Universitatea Politehnica Timişoara
Facultatea de Construcţii
Departamentul de Construcţii Metalice şi Mecanica Construcţiilor

COMPOSITE STEEL-CONCRETE STRUCTURES

- CURS 6-b-

Composite Floors

Conf.dr.ing Adrian CIUTINA

Notele de curs pot fi descărcate de pe pagina de web
http://www.ct.upt.ro/users/AdrianCiutina/

CHAPTER V – COMPOSITE FLOORS
§ 5.1 Introduction

- Steel decking was first used to support a concrete floor in the 1920s. The engineers Loucks and Gillet described a steel-deck system in a patent filed in 1926.
- In this early development, the steel deck provided all the structural resistance, concrete was added to give a level surface and provide fire resistance.
- The use of a steel deck was attractive to contractors as it served as permanent formwork and a construction platform, and was thus an efficient alternative to reinforced concrete floors.
- Soon other advantages of steel decking floors became apparent including its comparatively light weight and the use of the troughs in the decking as ducts for wiring.
- The first composite slabs i.e. concrete reinforced by the steel deck, appeared in the 1950s. The first was a product known as Cofar, which was a trapezoidal deck section with cold drawn wires welded transversely across the deck troughs.

§ 5.1 Introduction

- Friberg (1954) analysed the system as a traditional reinforced concrete slab and found good correspondence between predicted strengths and experimental tests.
- Although composite floors are most closely associated with multi-storey office buildings, they are also used in renovation projects (where the low self weight of the floor is advantageous), car parks, warehouse and storage buildings (heavy point loads and wheel loads from fork-lift trucks may require special attention), housing and community service buildings.
- The design of composite floors requires particular consideration of the construction sequence. The metal decking must be sufficiently strong and stiff during construction as it is required to support the wet concrete.
- Once the concrete has hardened, the deck could acts as a part of the reinforcement to the slab and acts compositely with the concrete to support imposed live loading.

§ 5.2 Current Practice

- Composite floors are quick to construct and provide a cost-effective alternative to conventional cast in-situ reinforced concrete slabs or precast units. The steel deck forms a quick working platform.

- Many of the profiles can be tightly packed on top of each other. Large areas of flooring, up to 1500m^2, can be transported on a single lorry.
- Once the decking is secured in place and edge trims fitted, the deck forms permanent formwork for the concrete slab.
- Depending on the span of the slab and depth of the metal deck profile, temporary props could be required. This will sometimes slow down the construction process.
- The steel deck acts as the tensile reinforcement for the composite slab. In many cases there is no need to fix bar reinforcement to resist positive (sagging) moments.

§ 5.2 Current Practice

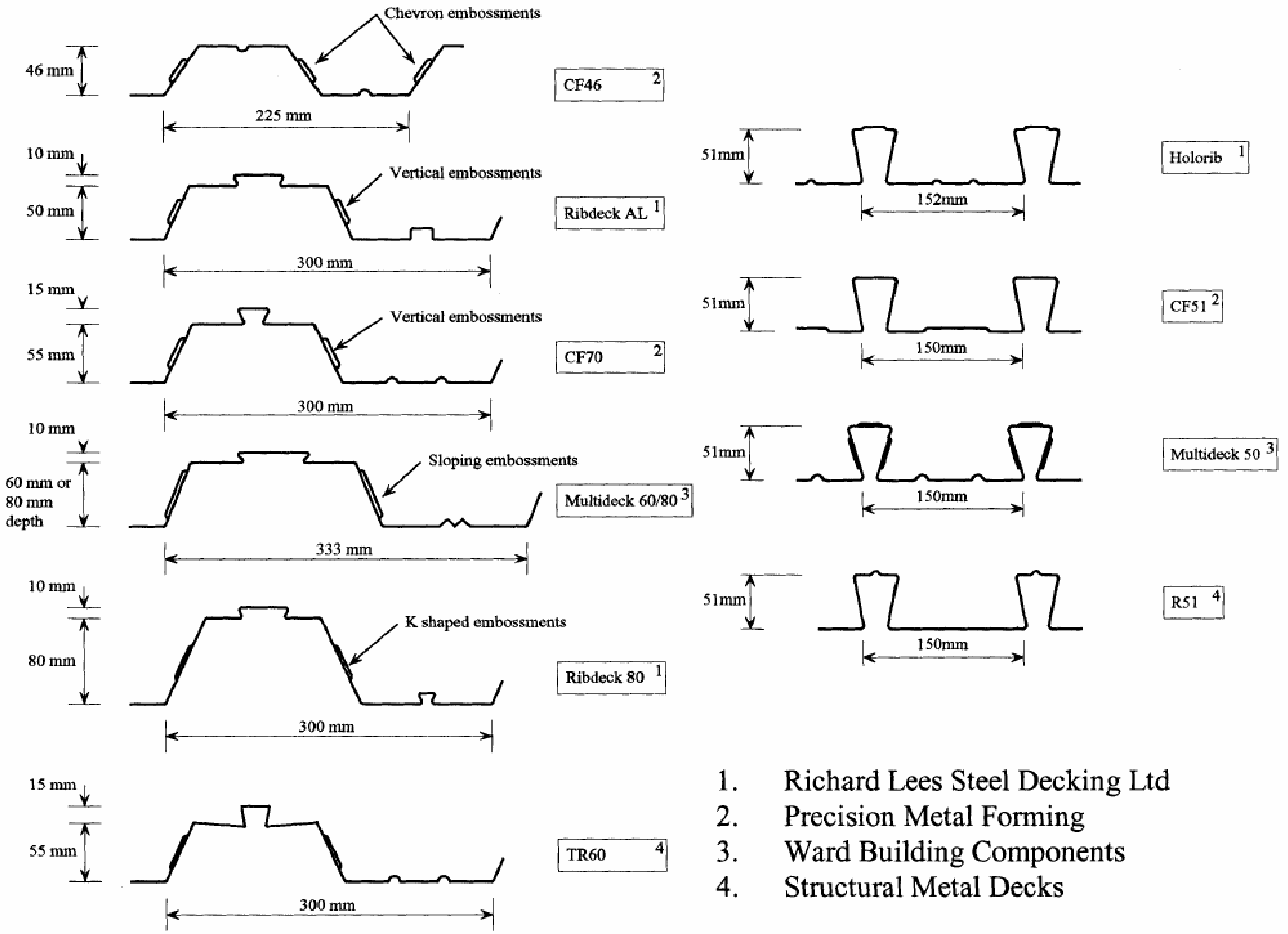
DECK TYPES

- Deck profiles are usually 45 to 80 mm high with troughs spaced at 150 to 300 mm.
- Decks can be of two types:
  - re-entrant (commonly known as dovetail) and
  - trapezoidal.
- Profiles are cold rolled from steel sheet of 0.9 to 1.5 mm thickness with yield strengths between 280 and 350 N/mm^2.
- For most applications, where the risk of corrosion is limited, galvanising to a thickness of 275 g/m^2 is usually specified.
- In many cases the ability of the deck to support the loads arising during construction determines the maximum span. For this reason it is often advantageous to specify lightweight concrete (wet density 1850-1950 kg/m^3).
- Spans for conventional shallow decks are typically in the range of 3 to 4 m; deep decks can span more than 6 m.

§ 5.2 Current Practice

DECK TYPES

Figure: Common deck profiles



1. Richard Lees Steel Decking Ltd
2. Precision Metal Forming
3. Ward Building Components
4. Structural Metal Decks

§ 5.3 Behaviour as Formwork

- During construction the deck must support the **weight of wet concrete and construction operatives**. For unpropped construction this often constitutes the critical loading condition for the metal decking.
- The profiled steel sheeting is subjected to bending and shear and, due to the slender nature of the cross-section, **is prone to local buckling**.
- Rolled grooves and embossments tend to stiffen the flanges and webs of the cross-section but nonetheless buckling prior to yield is likely to occur and hence reduce the strength and stiffness of the deck.
- Because of the inherent difficulties and conservatism in analytical methods, many manufacturers have conducted tests to more accurately predict the performance of their decks.

DESIGN LOADING

- At the ultimate limit state, loads arising from the weight of the wet concrete and steel deck, construction loads (operatives and equipment) and any 'ponding' effects (increased depth of concrete due to deflection of the sheeting) should be considered.

§ 5.3 Behaviour as Formwork

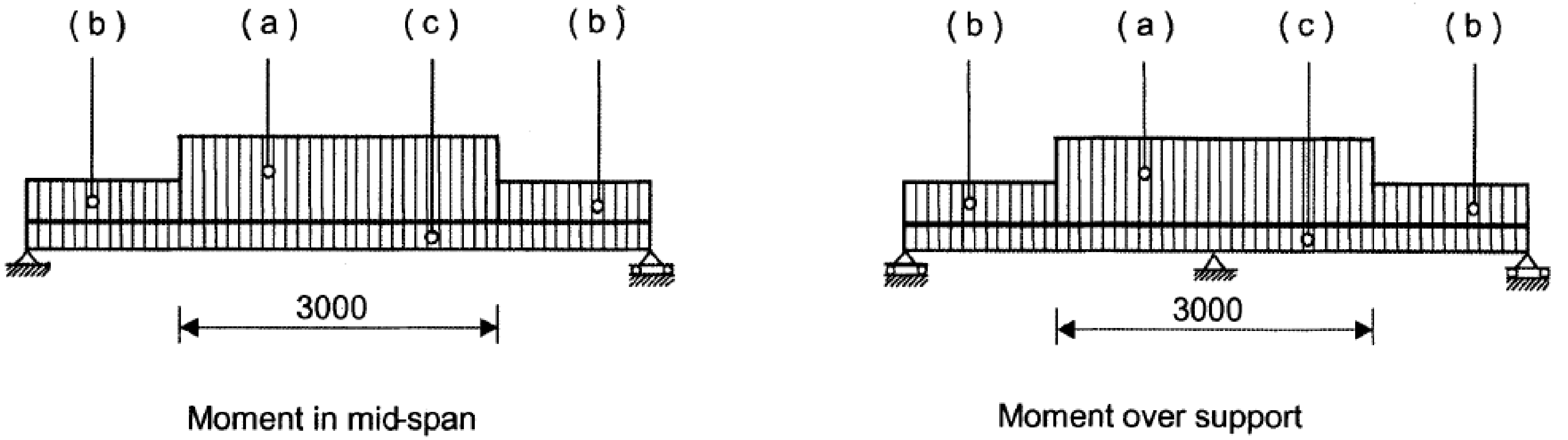
DESIGN LOADING

- Although construction loads account for the weight of the operatives and concreting plant, and also allow for any impact or vibration that may occur during construction, they are not necessarily sufficient for excessive impact (for example, by dropping concrete from a skip too high above the deck) or heaping concrete, etc.
- Eurocode 4 recommends a uniform characteristic loading of 0.75 kN/m^2 over the entire slab but locally increased to 1.5 kN/m^2 in any area of 3 m by 3 m (or span, if less).
- These loads should be placed so that to cause the maximum bending moment and/or shear as shown in figure below.
- In addition to the loads specified above, consideration should be given to the ability of the deck to resist concentrated point loads.
- If the central deflection of the sheeting under its own weight plus that of the wet concrete, calculated for serviceability, is less than 1/10 of the slab depth the effect of ponding may be ignored in the design of the steel sheeting. Above this limit ponding should be allowed for.

§ 5.3 Behaviour as Formwork

DESIGN LOADING

Figure: Critical load arrangements for sheeting acting as shuttering



(a) Concentration of construction loads 1.5 kN/m²

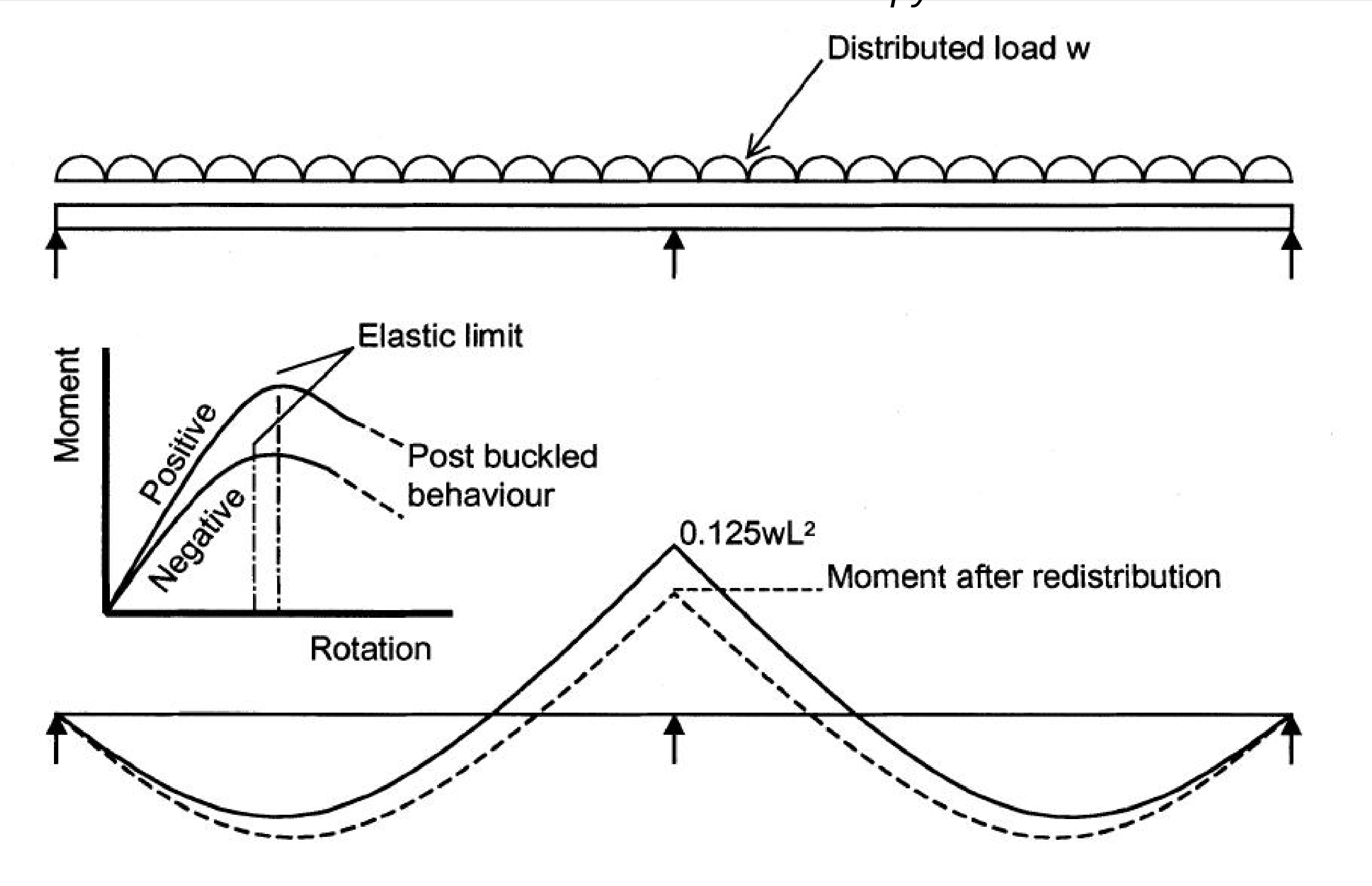
(b) Distributed construction load 0.75 kN/m² **c) Self weight**

ANALYSIS

- Continuous decking may be analysed using elastic analysis. The flexural stiffness is determined without consideration of the variation of stiffness due to parts of the cross-section in compression not being fully effective.

§ 5.3 Behaviour as Formwork
ANALYSIS

- Figure below shows a deck continuous over two spans. The maximum negative (hogging) moment ($WL^2/8$) must be less than the resistance of the effective cross-section, $W_{eff}f_{py}$.



§ 5.3 Behaviour as Formwork

ANALYSIS

- As the effective plastic modulus for positive bending is greater than that for negative bending (as a result of the relatively narrow top flange), it is implied that the strength of continuous sheeting is lower than that for the simply supported case where the mid-span moment is $WL^2/8$.
- Tests demonstrate that there is some redistribution of moment in the elastic range from the highly stressed support regions to the mid-span because of the variation in stiffness with moment.
- As shown in figure above, a steel deck has some limited postbuckling moment-rotation capacity and exists some residual negative moment resistance as the limiting mid-span moment is reached.
- Many manufacturers prepare load-span tables on the basis of tests rather than analysis.

SERVICEABILITY CONSIDERATIONS

- Under the SLS conditions it is necessary to check if the residual deflection after the concreting operation is not excessive.

§ 5.3 Behaviour as Formwork

SERVICEABILITY CONSIDERATIONS

- The Eurocode 4 recommends that the deflection of the sheeting under its own weight plus the weight of wet concrete, but excluding the construction load, should not be greater than *L/180*

where *L* - the effective span between supports, (permanent or temporary)

- Decking is usually installed over a minimum of two spans. The continuity will reduce the mid-span deflection.
- For continuous decking it is also recommended to check that under characteristic loading the combination of bending moment and support reaction causes no plastic deformation. This is done by:

$$M_{S,ser} \le 0.9\, M_{Rd}$$
$$R_{S,ser} \le 0.9\, R_{Rd}$$

and

$$\left(\frac{M_{S,ser}}{0.9 M_{Rd}}\right)^2 + \left(\frac{R_{S,ser}}{0.9 R_{Rd}}\right)^2 \le 1.25$$

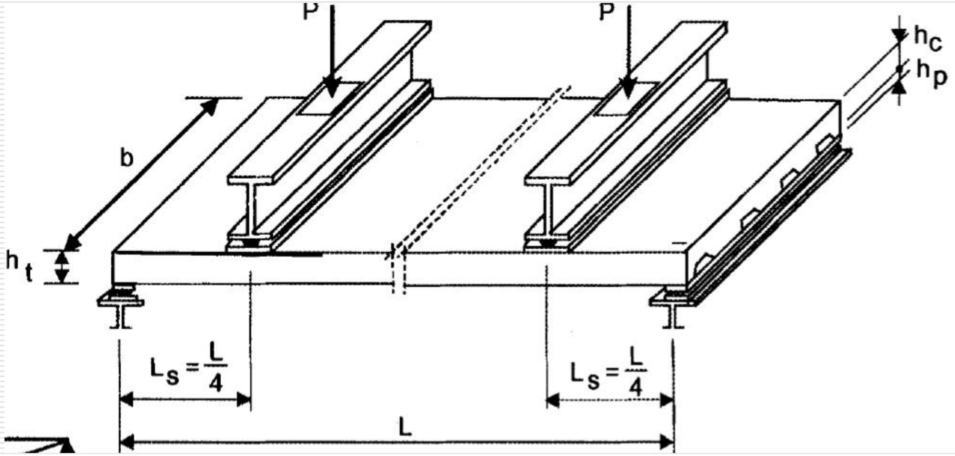
where - $M_{s,ser}$ and $R_{s,ser}$ are the bending moment and support reaction due to construction loads, without partial load factors (i.e. $\gamma_G = \gamma_Q = 1.0$)

- M_{Rd} and R_{Rd} are the design moment and support reaction resistance for the serviceability limit state.

§ 5.3 Composite Behaviour

- Once the concrete has hardened the steel deck and concrete combine to form a single structural unit, the composite slab.
- The response of a composite slab to load is analogous to that of a conventional reinforced concrete slab with an important condition: the bond between the steel deck and concrete may not be fully effective and longitudinal slip may occur before the steel deck yields. As a result, two primary failure modes are possible:
  - flexural failure;
  - shear-bond failure.
- The failure mode results from a simple test: a composite slab bears on two external supports and is loaded symmetrically with two loads, *P*, applied at ¼ and ¾ of the span. A typical load-deflection curve, P-δ, is illustrated in the figure below.
- The behaviour of the slab depends on the effectiveness of the steel to concrete connection, which is a function of the profile shape and embossment type and pattern.

§ 5.3 Composite Behaviour



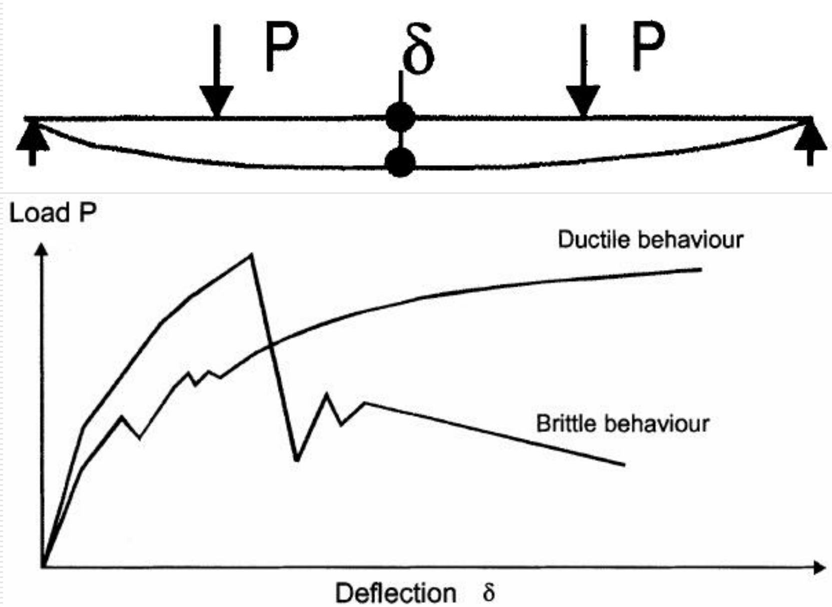


Figure: Composite slab test with typical load-deflection responses

- As load is applied to the slab the initial behaviour is elastic as the concrete is uncracked and the composite action between the concrete and steel is complete.
- As further load is applied, the concrete below the neutral axis cracks, reducing the slab stiffness and increasing deflections. At this stage the adhesion between the sheet and the concrete is still capable of transferring the shear force between the cracks.

§ 5.3 Composite Behaviour

- For higher load, slip may occur between the concrete and steel deck as the shear-bond between them is exceeded. Two modes of behaviour may then follow:
  - **Brittle behaviour** in which slip causes a sudden decrease in load carrying capacity as the surface bond is broken. The extent to which the load reduces is dependent on the effectiveness of the mechanical embossments. This load reduction is not due to concrete cracking; it arises from relative slip between the concrete and steel. As the slab is deflected further the resistance to load is increased slightly but the mechanical means by which shear is transferred does not equal that arising from surface adhesion.
  - **Ductile behaviour**, in which case the mechanical shear connection is capable of transferring the shear force until failure occurs. This may be flexural or by longitudinal shear.
- Whether a brittle or ductile mode of failure occurs depends on the characteristics of the steel-concrete interface and has to be determined by experimental tests.

§ 5.3 Composite Behaviour

ANALYSIS FOR INTERNAL FORCES AND MOMENTS

- Composite slabs may be analysed by elastic, rigid-plastic or elastic plastic methods.
- **Elastic analysis** may be used for both the serviceability and ultimate limit states and is the simplest method.
- The effects of longitudinal slip, buckling of the deck or yielding are ignored.
- Cross-sectional properties can be considered constant and uniform in both positive and negative moment regions.

- **Plastic methods** may be used only at the ultimate limit state. It is permissible to consider a slab as a series of simply supported spans with failure occurring either by slip between the decking and the concrete or by formation of a plastic hinge at the mid-span.
- If it is assumed a collapse mechanism involving plastic moments at the supports, the cross-section must have sufficient rotation capacity.

§ 5.3 Composite Behaviour

BENDING RESISTANCE

- Either the steel sheeting yielding in tension or the concrete reaching its resistance in compression determines the sagging bending resistance. Where reinforcing bars have been placed in the troughs, these may be taken into account in calculating the composite slab resistance.

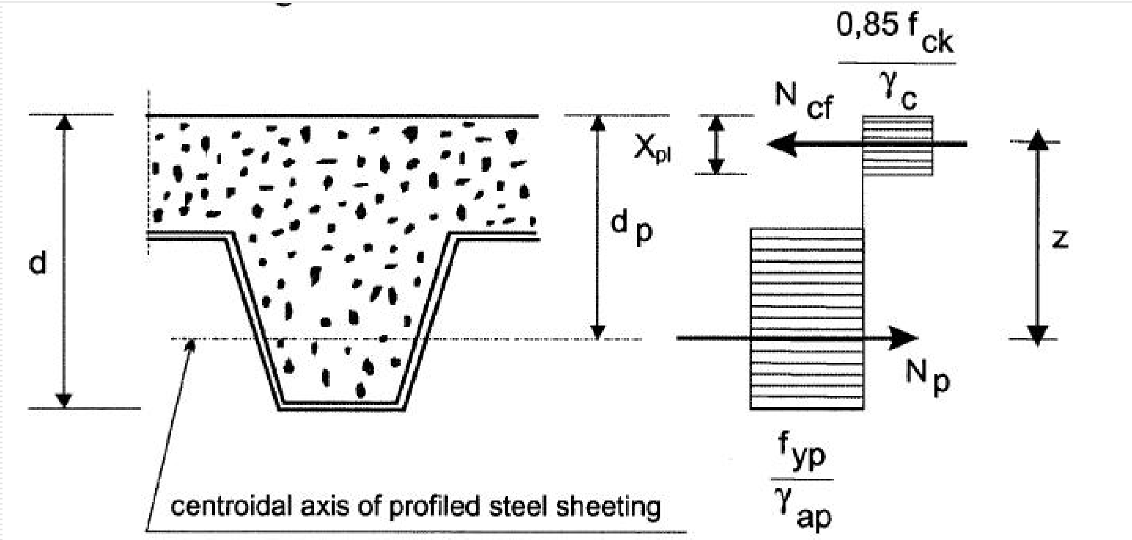
- Eurocode 4 assume idealised rigid plastic stress-blocks as the basis for determining the resistance at the ultimate limit state.
- Mesh reinforcement, or tension reinforcement for hogging bending, is usually in compression under sagging bending and neglected when evaluating the sagging bending resistance.

- The plastic neutral axis will most commonly lie above the steel decking as illustrated in figure below.

§ 5.3 Composite Behaviour

BENDING RESISTANCE

Figure: Stress distribution for sagging bending. Plastic neutral axis lies above the steel deck.



- The resistance of concrete in tension is ignored. The tension force in the steel sheeting is: $N_p = A_{pe} f_{ypd}$

Where: $f_{ypd} = f_{yp} / \gamma_{ap}$ is the design strength of the steel sheeting

A_{pe} is the effective area of sheeting

- Equating this force with the compression force in the concrete over the width *b* of the cross-section and depth x_{pl} it results:

$$N_{cf} = b x_{pl} \frac{0{,}85\, f_{ck}}{\gamma_c} = A_{pe} f_{yp,d}$$

from where results:

$$x_{pl} = \frac{A_{pe} f_{yp,d}}{\dfrac{0{,}85\, b\, f_{ck}}{\gamma_c}}$$

§ 5.3 Composite Behaviour

BENDING RESISTANCE

- The design resistance moment is:

$$M_{ps.Rd} = A_{pe} \frac{f_{yp}}{\gamma_{ap}} (d_p - \frac{x_{pl}}{2})$$

- If the plastic neutral axis lies in the steel sheeting (which is not a common situation), the calculation is made considering a part of the steel sheeting in compression.
- For simplification, the concrete in the ribs as well as the concrete in tension are neglected.

§ 5.4 Slim Floor Decking

- The 1980s saw dramatic increases in the market share for steel framed multi-storey office buildings. This was mainly due to the development of floor systems which contained the structural floor beams within the depth of the concrete slab.
- These floor systems offer a number of advantages over conventional slab-over-beam composite construction:
  - A reduction in overall structural depth reduces the total height of the building, permitting the construction of extra floors in a given height.
  - Often, it reduces the cost of cladding the building.
  - Slim floor systems makes installation and later replacement of services much easier.
  - Inherent fire resistance of slim floor systems is significantly improved as only the bottom flange of the steel section is exposed and, depending on the required fire resistance period, fire protection may not be necessary.

§ 5.4 Slim Floor Decking

- Initially, fabricated beams in a "top hat" cross-section were used. Later, built up asymmetric beams were produced from the upper half of an I beam with a welded bottom plate (ARBED integrated floor beam) or an H section welded to a bottom plate (British Steel Slidor beam).
- In each case the floor slab was usually a hollow-core slab or in-situ concrete cast on concrete planks.
- However, these are heavy and difficult to manoeuvre and an alternative deep metal deck capable of spanning 6 m unpropped, was developed by Precision Metal Forming Ltd.
- In 1995 British Steel launched a rolled asymmetric beam designed to be used with a revised and slightly deeper decking in a combined slim floor system called Slimdek (see picture below).

§ 5.4 Slim Floor Decking

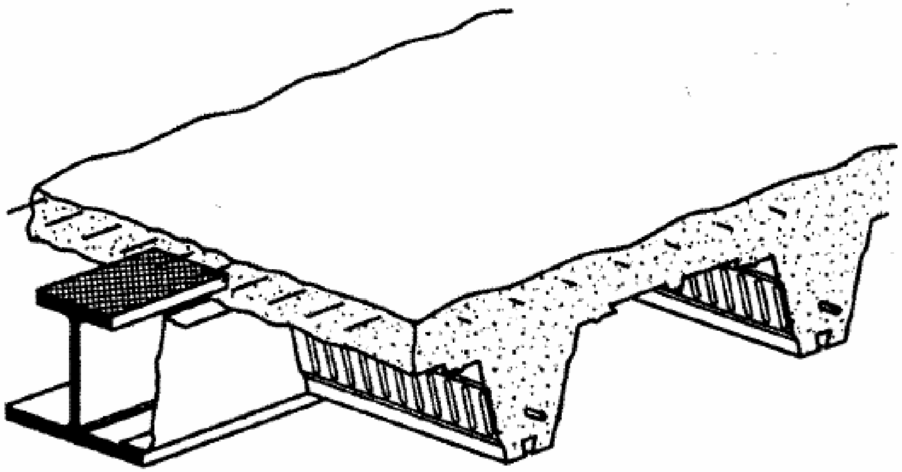
Picture: Installation of deep decking (notice the closure pieces fixed to the rolled steel beams)

STEEL DECKING IN SLIM FLOOR SYSTEMS

- Steel decking for slim floor construction is typically 200-225 mm deep and 1.0-1.25 mm thick.
- The decks are cold-rolled from galvanised strips units of 600mm wide.
- Each unit forms a single trough and clip together to form a completed rib.

§ 5.4 Slim Floor Decking

STEEL DECKING IN SLIM FLOOR SYSTEMS



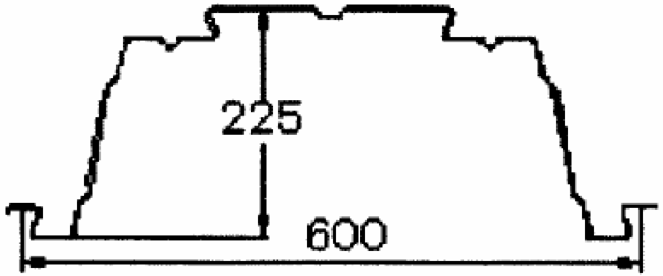


Figure: Cross section through deep decking (example SD225)

- End diaphragms fixed to the lower flange of the beam help to stabilise the deck and prevent concrete flowing out under the deck during construction.
- If lightweight concrete is used the slab weight can be as little as half that of an in-situ flat slab of the same depth.
- If propped construction is used then spans of up to 9m are possible to be covered by slim-floor systems.

§ 5.4 Slim Floor Decking

COMPOSITE ACTION IN DEEP DECKS

- Composite deep deck slabs differ from conventional shallow composite floors in two fundamental ways:
  - In conventional slabs, bar reinforcement in the deck troughs is not usually necessary except where fire considerations, heavy loading or large openings control the design. In deep deck composite slabs bars are placed in the troughs to enhance the moment resistance in both normal and fire conditions.
  - Secondly, the overall depth of a deep deck composite slab may in some cases be dictated not by structural and fire resistance requirements but the necessity to provide sufficient depth of concrete over the top flange of the integral floor beam.
- The bending resistance of a composite slab is significantly enhanced by the addition of bar reinforcement in the troughs.
- The resulting moment resistance may be determined by adding the capacity calculated for an equivalent reinforced concrete slab to the moment resistance of the composite slab limited by shear-bond resistance.

§ 5.4 Slim Floor Decking

COMPOSITE ACTION IN DEEP DECKS

- As the performance of composite slabs is based on test data, for practical design of deep deck composite slabs manufacturers provide load-span tables and/or software.
- Composite action is usually more than adequate for normal imposed loads and therefore the construction stage condition, where the metal deck acts alone, is generally critical.
- Detailed practical advise on the use of deep deck composite floors, including guidance on the provision of holes to accommodate services, should generally be provided by manufacturers.