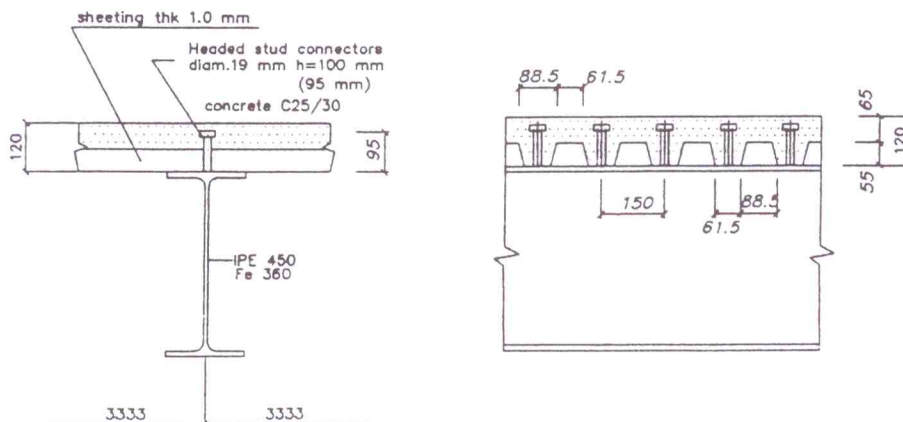


## WORKED EXAMPLE no.2

This worked example refers to a simply supported composite beam considered as a floor beam in a building. The span of the beam is equal to 12 m with a spacing of 3.33 m. The variable load has been considered equal to  $3.0 \text{ kN/m}^2$  and the load for interior finishings equal to  $1.0 \text{ kN/m}^2$ . The beam is unpropped during construction and is designed for partial shear connection between the steel and concrete. For simplicity the contribution of the longitudinal reinforcement has been neglected. The effect of creep has been taken into account for deflection checks (serviceability limit states), while those due to temperature and shrinkage have been ignored. The structural solution uses a composite slab (sheeting with ribs transverse to the supporting beam), rolled steel beam and headed stud connectors. The steel beam is also checked for its ability to support the loads during construction.



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## 1. COMPOSITE BEAM CHARACTERISTICS

Span :  $L = 12000 \text{ mm}$

Structural scheme : **simply supported beam**

Beam spacing :  $b = 3333 \text{ mm}$

Construction type : **unpropped**

## 2. DESIGN LOADS

### Characteristic values

**permanent loads**  $g'_k = 2.40 \cdot 3.33 = 8.00 \text{ kN/m}$  normal weight concrete

$g''_k = 0.15 \cdot 3.33 = 0.50 \text{ kN/m}$  profiled steel sheeting

$g'''_k = \quad = 0.80 \text{ kN/m}$  steel beam

$g''''_k = 1.00 \cdot 3.333 = 3.33 \text{ kN/m}$  interior finishings

**variable loads**  $q'_k = 1.00 \cdot 3.333 = 3.33 \text{ kN/m}$  partitions

$q''_k = 2.00 \cdot 3.333 = 6.67 \text{ kN/m}$  imposed load

$q'''_k = 0.75 \cdot 3.333 = 2.50 \text{ kN/m}$  construction load

**accidental loads**  $a_k = 0$

## 3. LOAD COMBINATIONS

### 3.1 Ultimate limit states

[Table 3.1]

$\gamma_G \cdot \Sigma G_{k,j} + \gamma_Q \cdot Q_{k,1}$  considering only the most unfavourable action

$\gamma_G \cdot \Sigma G_{k,j} + 0.9 \cdot \gamma_Q \cdot \Sigma Q_{k,j}$  considering all unfavourable variable actions

whichever is larger.

Partial safety factors:

$$\gamma_G = 1.35$$

$$\gamma_Q = 1.50$$

### 3.2 Serviceability limit states

[Table 3.2]

$\Sigma G_{k,j} + 1.0 Q_{k,1}$  considering only the most unfavourable variable action

$\Sigma G_{k,j} + 0.9 \Sigma Q_{k,i}$  considering all unfavourable variable actions

**4. MATERIALS** [4.2]

**4.1 Concrete** [4.2.1]

Concrete strength class : **C25/30**

Characteristic strength :  $f_{ck} = 25 \text{ N/mm}^2$

Shrinkage :  $\varepsilon_{cs} = 325 \cdot 10^{-6}$

Secant modulus of elasticity of short-term loading :

$E_{cm} = 30.5 \text{ kN/mm}^2$

modular ratios : [7.2.2]

$n = E_a/E_{cm} = 210/30.5 = 6.88$  (short term effects)

$n = E_a/(E_{cm}/3) = 20.65$  (long term effects)

**4.2 Reinforcing steel** [4.2.2]

Type of steel : **S 420**

Steel grade :  $f_{sk} = 420 \text{ N/mm}^2$

Modulus of elasticity :  $E_s = 210 \text{ kN/mm}^2$

**4.3 Structural steel** [4.2.3]

Nominal steel grade : **Fe 360**

Nominal yield strength :  $f_y = 235 \text{ N/mm}^2$  ( $t \leq 40 \text{ mm}$ )

Modulus of elasticity :  $E_a = 210 \text{ kN/mm}^2$

**4.4 Profiled steel sheeting** [4.2.4]

Nominal steel grade : **Fe 360**

Characteristic strength :  $f_{yb} = f_{yp} = 235 \text{ N/mm}^2$

Modulus of elasticity :  $E_a = 210 \text{ kN/mm}^2$

**4.5 Shear connectors**

Type : **headed studs 19 mm diameter**

Ultimate tensile strength :  $f_u = 450 \text{ N/mm}^2$

Yield strength :  $f_y = 350 \text{ N/mm}^2$

4.6 Partial safety factors  $\gamma_M$  [4.3]

4.6.1 Ultimate limit states

Structural steel  $\gamma_a = 1.10$

Profiled steel sheeting  $\gamma_{ap} = 1.10$

Concrete  $\gamma_c = 1.50$

Steel reinforcement  $\gamma_s = 1.15$

Shear connectors  $\gamma_v = 1.25$

4.6.2 Serviceability limit states

$$\gamma_M = 1.0$$

5. DESIGN MOMENT AND SHEAR

5.1 Construction stage



Loading

$$\begin{aligned} \gamma_G \cdot (g'_k + g''_k + g'''_k) + \gamma_Q \cdot q''_k &= 1.35 \cdot (8.00 + 0.50 + 0.80) + 1.50 \cdot 2.5 = \\ &= 16.3 \text{ kN/m} \end{aligned}$$

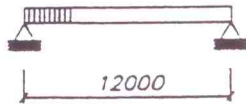
**At midspan section (maximum bending moment)**

$$M_{Sd} = 16.3 \cdot 12^2 / 8 = 293.5 \text{ kNm}$$

**At supports**

$$V_{Sd} = 16.3 \cdot 12 / 2 = 97.8 \text{ kN}$$

## 5.2 Composite stage



$$q_d = 32.05 \text{ kN/m}$$

$$\gamma_G \cdot \Sigma g_k + \gamma_Q \cdot (q'_k + q''_k) = 1.35 \cdot (8.00 + 0.50 + 0.80 + 3.33) + 1.50 \cdot (3.33 + 6.67) = 32.05 \text{ kN/m}$$

**At midspan section (maximum bending moment)**

$$M_{Sd} = 32.05 \cdot 12^2 / 8 = 576.9 \text{ kNm}$$

**At supports**

$$V_{Sd} = 32.05 \cdot 12 / 2 = 192.3 \text{ kN}$$

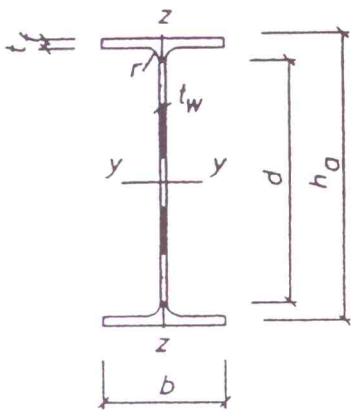
## 6. ULTIMATE LIMIT STATE VERIFICATION [6.]

### 6.1 Construction stage

#### 6.1.1 Cross-section properties

**Cross section classification [6.1.4]**

A cross section is classified according to the least favourable class of its steel elements in compression.



**IPE 450**

$$\begin{aligned} h_a &= 450.0 \text{ mm} \\ d &= 378.8 \text{ mm} \\ b &= 190.0 \text{ mm} \\ t_f &= 14.6 \text{ mm} \\ t_w &= 9.4 \text{ mm} \\ r &= 21.0 \text{ mm} \\ A_a &= 9880 \text{ mm}^2 \\ I_{a,y} &= 33740 \cdot 10^4 \text{ mm}^4 \\ W_{el,y} &= 1500 \cdot 10^3 \text{ mm}^3 \\ W_{pl,y} &= 1702 \cdot 10^3 \text{ mm}^3 \\ i_y &= 185 \text{ mm} \\ i_z &= 41.2 \text{ mm} \end{aligned}$$

### Upper flange

$$(b/2)/t_f = 95/14.6 = 6.51$$

$$\varepsilon = 1 \quad (\text{Fe 360})$$

$$6.51 < 10\varepsilon = 10$$

and therefore the flange is in Class 1

### Web

$$d/t_w = 378.8/9.4 = 40.3$$

$$\varepsilon = 1 \quad (\text{Fe 360})$$

$$40.3 < 72\varepsilon = 72$$

and the requirements for Class 1 cross-section are satisfied.

#### **6.1.2 Plastic resistance moment of the section**

$$\begin{aligned} M_{\text{ap1,Rd}} &= f_y \cdot W_{\text{pl}} / \gamma_a = (235 \cdot 1702 \cdot 10^3 / 1.10) \cdot 10^{-6} = \\ &= 363.6 \text{ kNm} > M_{\text{Sd}} = 293.5 \text{ kNm} \end{aligned}$$

and the verification is satisfied.

#### **6.1.3 Vertical shear**

$$V_{\text{pl,Rd}} = A_v \cdot (f_y / \sqrt{3}) / \gamma_a = [4399.2 \cdot (235 / \sqrt{3}) / 1.10] \cdot 10^{-5} = 542.6 \text{ kN}$$

where

$$A_v = 1.04 \cdot h_a \cdot t_w = 4399.2 \text{ mm}^2$$

$$V_{\text{pl,Rd}} = 542.6 \text{ kN} > V_{\text{Sd}} = 97.8 \text{ kN}$$

### Shear buckling

$$d/t_w = 40.3 < 69\varepsilon = 69$$

and therefore the steel web is verified.

#### **6.1.4 Bending and vertical shear**

As the beam is subject to uniform load it is not necessary to check for coincident moment and shear.

### 6.1.5 Lateral-torsional buckling of the steel beam

It is assumed that the steel beam is laterally restrained by the steel sheeting during construction. In order to provide restraint, the sheeting is fixed to the beam either by the action of through-deck welding, or by shot-fired pins.

## 6.2 Composite stage

### 6.2.1 Cross-section properties [6.1.2]

**Effective width of concrete flange:** [6.1.3]

$$b_{eff} = 2 \cdot 12000 / 8 = 3000 \text{ mm}$$

**Cross section classification**

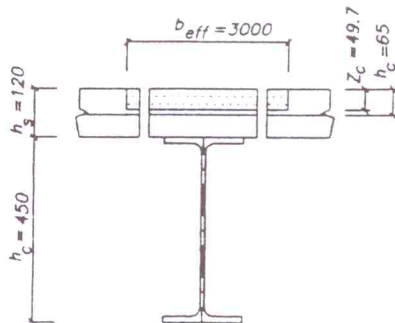
Upper flange **Class 1** from calculation in 6.1.1.

### 6.2.2 Plastic resistance moment of the section with full shear connection [6.2.1-2]

From equilibrium of longitudinal forces:

$$\begin{aligned} 0.85 \cdot f_{ck} \cdot b_{eff} \cdot h_c / \gamma_c &= (0.85 \cdot 25 \cdot 3000 \cdot 65 / 1.5) \cdot 10^{-3} = \\ &= 2762.5 \text{ kN (concrete slab)} \end{aligned}$$

$$f_y \cdot A_a / \gamma_a = 235 \cdot 9880 / 1.10 = 2111 \text{ kN (steel beam)}$$



The plastic neutral axis lies in the slab; in this case the depth ( $z_c$ ) of the neutral axis is given by:

$$z_c = (f_y \cdot A_a / \gamma_a) / (0.85 \cdot f_{ck} \cdot b_{eff} / \gamma_c) = 49.7 \text{ mm}$$

