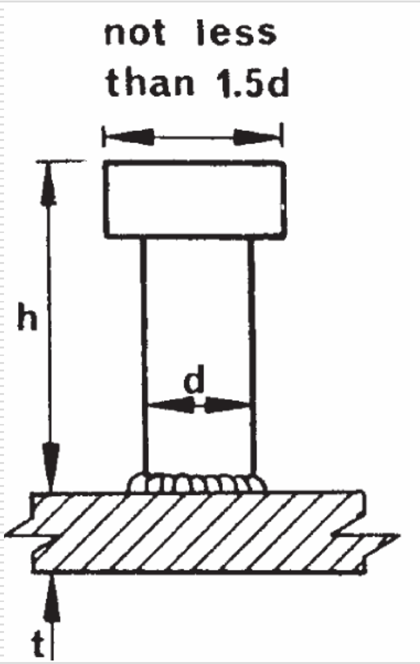
(a) bar connector

(b) channel connector

§ 1.3 Material Properties

Shear connectors (connecting devices)

- By comparison with today's near universal use of welded, headed shear studs of the type shown in figure below. They are cumbersome and expensive but provide significantly higher strengths.

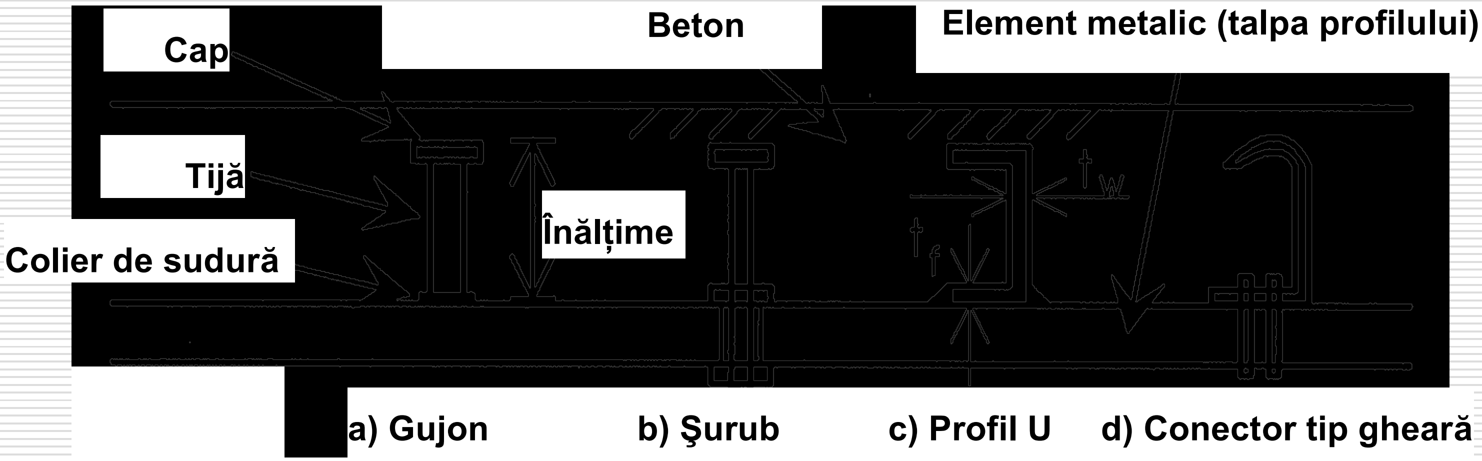


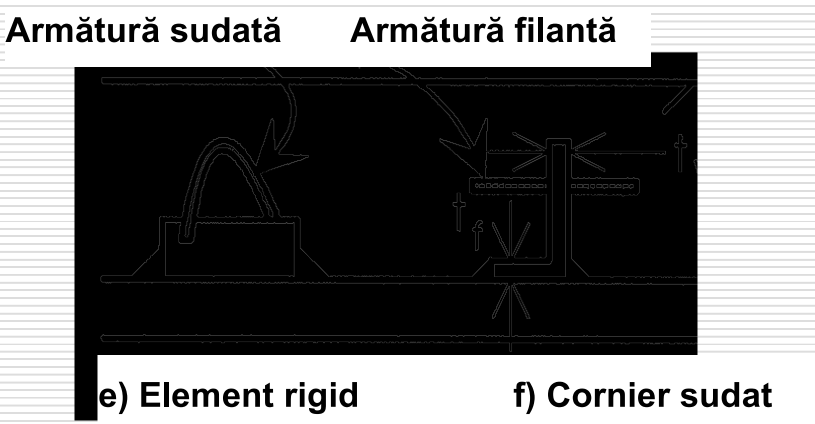
- Studs range typically between 13 & 25mm in diameter, although since the welding process becomes significantly more difficult and therefore expensive for diameters exceeding 20mm, 19mm studs are by far the most commonly used. Since the resistance developed by a stud depends (among other things) on the thickness t of the flange to which it is welded, a limit of d/t of 2.5 is specified in Eurocode 4.

§ 1.3 Material Properties

Shear connectors (connecting devices)

- other (common) types of connecting devices:



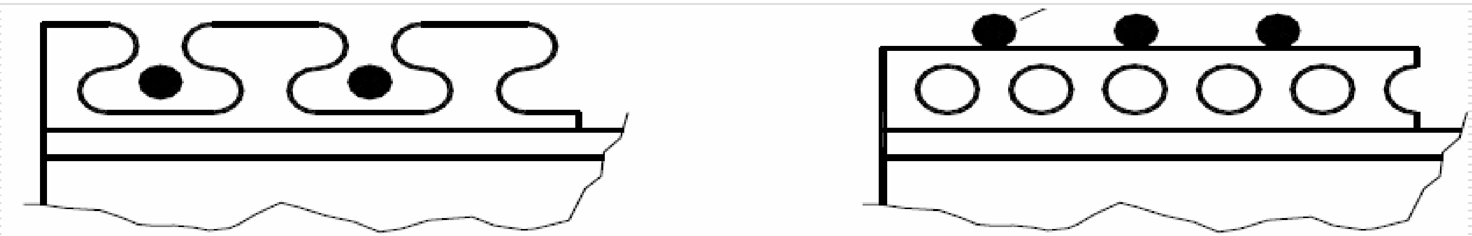


§ 1.3 Material Properties

Shear connectors (connecting devices)

- other (new) types of connecting devices:

comb-shaped strip connectors

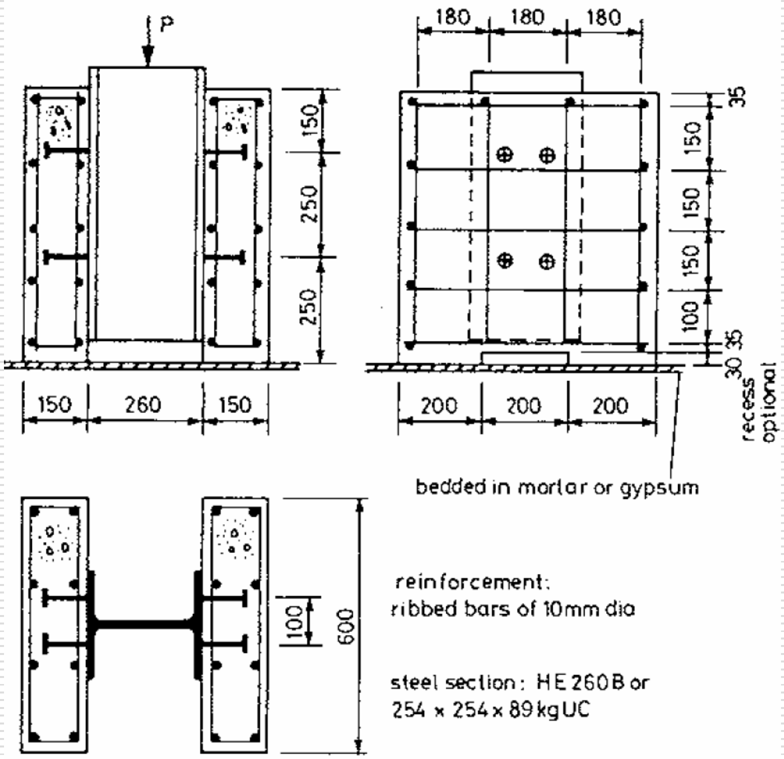


prefobond connectors

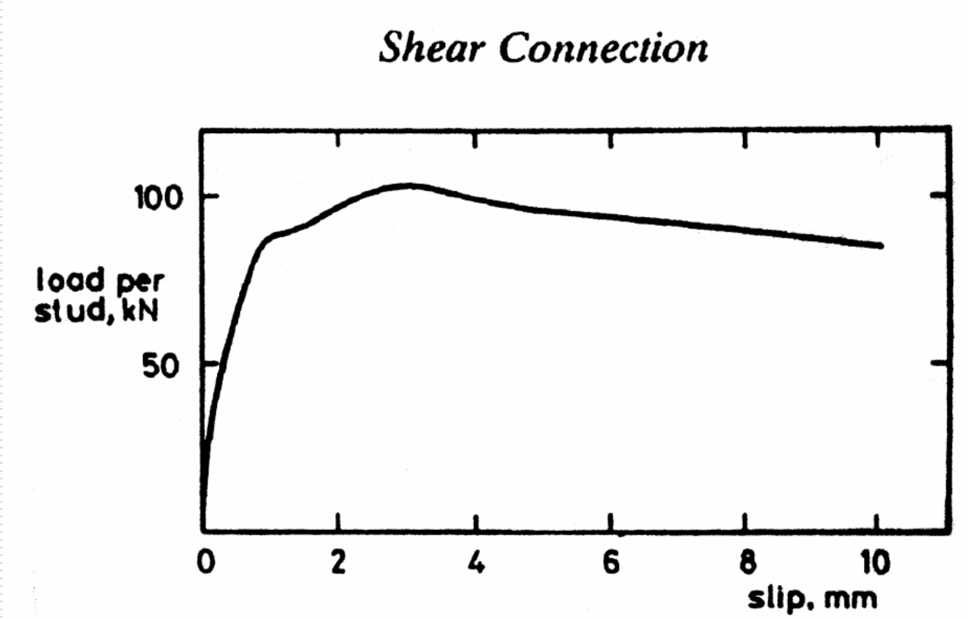
§ 1.3 Material Properties

Shear connectors (connecting devices)

- Stud strengths are normally obtained from "push-off" tests, in which a load–slip curve is determined using a standard test arrangement.



Test arrangement



Typical load–slip relationship

§ 1.3 Material Properties

Shear connectors (connecting devices)

- The steel used to manufacture studs typically has an ultimate tensile strength of at least 450N/mm^2 and an elongation of at least 15%.
- Stud resistances, depending on size and other factors, of up to about 150 kN are achievable using simple welding procedures. Studs have equal strengths in all directions and provide little interference to the positioning of reinforcement.
- For studs with h/d > 4 EC4 requires designers to use the lower of the values for stud strength P_{Rd} of:

$$P_{Rd} = \frac{0.8 f_u (\pi d^2/4)}{\gamma_v}$$

$$P_{Rd} = \frac{0.29 d^2 (f_{ck} E_{cm})^{1/2}}{\gamma_v}$$

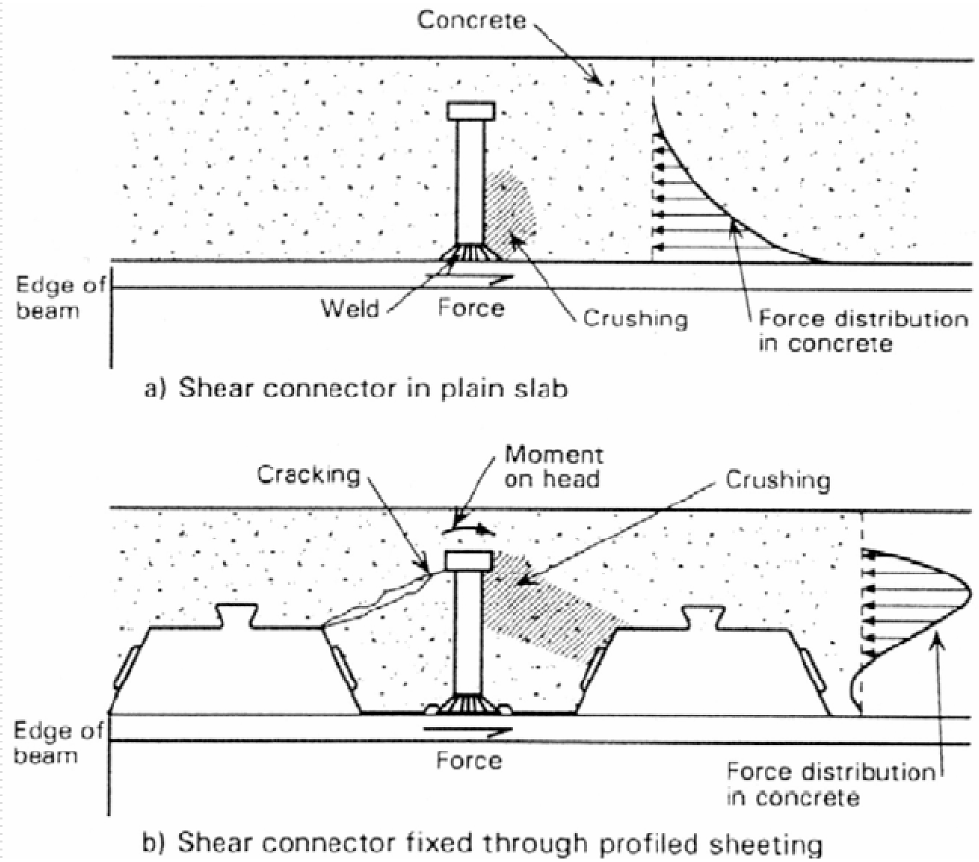
§ 1.4 Influence of slab type

- Of particular importance in building construction is the type of composite slab illustrated in figure below in which the concrete is cast directly on top of metal decking.

This is more properly referred to as **profiled steel sheeting**. This provides permanent formwork during the curing operation and then acts as bottom reinforcement to the slab spanning transversely between the beams.

§ 1.4 Influence of slab type

- The presence of the sheeting means that the system of forces to which a shear connector, attached by through deck welding to the beam's top flange in the trough region, is subjected differs from that experienced by a stud in a solid slab. Figures below illustrate this. The most important feature is that the large fraction of load carried by the weld collar is now very significantly reduced.



- EC 4 addresses this through the use of a pair of reduction factors, k_l and k_t used for slabs with ribs parallel or perpendicular to the beam:

§ 1.5 Design for Ultimate Limit State

- According to the usual design of Eurocodes, the composite structures should be verified in ULS against:

  - **Loss of equilibrium** of the structure or any part of it, considered as a rigid body.

  - **Failure** by excessive deformation, rupture, or loss of stability of the structure or any part of it, including shear connection, supports and foundations.

- The first of these requires comparison of the design effects of destabilising and stabilising actions and is actually a general requirement for all forms of construction.
- The second involves determination of the design value of internal force, moment, combination etc. for comparison with the corresponding design resistance.

§ 1.6 Design for Serviceability Limit State

- Adoption of the limit states design philosophy has highlighted the need to give proper attention to ensuring that structures perform adequately under in-service conditions. Explicit consideration of each condition that might render the structure unfit for use is now required. Eurocode 4 lists 5 such conditions:

  - **Deformations or deflections** which adversely affect the appearance or effective use of the structure or cause damage to finishes or nonstructural elements.
  - **Vibration** which causes discomfort to people, damage to the building or its contents or which limits its functional effectiveness.
  - **Cracking** of the concrete which is likely to affect appearance, durability or water-tightness adversely.
  - **Damage to concrete** because of excessive compression, which is likely to lead to loss of durability.
  - **Slip at the steel–concrete interface** when it becomes large enough to invalidate design checks for other serviceability limit states in which the effects of slip are neglected.

§ 1.6 Design for Serviceability Limit State

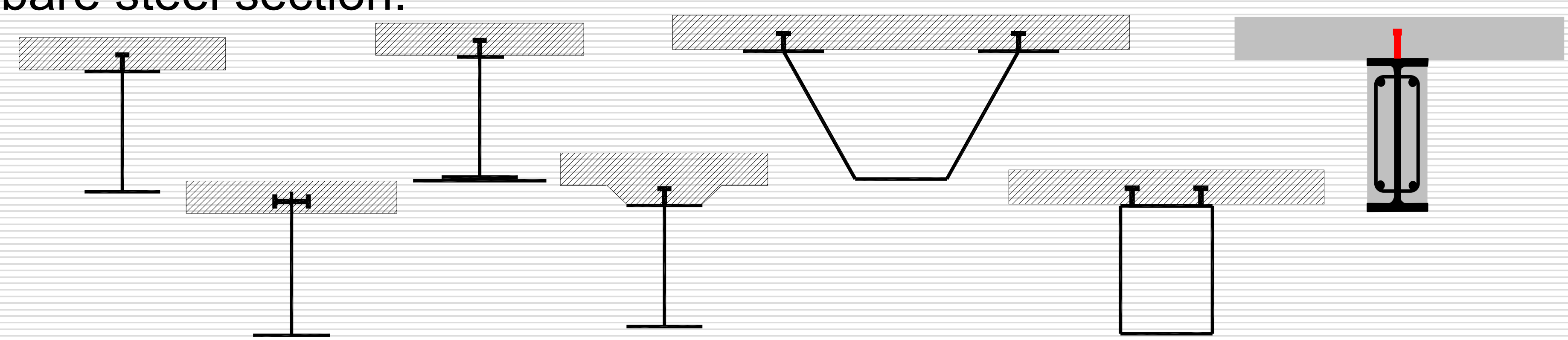
- Worldwide experience shows that risk of a structural failure is greatest during the construction phase due to the combination of: absence of helpful “non-structural” components that will be present in the final condition, greater inability to accurately determine the applied loading and a tendency to give less attention to the structural checking.

§ 1.7 Current usage

- Composite action is presently most often used between beams and slabs – in the form of building floors or bridge decks—in certain types of column – particularly in very tall buildings where extremely high compressive loads must be resisted.

BEAMS

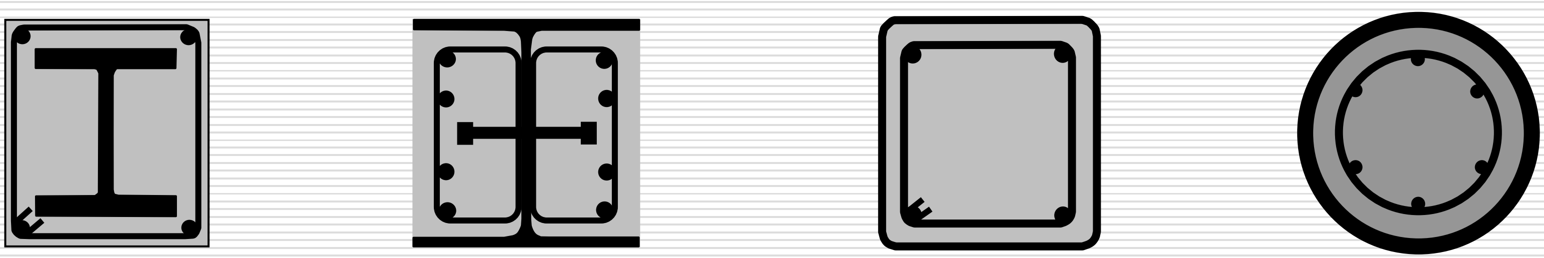
- Almost certainly, the most frequent use of composite construction is for beams, in which a part of the slab acts with the steel section to provide a structural member with greater strength and stiffness than the bare steel section.



§ 1.7 Current usage

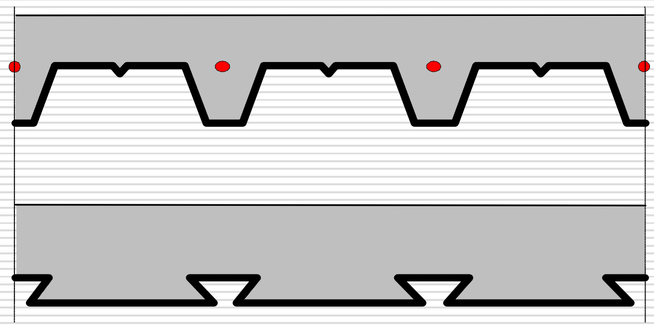
COLUMNS

- Composite columns tend to be used either when the bare steel section is unable to develop sufficient resistance to cope with the design loading or, in certain more specialised applications, where the clever combination of the two materials permits very economic solutions to be devised. An important feature of their use is ensuring that the concrete takes its share of the load, a matter that often requires careful attention to detailed aspects of load introduction.

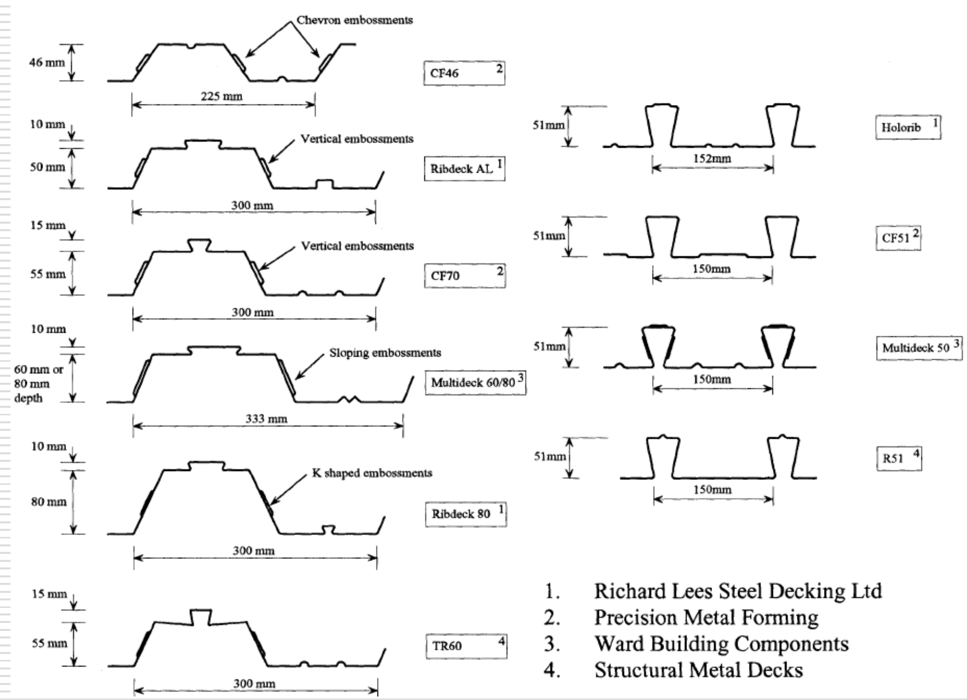


§ 1.7 Current usage

FLOORS



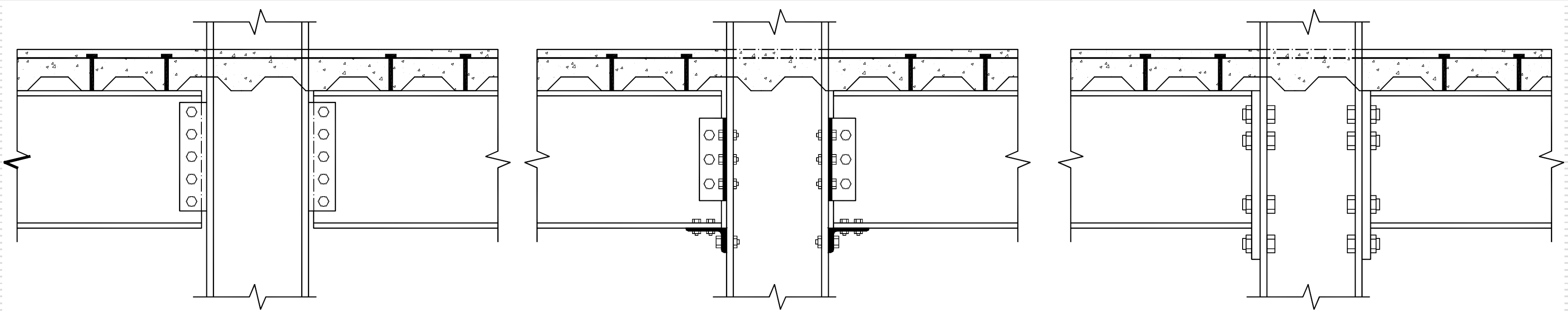
- In buildings, composite beams will normally comprise longitudinal steel members acting with part of the floor slab. However, in the case in which the concrete slab has an interaction with the steel deck (used also as formwork during the casting of concrete), we can speak of **composite floors**. In some cases, the steel deck could act partial or even total as bottom reinforcement



§ 1.7 Current usage

CONNECTIONS

- Although it is still the usual practice to design beam to column and beam to beam joints as if they were bare steel, there is an increasing realisation that significant benefits are available by deliberately providing some degree of load transfer between members through the use of composite joints.



§ 1.8 Partial safety factors

- The resistance is determined by using the different materials and components, X_d , that takes into account uncertainties at ULS with partial safety factors γ_M factors are explicitly introduced in design formulae.

- Partial safety factors γ_M for resistances and material properties at ULS

- Resistance of *structural steel* :		
. γ_a is equivalent to γ_{M0} of Eurocode 3	:	$\gamma_a = 1{,}10$
. γ_{Rd} is equivalent to γ_{M1} of Eurocode 3 (if buckling of structural steel)	:	$\gamma_{Rd} = 1{,}10$
. $\gamma_{Ma} = \gamma_a$ or γ_{Rd} (see clause II.6 (2))		
- Resistance of *concrete*	:	$\gamma_c = 1{,}50$
- Resistance of *reinforcement steel*	:	$\gamma_s = 1{,}15$
- Resistance of *profiled steel decking*	:	$\gamma_{ap} = 1{,}10$
- Resistance of *shear connectors* and longitudinal *shear in slabs*	:	$\gamma_v = 1{,}25$

Text şi figuri adaptate după "Composite Construction", Spon Press, 2004 editor David A. Nethercot.