draft
Composite structures
5
Composite joints

5.3.2 Calculation methodology

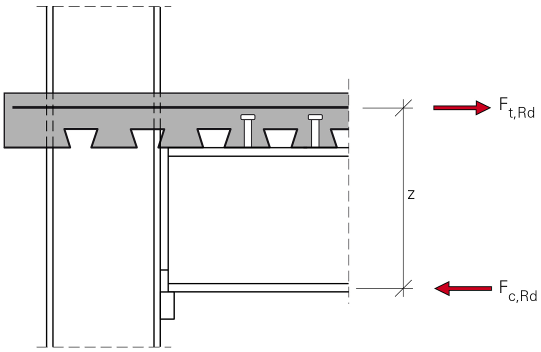
The calculation methodology for a composite joint consists of three phases:

phase 1: determining the components that contribute to strength and stiffness;

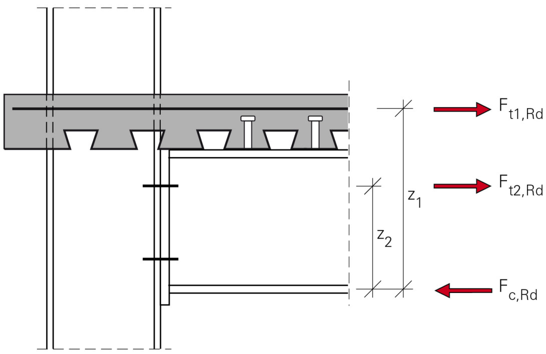
phase 2: determining the properties of these components (see section 5.3.1);

phase 3: assembling the components to determine the properties of the complete joint.

The procedure is explained below for two relatively uncomplicated joints, namely a joint with a contact plate (fig. 5.24) and a joint with an end-plate (fig. 5.25). The moment resistance $M_{j,Rd}$ and the initial stiffness $S_{j,ini}$ are determined for both joints.



5.24 Beam-to-column joint with a contact plate.



5.25 Beam-to-column joint with an end-plate.

Joint with contact plate: moment resistance
The relevant components (identified by the letter C) of this joint, with reference to clauses in EN 1994-1-1, are listed in table 5.26.
Assuming that the resistance of the shear panel is insufficient, the moment resistance of the joint can be determined by:

$$M_{j,Rd} = F_{min,Rd}z \qquad (5.2)$$

Where:
$F_{min,Rd}$ lower value of $F_{t,Rd}$ and $F_{c,Rd}$;
$F_{t,Rd}$ tension resistance of the reinforcement;
$F_{c,Rd}$ resistance of the critical component in the compression zone;
z internal lever arm for $F_{t,Rd}$ and $F_{c,Rd}$.

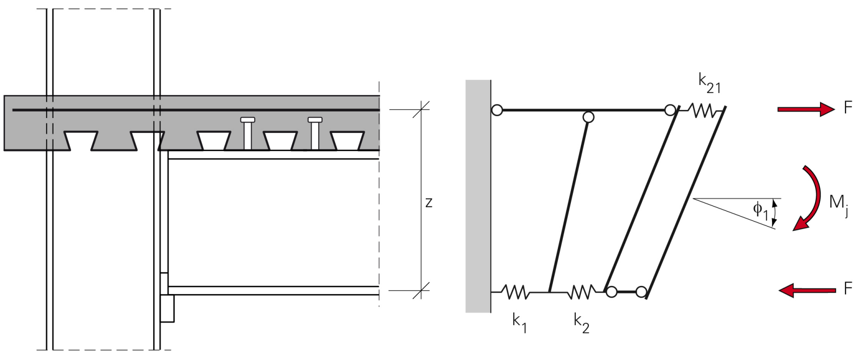
5.26 Relevant components for a joint with a contact plate connection.

resistance	component	reference	EN clause
tension resistance $F_{t,Rd}$	reinforcement in composite slab	C21	EN 1994-1-1, cl. 8.4.2.1
resistance of shear panel $V_{wp,Rd}$	column web in shear, not encased	C1	EN 1993-1-8, cl. 6.2.6.1
	column web in shear, encased	C1	EN 1994-1-1, cl. 8.4.4.1
compression resistance $F_{c,Rd}$	column web in compression	*C2*	EN 1993-1-8, cl. 6.2.6.1 EN 1994-1-1, cl. 8.4.3
	beam flange in compression	*C2*	EN 1993-1-8, cl. 6.2.6.7
	contact plate in compression	*C7*	EN 1994-1-1, cl. 8.4.2.2

Joint with contact plate: stiffness
The elastic behaviour of each component is modelled as a spring, and the initial rotational stiffness of the joint $S_{j,ini}$ is derived from the elastic spring stiffnesses of the components. The relationship between the force in a spring (F_i) and the displacement (w_i) is given by:

$$F_i = E_a k_i w_i \qquad (5.3)$$

The spring model for a joint with a contact plate is shown in figure 5.27. Separate stiffnesses can be determined for the shear panel in the column web (k_1), the column web in compression (k_2), and the reinforcement in tension (k_{21}). It is assumed that the contact plate itself is infinitely rigid.



5.27 Spring model for a joint with a contact plate.

The force in each spring is equal to F, so the moment M_j based on the spring model is equal to F·z, where z is the internal lever arm. This lever arm is equal to the distance from the centre of the reinforcement to the centreline of the bottom flange.
The rotation ϕ_j of the joint is equal to $(w_1 + w_2 + w_3)/z$. The stiffness of the joint is therefore given by:

$$S_{j,ini} = \frac{M_j}{\phi_j} = \frac{Fz}{\sum \frac{w_i}{z}} = \frac{Fz^2}{\frac{F}{E_a} \sum \frac{1}{k_i}} = \frac{E_a z^2}{\sum \frac{1}{k_i}} \qquad (5.4)$$

Where:
M_j moment in the joint (Nmm);
ϕ_j rotation of the joint (rad);
F force in the spring (and the corresponding components) (N);
w_i deflection of the spring (mm);
E_a modulus of elasticity of steel (N/mm^2);
k_i coefficient of stiffness for component i (mm);
z distance from the centre of the reinforcement to the line gravity of the bottom flange (mm);
$S_{j,ini}$ initial stiffness of the joint (Nmm/rad).

Joint with end-plate: moment resistance
The relevant components (identified by the letter C) of this joint, with reference to the relevant clauses in EN 1994-1-1, are listed in table 5.28.

5.28 Relevant components for a joint with an end-plate connection.

resistance	component	reference	EN clause
tensile resistance $F_{t1,Rd}$	reinforcement in composite slab	C21	EN 1994-1-1, cl. 8.4.2.1
tensile resistance $F_{t2,Rd}$	column web in tension	C3	EN 1993-1-8, cl. 6.2.6.3
	column flange in transverse bending	C4	EN 1993-1-8, cl. 6.2.6.4
	end-plate in bending	C5	EN 1993-1-8, cl. 6.2.6.5
	bolts in tension	C10	EN 1993-1-8, cl. 6.2.6.4 and cl. 6.2.6.5
	beam web in tension	C8	EN 1993-1-8, cl. 6.2.6.8
resistance shear panel $V_{wp,Rd}$	column web in shear, not encased	C1	EN 1993-1-8, cl. 6.2.6.1
	column web in shear, encased	C1	EN 1994-1-1, cl. 8.4.4.1
compression resistance $F_{c,Rd}$	column web in compression	C2	EN 1993-1-8, cl. 6.2.6.2 EN 1994-1-1, cl. 8.4.3
	beam flange in compression	C7	EN 1993-1-8, cl. 6.2.6.7

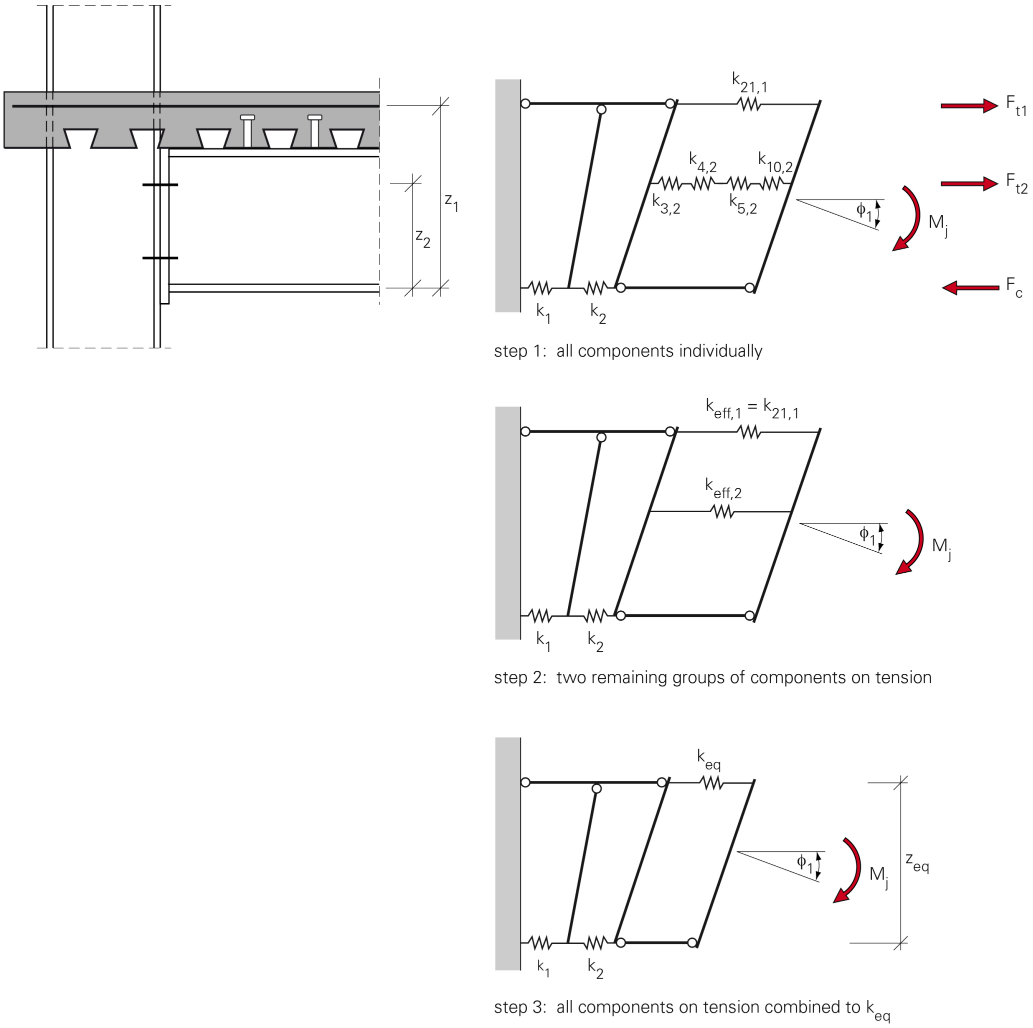
If it is assumed that the tension zone is critical ($F_{c;Rd} > F_{t1,Rd} + F_{t2,Rd}$) – this could be achieved by adding a stiffener between the column flanges – the moment resistance of the joint is determined by:

$$M_{j,Rd} = F_{t1,Rd}\, z_1 + F_{t2,Rd} z_2 \qquad (5.5)$$

When the compression zone is critical, the forces in the bolts, and possibly in the reinforcement, are reduced on the basis of equilibrium and the moment can be calculated similar to equation (5.5).

End-plate joint: stiffness

Figure 5.29 shows the spring model for an end-plate joint. In this case tension resistance is not only provided by the reinforcement, but also by the upper row of bolts. In the subscripts, the number after the comma indicates the bolt row. Table 6.10 of EN 1993-1-8 indicates which stiffness coefficients shall been taken into account. It is assumed that the deformations are proportional to the distance from the centroid of the compression zone, and that the forces are determined by the stiffnesses of the components. Step 2 in figure 5.29 shows how the deformations at bolt row 2 due to the column web in tension ($k_{3,2}$), the column flange in bending ($k_{4,2}$), the end-plate in bending ($k_{5,2}$) and the bolts in tension ($k_{10,2}$) can be combined into one spring with an effective stiffness $k_{eff,2}$. Finally, step 3 shows how these effective springs at different levels are replaced by one equivalent spring at a distance z_{eq} from the centroid of the compressive zone.



5.29 Spring model for a joint with an end-plate.

The effective stiffness coefficient can be determined with:

$$k_{eff,r} = \frac{1}{\sum_i \frac{1}{k_{i,r}}} \qquad (5.6)$$

Where $k_{i,r}$ is the stiffness coefficient of component i in the bolt row or reinforcement layer r. The equivalent stiffness coefficient k_{eq} follows from:

$$k_{eq} = \frac{\sum_r k_{eff,r} h_r}{z_{eq}} \qquad (5.7)$$

Where:
h_r distance between the force in layer or row r and the centre of the compression zone;
$k_{eff,r}$ effective stiffness coefficient i in bolt row r or reinforcement layer r.

In the case of multiple layers of reinforcement, or multiple rows of bolts, all layers or rows must be treated as separate components. The equivalent lever arm z_{eq} can be determined with:

$$z_{eq} = \frac{\sum_r k_{eff,r} h_r^2}{\sum_r k_{eff,r} h_r} \quad (5.8)$$

The stiffness of a bolted end-plate joint is given by:

$$S_{j,ini} = \frac{E_a z_{eq}^2}{\sum_i \frac{1}{k_{i,com}} + \frac{1}{k_{eq}}} \quad (5.9)$$

Where:
E_a modulus of elasticity of steel(N/mm^2);
$k_{i,com}$ stiffness coefficient of component i in compression (mm).