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Composite Slabs

Dalles mixtes

Verbunddecken

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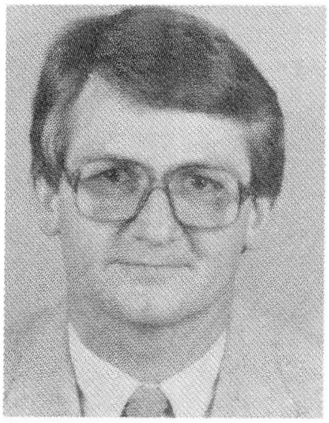

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SUMMARY

Descriptions of composite slabs, typical profiled sheeting and means of ensuring composite behaviour are given. Design criteria are identified in terms of actions, design resistance and serviceability limits. Analysis of continuous slabs is based on elastic or plastic theories. Critical cross-section resistance is calculated using all possible modes of failure. The ultimate limit state design consists of checking that slab resistance is sufficient to withstand maximum predicted forces. Service limit state checks are performed to limit concrete cracking and slab deflections, taking into account creep and shrinkage of the concrete. The above methods are illustrated by a design example.

RÉSUMÉ

Cet article fournit la description des dalles mixtes, des tôles profilées typiques et des moyens de connexion assurant le comportement mixte de ces structures. Les critères de dimensionnement sont définis sous forme d'actions, de résistance de calcul et de limites de service. L'analyse des dalles continues est basée sur la théorie du calcul élastique ou plastique. La résistance des sections critiques est calculée en prenant en compte tous les modes de rupture possibles. Le calcul à l'état limite ultime consiste à vérifier que le résistance de la dalle est suffisante pour supporter les charges maximales prévues. Les vérifications à l'état limite de service sont faites en vue de limiter la fissuration du béton et la déformation de la dalle, en prenant en compte le fluage et le retrait du béton. Un exemple de calcul illustre les méthodes décrites ci-dessus.

ZUSAMMENFASSUNG

Der Aufsatz beschreibt Verbundplatten, typische Profilblechformen und Verbindungsmittel. Bemessungskriterien werden bezüglich der Einwirkungen und der Anforderungen an Trag- und Gebrauchsfähigkeit behandelt. Die Berechnung kann wahlweise elastisch oder plastisch erfolgen, der massgebliche Querschnittwiderstand umfasst alle möglichen Versagensarten. Die Grenztragfähigkeit ist nachgewiesen, wenn der Widerstand der Platte den grössten Bemessungsbeanspruchungen genügt. Die Überprüfung der Gebrauchsfähigkeit bezüglich Betonrissebeschränkung und Plattendurchbiegung berücksichtigt Kriechen und Schwinden des Betons. Ein Bemessungsbeispiel illustriert die Methoden.

1. INTRODUCTION

1.1 Definition

A composite slab consists of a cold-formed profiled steel sheet covered with a concrete slab containing reinforcement (FIGURE 1). Such slabs are generally situated in frame structures with steel floor beams.

In this type of construction the profiled sheet has several functions :
- provides a working platform for construction,
- acts as formwork for the concrete slab,
- constitutes bottom reinforcement for the slab.

The present course is only concerned with calculations for composite slabs (after hardening of the concrete) when the steel-concrete bond has been formed.

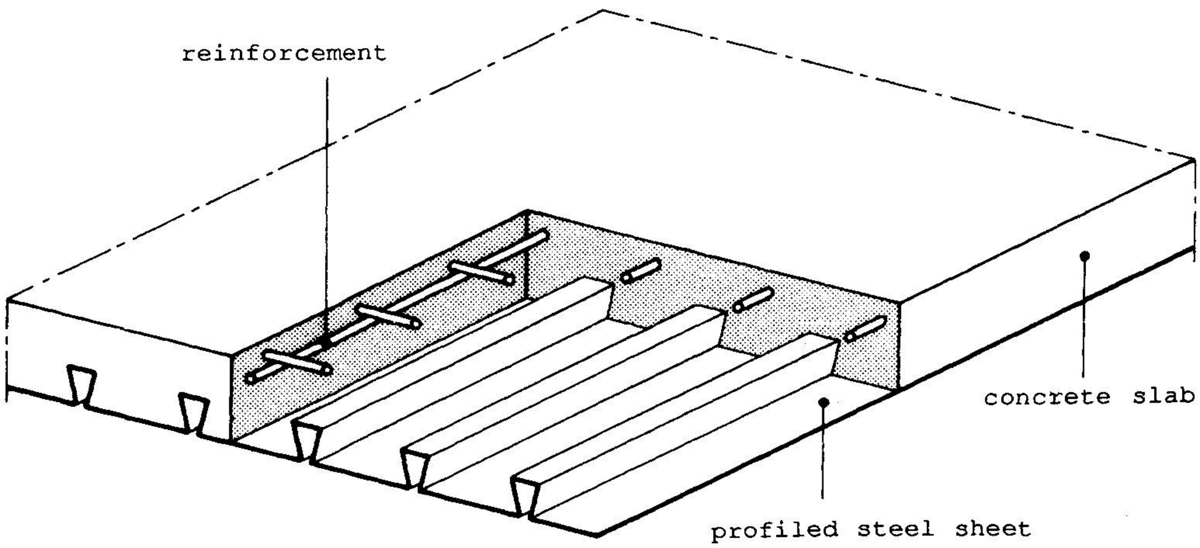


FIGURE 1 Composite slab with profiled steel sheet.

1.2 Types of profiled sheet

There are many types of profiled sheet used for the construction of composite slabs (FIGURE 2). These types vary in form, rib depth, rib spacing, sheet size, style of lateral over-lapping, by the methods of stiffening the flat elements of the profile and by the methods of mechanical connection which ensure bond between the steel sheet and concrete slab.

Whatever the particular requirements for a steel framed building, it is probable that they can be met by using a profiled sheet from this range. In particular the criteria for sound insulation, fire protection, maximum span and maximum load can be satisfied.

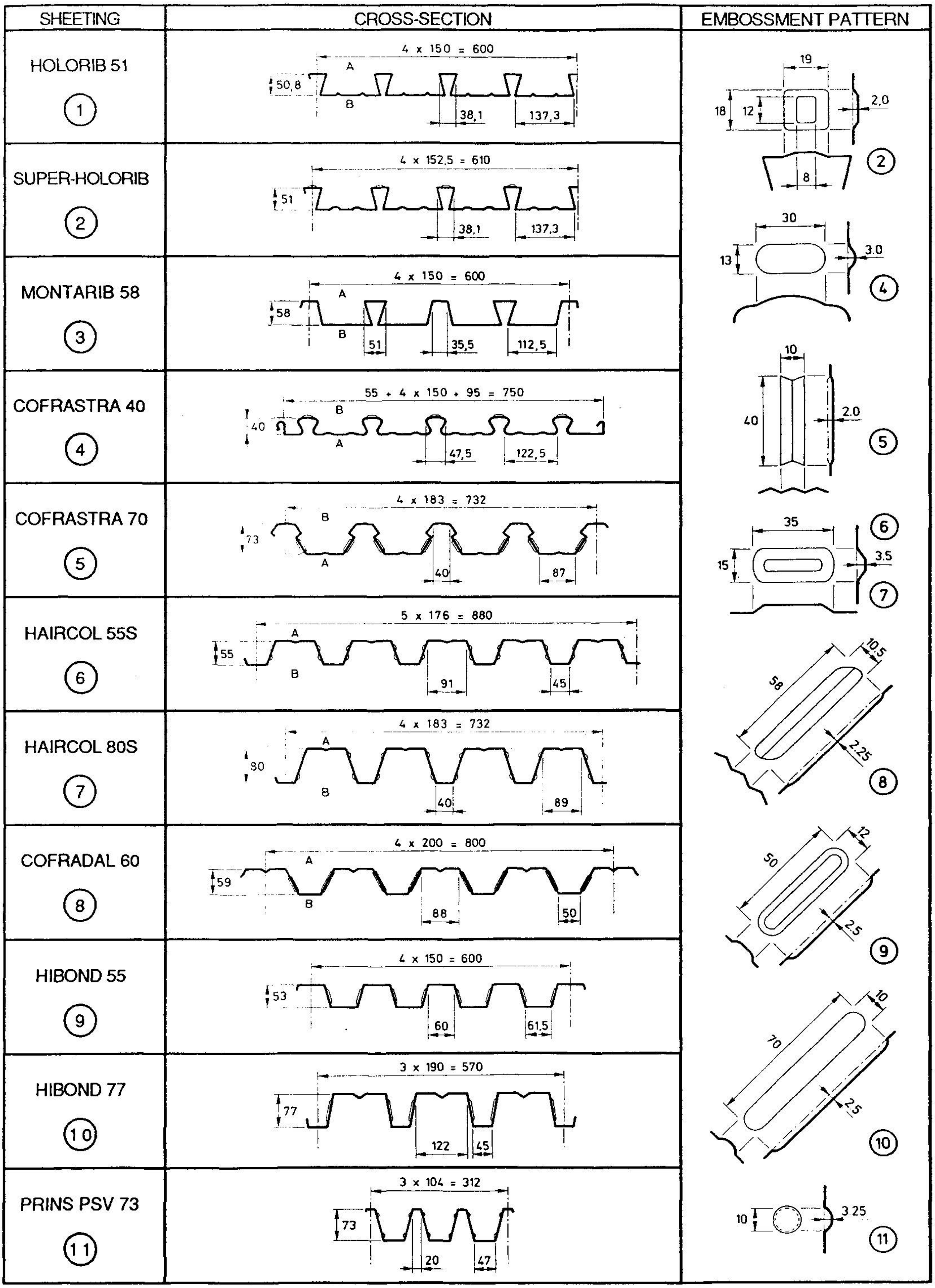
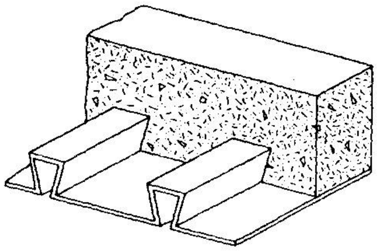


FIGURE 2 Sheeting profiles used in composite slabs.

1.3 Steel-concrete connection

The bond between the concrete slab and the profiled sheet must be capable of transmitting longitudinal shear at the steel-concrete interface.

This connection can be made in one of three ways :
- by the re-entrant shape on the ribs creating a bond by friction (FIGURE 3a);
- by embossments on the flanges or ribs of the sheet (FIGURE 3b);
- by anchorages situated at the ends of the slab, consisting of stud connectors welded through the sheet (FIGURE 3c) or by deformation of the ribs (FIGURE 3d).



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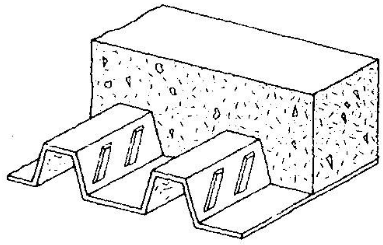

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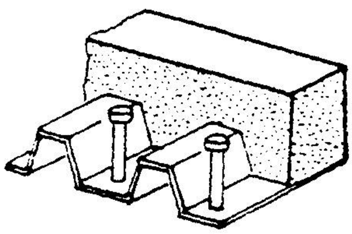

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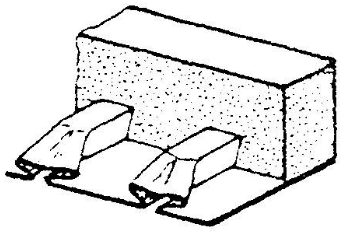

d)

FIGURE 3 Typical forms of interlock in composite slabs.

2. DESIGN CRITERIA

2.1 Loads and actions

The loads to consider for the ultimate limit state and the service limit state are given in the relevant national codes of practice or Eurocodes.

For the condition where the profiled sheet acts as formwork, the following loads should be considered in the calculations taking into account any support :
- self-weight of the profiled sheet,
- self-weight of the wet concrete,
- construction loads,
- temporary storage load, if applicable.

The construction loads represent the weight of the operatives, any loads due to placing the concrete and take into account any impact or vibration likely to occur during construction. In accordance with Eurocode No 4 [1], a representative value of construction loads (including any excess of concrete) can be taken to be 1.5 kN/m^2, distributed on an area 3 m x 3 m (or the span of the sheeting, if less) and 0.75 kg/m^2 on the remaining formwork surface.

The loads acting on the composite slab should comply with Eurocode No 1 "Actions on structures" (in preparation).

The Swiss national code SIA 160 (1989) "Actions on structures" [2] prescribes the representative values given in Table 1.

USE OF BUILDING	ULTIMATE LIMIT STATE	SERVICE LIMIT STATE	
		LONG DURATION	SHORT DURATION
Dwelling, hotel	2.0	0.5	1.5
Office, hospital, school	3.0	1.0	2.0
Conference room, lecture theatre, concert hall, exhibition hall	4.0 * 5.0	2.0 * 4.0	4.0 * 5.0
Commercial premises	5.0	4.0	5.0
Garage (heavy vehicles)	2.0	--	2.0

(* = fixed seats)

Table 1 Representative values of loads in buildings, kN/m^2

The values given for the long duration service limit state correspond to calculations of deformation taking into account creep and shrinkage of the concrete.

2.2 Ultimate material resistance

Profiled sheet

Steel used for the fabrication of profiled sheeting has a guaranteed minimum yield strength of 220 N/mm^2. In general however, we are concerned with steel of grades 280 or 320 according to the International Standard ISO 4998-1977 [3]. The respective yield strengths of these steels are :

Steel grade 280 : f_{yb} = 280 N/mm^2
Steel grade 320 : f_{yb} = 320 N/mm^2

The characteristic yield strength, f_y, is equal to the yield strength of the material, f_{yb}, quoted above for calculating ultimate resistance.

Concrete

Concrete used for composite slabs can be made with normal or lightweight aggregate.

The most commonly used grades of concrete (grading according to Eurocode No 2 [4]) are given in Table 2 with the following properties : characteristic cylinder compressive strength, f_{ck}, after 28 days; mean tensile strength, f_{ctm}, which is associated with the shear strength τ_c; and the secant modulus of elasticity, E_{cm}.

Concrete grade	C12/15	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55	C50/60
f_{ck} [N/mm^2]	12	16	20	25	30	35	40	45	50
f_{ctm} [N/mm^2]	1.6	1.9	2.2	2.6	2.9	3.2	3.5	3.8	4.1
τ_c [N/mm^2]	0.18	0.22	0.26	0.30	0.34	0.37	0.41	0.44	0.48
E_{cm} [kN/mm^2]	26	27.5	29	30.5	32	33.5	35	36	37

Table 2 Concrete grades and associated properties

Reinforcement

All reinforcing steels used in composite slabs should correspond to the requirements of Eurocode No 2.

The values of design yield strength given in Table 3 are applicable to the calculation of ultimate resistance of sections.

Steel grade	S 235	S 500	S 550
f_{ys} [N/mm^2]	220	460	520

Table 3 Design values of yield strength for reinforcing steel

2.3 Limiting values of deformation

A distinctive characteristic of composite slabs is the two structural states that exist : firstly, the temporary state of construction when only the sheeting resists the applied loads and secondly, the permanent state when the concrete is bonded to the steel allowing composite action. For both of these states limiting values of deformation are defined.

Deflection during construction

At the time of construction, deflection of the profiled sheet under loads of self-weight and wet concrete must not exceed a limiting value.

For example, in the planned Eurocode No 4, this limit is $l/180$ or 20 mm, where l is the span of the slab between supports. In the case of propped profiled sheets, props are considered as supports. In situations where greater deflection can be tolerated, calculations for the ultimate limit state should take into account the self-weight of additional concrete due to the deflection (the "ponding" effect).

Equally this thickness of additional concrete may be taken into account when calculating the resistance of the section.

Deflection in the service limit state

Deflections in the service limit state must be limited in order that the slab may fulfil the intended function and that any other elements in contact with it will not be damaged (false ceilings, pipework, screeds, partitions). One should consider requirements relative to the use of the slab, the construction procedure and architectural aspects (aesthetics).

The values recommended by Eurocode No 3 [5] for floors and roofs in buildings are the following :

$$\delta_{max} \leq l/250$$
$$\delta_2 \leq l/300$$

δ_{max} is the total deflection of the floor or roof including any pre-camber and any variation of the deflection due to the permanent loads immediately after loading and including δ_2.

δ_2 is the variation of the deflection due to variable loading acting on the slab plus any time dependent deformations due to the permanent loads.

If the composite slab supports brittle elements (cement floor finishes, non flexible partitions, etc.), δ_2 must be limited to $l/350$.

3. ANALYSIS OF COMPOSITE SLABS

The analysis of a composite slab may be made according to one of the following methods :
- linear elastic,
- linear elastic with moment redistribution,
- plastic according to the theory of plastic hinges,
- a higher order analysis which takes into account non-linear material behaviour and slip between profiled sheeting and concrete slab.

3.1 Analysis for the ultimate limit state

In most cases analysis of composite slabs, continuous over several spans, is performed according to the elastic method for a slab of unit width (1 m) comparable to a beam of constant inertia (FIGURE 4).

It is possible to take concrete cracking into account in several ways :
- Consider that the slab is a beam with variable inertia, depending on the reinforcement.
- Arbitrarily reduce the moment at the supports (maximum reduction 30 %) and consequently increase the span moments.
- Totally neglect reinforcement over the supports and consider the slab as a series of simply supported beams. Minimum reinforcement must always be placed over supports to provide at least 0.2 % of the concrete section area above the ribs of the sheet for serviceability reasons.

The analysis will use one of the above statical systems in conjunction with the loads given in Section 2.

Design values are obtained by multiplying the various loads by appropriate factors. The numerical example given at the end of this course will give an idea of how the stresses and strains are determined and the interior forces and moments (M, N, V) are calculated for the structural system chosen.

3.2 Analysis for the service limit state

The verification for the service limit state is essentially a control on deflection.

It is first necessary to analyse the profiled sheeting under its own self-weight and that of the wet concrete and secondly to calculate the deflection of the composite slab.

For an analysis of the profiled sheeting acting as formwork, see Annex A of Eurocode No 3, "Cold formed steel sheeting and members".

An analysis of the composite slab may take advantage of the following simplifications for calculating deflection :
- The slab is comparable to a continuous beam of constant inertia, equal in value to the average inertia of the cracked and uncracked sections.
- Long term loading effects on the concrete are taken into account and an average modular ratio, E_a/E_c, equal to 15 is used for the case of normal weight concrete.

Possible slip between the profiled sheeting and concrete slab must be taken into account at the service limit state. This may occur in the span and greatly influence deflection. Thus, it is necessary to know the behaviour of composite slabs through approved testing.

To eliminate excessive slip it is possible to place anchorages at the ends of the spans, for example welded studs or shot-fired connectors. These anchorages may equally be taken into account in calculating resistance to longitudinal shear.

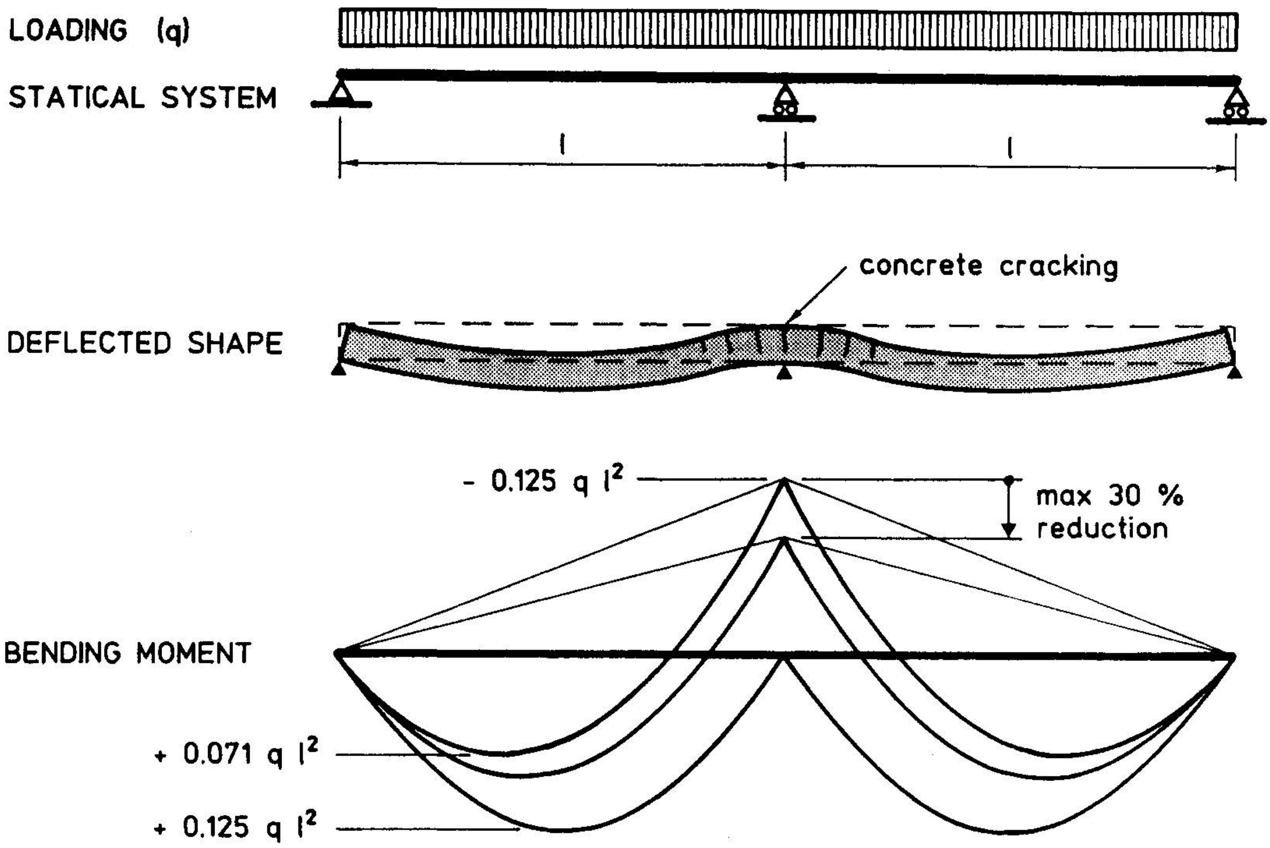

FIGURE 4 Continuous slab analysis (example)

4. ULTIMATE RESISTANCE OF SECTIONS

According to Section 3, the critical sections where a verification should be made are the following (FIGURE 5) :

- Section I : ultimate moment of resistance failure for positive bending,
- Section II : ultimate moment of resistance failure for negative bending,
- Section III - IV : ultimate resistance to vertical shear failure,
- Section V : ultimate resistance to longitudinal shear failure.

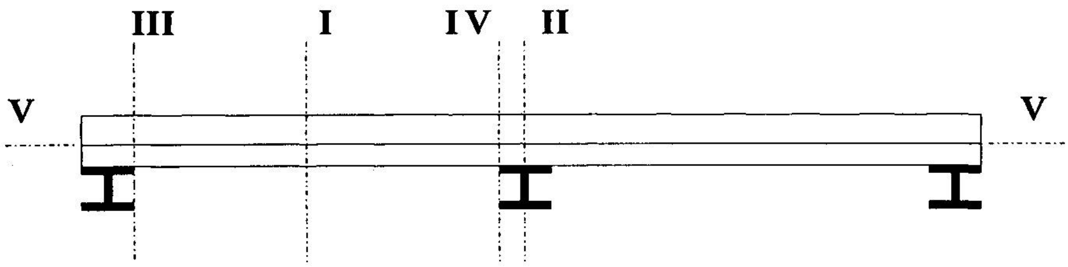

FIGURE 5 Critical sections

4.1 Moment resistance for positive bending

The ultimate moment of resistance of a section, M_{pc}, may be determined by assuming a plastic distribution of stresses (FIGURE 6). For a underreinforced section, the position of the plastic neutral axis is given by :

$$x = \frac{A_a \cdot f_y / \gamma_a}{b \cdot 0.85\ f_{ck}/\gamma_c} \qquad (1)$$

A_a : area of the profiled sheet section
f_y : characteristic yield strength of the sheet steel
γ_a : factor for steel sheeting resistance
b : width of the slab ($b = 1000$ mm)
f_{ck} : characteristic compressive strength of the concrete
γ_c : factor for concrete resistance.

If the neutral axis is situated above the profiles of the sheeting ($x \leq h_c$) the moment resistance for positive bending has the value :

$$M^+_{pc} = A_a \cdot f_y \left(d_s - \frac{x}{2}\right) \qquad (2)$$

If the neutral axis is situated within the height of the profiled sheeting, the relationship for calculating M^+_{pc} is more complicated. All commonly used profiled sheets ($h_a \leq 60$ mm), in conjunction with a concrete slab of minimum thickness $h_c = 50$ mm, have a plastic neutral axis situated above the profiles. For deeper sheets, a simplified model has been proposed [10].

The depth of the concrete in compression, x, should not exceed 0.5 d_s.

4.2 Moment resistance for negative bending

The section of a continuous composite slab at a support can be compared to a reinforced concrete section. As a simplification, the contribution of the profiled sheet is neglected. The design section and the distribution of stresses at the ultimate limit state are shown in FIGURE 7.

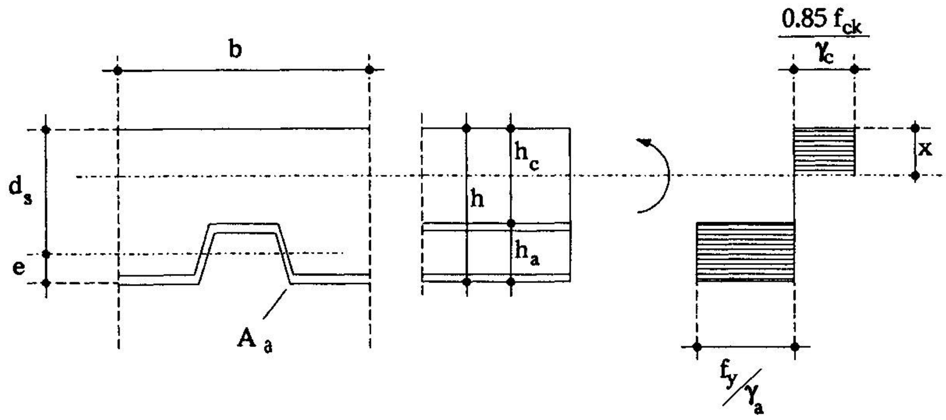

FIGURE 6 Section I under positive bending, plastic distribution of stresses

The moment resistance for negative bending, M^-_{pc}, is given by the plastic yield of the reinforcement at the support (under-reinforced slab) :

$$M^-_{pc} = A_s \cdot f_{ys} \cdot z$$

where z is the lever-arm of the internal forces F_c and F_t. The condition of equilibrium between these forces allows the determination of z :

$$F_c = b_o \cdot x \cdot 0.85\ f_{ck} \ / \ \gamma_c = A_s \cdot f_{ys} \ / \gamma_s = F_t$$

$$x = \frac{A_s \cdot f_{ys} \ / \ \gamma_s}{b_o \cdot 0.85\ f_{ck} \ / \ \gamma_c} \tag{4}$$

$$z = d_s - x/2 \tag{5}$$

where A_s : area of reinforcement
f_{ys} : yield strength of the reinforcement
γ_s : resistance factor for the reinforcement

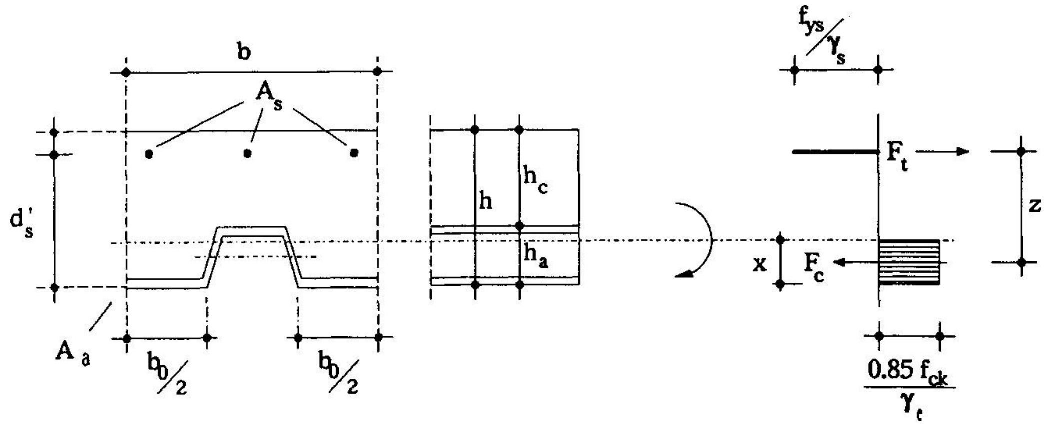

FIGURE 7 Section II under negative moment, plastic distribution of stresses

4.3 Vertical shear resistance

In general the vertical shear resistance is given by the concrete section since the contribution of the steel sheet is negligible.

This resistance has the value :

$$V_{Rv} = b_o \cdot d_s \cdot \tau'_c \qquad (6)$$

where τ'_c is the limiting shear stress appropriate for composite slabs (γ_c included)

$$\begin{aligned} \tau'_c &= \tau_c \cdot k_1 \cdot k_2 \\ k_1 &= 1.6 - d_s \geq 1.0 \quad (d_s \text{ in m}) \qquad (7) \\ k_2 &= 1.2 + 40\,\rho_o \\ \rho_o &= A_s/b_o \cdot d_s < 0.002 \end{aligned}$$

A_s is the area of reinforcement provided in order to distribute cracking.

4.4 Longitudinal shear resistance

Resistance to longitudinal shear in composite slabs is due to the steel-concrete bond established at the interface of these two materials, by friction, embossments or connectors placed at the ends of the slabs (see FIGURE 3). The ultimate resistance of these connections can only be determined by testing.

Presently, the most commonly used method which enables ultimate longitudinal shear to be predicted is that developed in the United States [6] and which is used in many codes of practice, in particular Eurocode No 4. This semi-empirical method is based on at least six tests of simply supported composite slabs which determine two coefficients (m and k) for types of profiled sheeting (FIGURE 8).

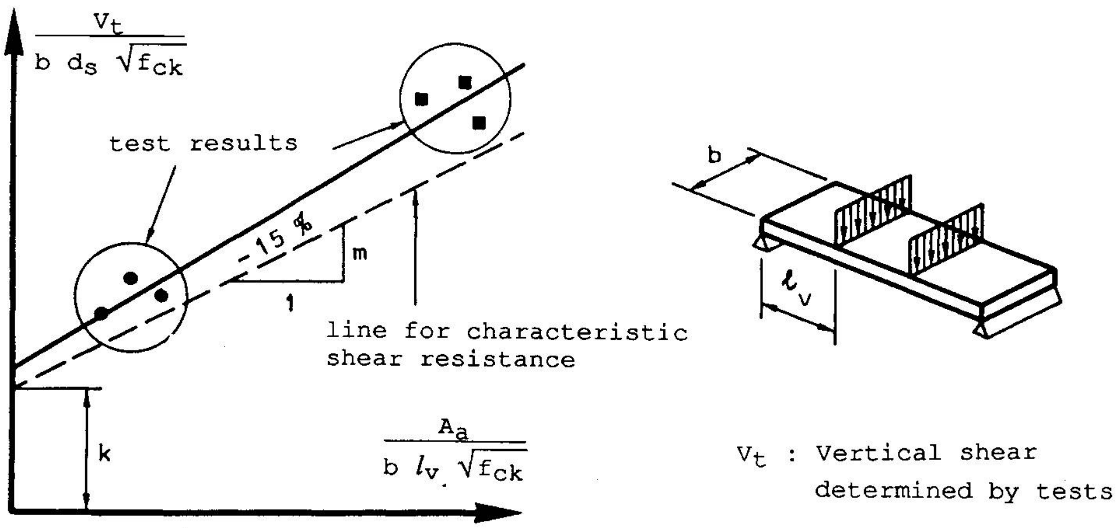

FIGURE 8 Empirical method for evaluating longitudinal shear resistance

The longitudinal shear resistance of a composite slab consisting of the same type of profiled sheet is given by the following ultimate shear :

$$V_{Rl} = bd_s \left[m \frac{A_a}{b \cdot l_v} + k\sqrt{f_{ck}} \right] \qquad (8)$$

Where, l_v is the shear span.

For a uniformly loaded slab, $l_v = l/4$. For simply supported beams l is the span, whereas for continuous beams l is the equivalent simple span between points of contraflexure. For end spans, the full exteriour span length is used in design.

If the connection provided by friction (due to the rib shape) or by embossments is not sufficient, it is possible to place anchorages (generally steel-concrete connectors) at the ends of the slab.

The ultimate resistance of such anchorages is generally governed by the pull-out strength of the sheet. For a stud, this resistance is given by the following expression :

$$N_{at} = k_3 \cdot d_w \cdot t \cdot f_y \tag{9}$$

$k_3 = 1 + a/d_w \leq 4.0$
d_w : diameter of weld around the stud
a : distance between the axis of the stud and the extremity of the profiled sheet ($a \leq 2\ d_w$)

4.5 Elastic properties of cross-sections

The evaluation of deflections of the composite slab is made using elastic theory.

The second moment of area I_{vc} of the cracked section can be obtained from :

$$I_{vc} = \frac{b \cdot x^3}{3\ n} + A_a\ (d_s - x)^2 + I_a \tag{10}$$

where x is the position of the elastic neutral axis :

$$x = \frac{n\ .\ A_a}{b} \left(\sqrt{1 + \frac{2b \cdot d_s}{n\ A_a}} - 1 \right) \tag{11}$$

$n = E_a / E_c$

I_a : unreduced moment of area of the sheet based upon the nett sheet thickness

5. VERIFICATION OF COMPOSITE SLABS

Two verifications are necessary to ensure that safety and serviceability requirements are met :

- Structural safety check of the resistance of sections and stability.
- Aptitude for service checks including checks for concrete cracking, deformations and vibrations.

5.1 Structural safety check

The resistance of the composite slab must be sufficient to resist the exterior actions at the ultimate limit state. Each critical section (FIGURE 5) must be capable of resisting the internal forces determined by an analysis of the structure (FIGURE 4).

The condition for verification is generally expressed by :

$$S_d \leq R/\gamma_R \tag{12}$$

S_d : design value of action effects

$S_d = S\,(\gamma_G \cdot G + \Sigma\, \gamma_Q \cdot Q)$
R = ultimate resistance
γ_R = resistance factor
G = permanent load (self weight, dead load)
Q = variable load (live load, service load)
γ_G, γ_Q = load factors applicable to G, Q.

a) Safety check for positive bending

This check is made at the section of maximum positive moment, generally in the external span of a continuous slab. The condition can be expressed as :

$$M_d^+ \leq M_{pc}^+ / \gamma_a \tag{13}$$

M_d^+ : design value of the positive bending moment

b) Safety check for bending at supports

This check is made with the negative moment from the analysis at the supports (see chapter 3).

The negative moment can be expressed as :

$$M_d^- \leq M_{pc}^- / \gamma_{rc} \tag{14}$$

M_d^- : design value of the negative bending moment

γ_{rc} is the value of the resistance factor applicable to reinforced concrete structures. This factor can vary according to the failure mode, plastic yielding of the steel (generally in an under-reinforced section, $\gamma_{rc} = \gamma_s$) or concrete crushing (over-reinforced section, $\gamma_{rc} = \gamma_c$).

c) Safety check for vertical shear

This check is rarely critical, however it may be in the case of deep slabs with loads of relatively large magnitudes. This will occur at end supports where the bending moment is zero, or at intermediate supports. In the latter case no interaction between M and V is assumed. The condition is expressed as :

$$V_d \leq V_{Rv} \tag{15}$$

V_d : design value of vertical shear

V_{Rv} : design value of the ultimate shear resistance of the composite section (including the resistance factor, see 4.3).

d) Safety check for longitudinal shear

This check is often the determining factor for composite slabs with profiled sheeting but no anchorage. This implies that overall failure of the slab occurs by failure of the bond. The ultimate bending resistance at section I cannot be attained. This is the definition of partial shear connection.

Take note that methods of designing with partial connection are under development [7, 8, 9].

The condition can be expressed as :

$$V_d \leq V_{Rl} / \gamma_v \tag{16}$$

γ_v is the resistance factor applicable to the relevant critical section.

5.2 Aptitude for service check

The behaviour of the composite slab under permanent loads and variable service loads must fall within the accepted limits.

An aptitude for service check involves checking the following states :
- Concrete cracking reaching a limited width (corrosion of reinforcement, appearance).
- Deflection, or variation of deflection, attaining the admissible limit (use of slab, damage of non-structural elements, appearance, etc).
- Vibrations reaching a limiting value (this limit state will not be treated in this course).

a) Crack width check

Given that there is a profiled sheet on the lower surface of the concrete slab, only concrete cracking at the supports must be verified. Such verifications should be made according to the established rules for reinforced concrete, for example Eurocode No 2.

In normal circumstances minimum reinforcement placed at the supports is sufficient. Normal circumstances are : no exposure to aggressive physical or chemical environments; no damage other than cracking; no requirements regarding water proofing of the slab; cracking can be tolerated with regard to appearance. Such reinforcement is necessary when the slab is designed as a series of simply supported beams.

The amount of minimum reinforcement is given by the following :
- for slabs propped at the time of concreting,

$$\rho_{min} = \frac{A_s}{b\ h_c} = 0.4\ \%$$

- for slabs unpropped at the time of concreting

$$\rho_{min} = 0.2\ \%$$

b) Deformations

Vertical deflections calculated according to the analysis given in section 3.2 with loads as in section 2.1 must not exceed the limiting values given in section 2.3.

If the slenderness of the slab does not exceed the limiting values given in Eurocode No 2, this deflection check is not essential.

For one way continuous slabs, concrete lightly stressed, the basic ratio of span/effective depth is 32.

6. NUMERICAL EXAMPLE

6.1 Data

A 120 mm thick slab with HiBond 55/0.88 profiled sheeting has three equal spans of 2.80 m (span/effective depth ratio l/d_s = 30). The steel sheeting is Grade 320, the concrete Grade C30/37 and the reinforcement is Grade 550. Consider the following loads :

- self-weight of the slab g_1 = 2.3 kN/m^2
- self-weight of floor finishes g_2 = 1.2 kN/m^2
- live load q = 5.0 kN/m^2

A verification of the HiBond 55/0.88 sheeting for the temporary condition of concreting the slab has shown that props are not necessary.

A reinforcing steel mesh is placed in the concrete slab, with 25 mm top cover, providing 188 mm^2/m of reinforcement (ø 6 mm, a = 150 mm).

Verify the structural safety and the aptitude for service of the composite slab.

6.2 Structural safety check

Assume the slab to be a series of simple beams.

a) Bending resistance check

Calculation of the design bending moment :

Load :
$$p_d = [\gamma_G\ (g_1 + g_2) + \gamma_Q\ (q)] \cdot 1.0\ \text{m}$$
$$= [1.3\ (2.3 + 1.2) + 1.5 \cdot 5.0] \cdot 1.0 = 12.05\ \text{kN/m}$$

Bending moment :
$$M_d = \frac{p_d \cdot l^2}{8} = \frac{12{,}05 \cdot 2{,}8^2}{8} = 11{,}8\ \text{kNm/m}$$

Ultimate moment of resistance calculation

Position of the neutral axis :

$$x = \frac{A_a \cdot f_y/\gamma_a}{b \cdot 0{,}85\ f_{ck}/\gamma_c} = \frac{1295 \cdot 320\ /\ 1.0}{1000 \cdot 0{,}85 \cdot 30\ /\ 1{,}5} = 24{,}4\ \text{mm}$$

Ultimate moment of resistance :

$$M^+_{pc} = A_a \cdot f_y\ (d_s - \frac{x}{2}) = 1295 \cdot 320\ (120 - 27{,}5 - 12{,}2) = 33{,}3\ \text{kNm/m}$$

Check

$$M_d \leq \frac{M^+_{pc}}{\gamma_a} \rightarrow 11{,}8 < 33{,}3\ \text{OK}$$

b) Check for resistance to longitudinal shear

Calculation of the design shear force :

$$V_d = \frac{p_d \cdot l}{2} = \frac{12{,}05 \cdot 2{,}8}{2} = 16{,}9\ \text{kN/m}$$

Calculation of the ultimate resistance to longitudinal shear

The values m and k for the HiBond 55/0.88 sheeting are the following :

$m = 83 \qquad k = 0{,}014$

Shear force limit :

$$V_{Rl} = b \cdot d_s \left[m \frac{A_a}{b l_v} + k \sqrt{f_{ck}} \right] =$$

$$1000 \cdot 92.5 \left[83 \frac{1295}{1000 \cdot 2800/4} + 0.014 \sqrt{30} \right] = 21{,}3 \text{ kN/m}$$

Check

$$V_d \leq \frac{V_{Rl}}{\gamma_v} \rightarrow 16{,}9 < \frac{21{,}3}{1{,}25} = 17{,}00 \quad \text{OK}$$

c) Check for resistance to vertical shear

Design value of shear force : $V_d = 16{,}9$ kN/m

Calculation of ultimate vertical shear

Shear stress limit :

$$\tau'_c = \tau_c \cdot k_1 \cdot k_2$$

where
$\tau_c = 0{,}34 \text{ N/mm}^2$
$k_1 = 1{,}6 - d_s = 1{,}6 - 0{,}09 = 1{,}51$
$k_2 = 1{,}2 + 40\ \rho_o = 1{,}36$
$\rho_o = A_s/b_o\ d_s = 188/500 \cdot 92{,}5 = 0{,}004$

$$\tau'_c = 0{,}34 \cdot 1{,}51 \cdot 1{,}36 = 0{,}70 \text{ N/mm}^2$$

Ultimate resistance to vertical shear :

$$V_{Rv} = b_o \cdot d_s \cdot \tau'_c = 500 \cdot 92{,}5 \cdot 0{,}70 = 32{,}3 \text{ kN/m } (\gamma_c \text{ included})$$

Check

$$V_d \leq V_{Rv} \rightarrow 16{,}9 < 32{,}3 \quad \text{OK}$$

d) Conclusion

A longitudinal shear failure is the determining factor.

6.3 Aptitude for service check

a) Deflection calculations :

The deflection of the sheeting under self-weight of the concrete, for a side span, has the value :

$$\delta_a = \frac{2{,}65\ g_1\ l^4}{384\ EI_a} = \frac{2{,}65 \cdot 2{,}3 \cdot 2{,}8^4 \cdot 10^{12}}{384 \cdot 210'000 \cdot 0{,}66 \cdot 10^6} = 7{,}0 \text{ mm}$$

The deflection of the composite slab under self-weight of floor finishes, for a side span, has the value :

$$\delta_{v,g} = \frac{2,65\ g_2\ l^4}{384\ EI_{v,m}} = \frac{2,65 \cdot 1,2 \cdot 2,8^4 \cdot 10^{12}}{384 \cdot 210'000 \cdot 7,4 \cdot 10^6} = 0,33\ \text{mm}$$

The deflection of the composite slab under variable loading of long duration, for the case of only a side-span loaded, has the value :

$$\delta_{v,p} = \frac{3,4\ pl^4}{384\ EI_{v,m}} = \frac{3,4 \cdot 5,0 \cdot 2,8^4 \cdot 10^{12}}{384 \cdot 210'000 \cdot 7,4 \cdot 10^6} = 1,75\ \text{mm}$$

$I_{v,m}$ is the second moment of area taken as the average of the values for the cracked and the uncracked section, calculated with an average value of the modular ratio ($n = E_a/E_c = 15$) for both long and short term effects.

Checks

Deflection during construction :

$$\delta_a = 7,0\ \text{mm} < \frac{l}{180} = 15,6\ \text{mm} \quad \text{OK}$$

Deflection in the service limit state

$$\delta_{max} = \delta_a + \delta_{v,g} + \delta_{v,p} = 7,0 + 0,33 + 1,75 = 9,1\ \text{mm}$$

$$\delta_{max} = 9,1\ \text{mm} < \frac{l}{250} = 11,2\ \text{mm} \quad \text{OK}$$

$$\delta_2 = \gamma_{v,g} + \gamma_{v,p} = 0,33 + 1,75 = 2,1\ \text{mm}$$

$$\delta_2 = 2,1\ \text{mm} < \frac{l}{300} = 9,3\ \text{mm} \quad \text{OK}$$

This confirm that for non-slender composite slabs ($l/d_s = 30 < 32$), deflection is not determining case.

b) Cracking of concrete

The slab is designed as simply-supported and unpropped. The amount of reinforcement at intermediate supports is :

$$\rho = \frac{A_s}{b \cdot h_c} = \frac{188}{1000 \cdot 65} = 0.29\ \% > 0.2\ \% \quad \text{OK}$$

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