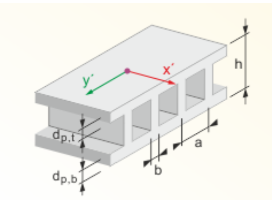
Bending Components	Shear Components	Membrane Components
$D_{11} = \dfrac{EI_{xx'}}{a(1-\nu^2)}$	$D_{44} = \dfrac{5}{6} G \dfrac{2I_x}{a} t$	$D_{66} = \dfrac{EA_{x'}}{a(1-\nu^2)}$
$D_{22} = \dfrac{EI_{yy'}}{1-\nu^2}$	$D_{55} = \dfrac{5}{6} Gt$	$D_{77} = \dfrac{EA_{y'}}{1-\nu^2}$
$D_{12} = \nu D_{22}$		$D_{67} = \nu D_{77}$
$D_{33} = GI_k$		$D_{88} = G(d_p - b)$

Table 3.7: Stiffness coefficients of orthotropy type *Coupling*

3.2.6 Unidirectional Box Floor



Access

Accessing this model can be done from the *Edit Surface - Orthotropic* dialog and choosing *Unidirectional box floor* under Orthotropy Type on the left, see Figure 3.20.

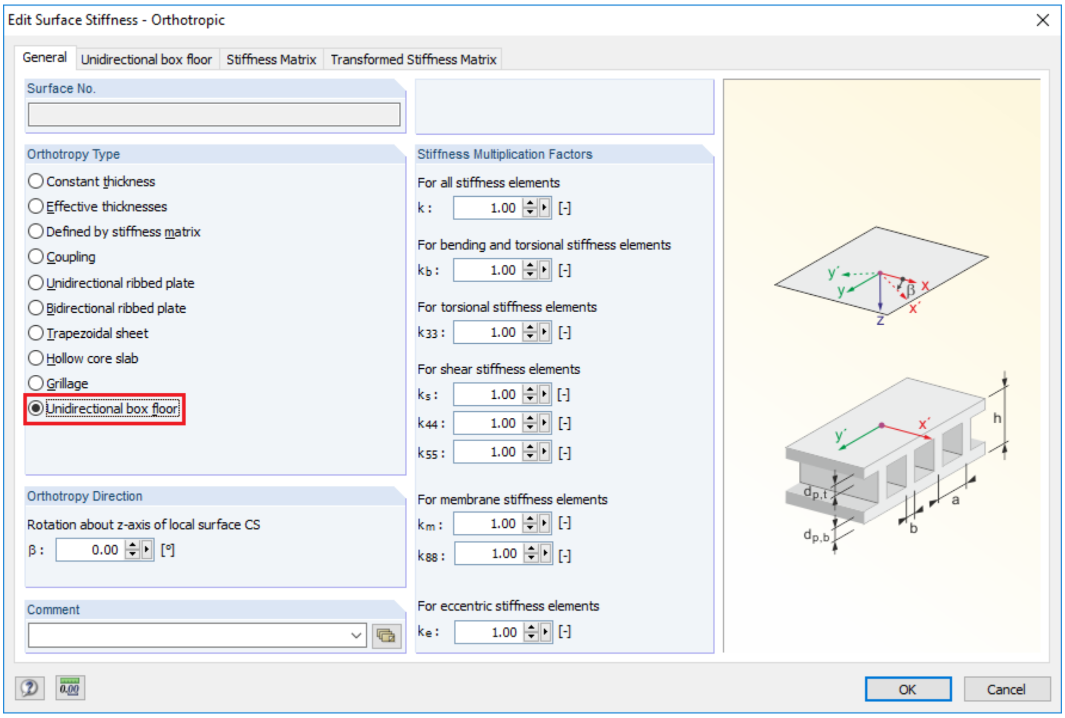


Figure 3.20: Accessing *Unidirectional box floor* material model via *Edit Surface Stiffness - Orthotropy* dialog

Description

The model represents a unidirectionally spanning constant thickness slab along the longitudinal direction of which rectangular openings (voids) have been protruded as a measure of self-weight reduction.

The geometric properties for this model, which are to be found under the *Unidirectional box floor* tab in the *Edit Surface - Orthotropic material* dialog, have the following format

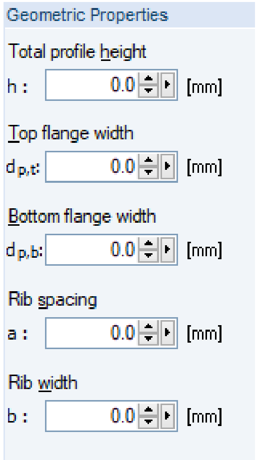


Figure 3.21: Dialog section *Geometric Properties*

The following geometrical restrictions apply

1. $\mathrm{h} > 0, \quad \mathrm{d}_{\mathrm{p,t}} > 0, \quad \mathrm{d}_{\mathrm{p,b}} > 0, \quad \mathrm{b} > 0, \quad \mathrm{a} > 0$
2. $\mathrm{d}_{\mathrm{p,t}} + \mathrm{d}_{\mathrm{p,b}} < \mathrm{h}$

ensuring that a rectangular void is fully integrated within a unit cell (I-beam cross-section).

Stiffness matrix coefficients

The stiffness matrix coefficients are given as

Bending Components	Shear Components	Membrane Components
$D_{11} = \dfrac{EI_{xx'}}{a(1-\nu^2)}$	$D_{44} = \dfrac{GA_{x'}}{a\beta_{x'}}$	$D_{66} = \dfrac{EA_{x'}}{a(1-\nu^2)}$
$D_{22} = \dfrac{EI_{yy'}}{1-\nu^2}$	$D_{55} = \dfrac{GA_{y'}}{\beta_{y'}}$	$D_{77} = \dfrac{EA_{y'}}{1-\nu^2}$
$D_{12} = \nu D_{22}$		$D_{67} = \nu D_{77}$
$D_{33} = GI_k$		$D_{88} = G(d_{p,t} + d_{p,b})$

Table 3.8: Stiffness coefficients of orthotropy type *Unidirectional box floor*

- $A_{x'}, A_{y'}$ = gross cross-sectional area in the correcponding direction, namely
$$A_{x'} = a \cdot (d_{p,t} + d_{p,b}) + b \cdot (h - d_{p,t} - d_{p,b}), \quad A_{y'} = 1 \cdot (d_{p,t} + d_{p,b}) \tag{3.44}$$
- $I_{xx'}, I_{yy'}$ = second moments of area of the corresponding unit I-cross-section
- I_k = torsional constant of the corresponding unit I-cross-section approximated as the sum of the torsional constant of the two flanges and the web, cf. (3.10)–(3.11)
- $\beta_{x'}, \beta_{y'}$ = Jurawski–Grashof shear coefficients of the corresponding unit I-cross-section

Model limitations

- Orthotropic material is not allowed to be used. This model allows the use of only linear elastic isotropic material. If concrete is the representative slab material, a Poisson ratio of 0.2 is recommended.
- Material remains fully elastic and fully uncracked, i.e., both tension and compression zones remain fully active. If concrete is to be used, we should regard this state as Concrete State I. Reinforcement effects are ignored, but could be approximately taken into account via the stiffness matrix modification factors.

- Only circular voids, symmetrically located about the statical neutral axis of the slab are allowed.
- Variable void spacing is not allowed.

Plate theory applicability – both Kirchhoff and Mindlin.

Analysis types applicable – I., II., and III. order in combination with geometrical nonlinearities only. Linear bending elastic static analysis uses the herein generated stiffness matrix coefficients. Membranes, second and third order analysis require as an additional parameter the equivalent thickness for self-weight computation d in order to form the geometrical sitffness matrix (also used in instability analysis), large displacement and rotation stiffnesses, membrane effects and soil–structure interaction. Material nonlinearity such as plasticity is not possible.

Material types applicable – Isotropic material only.

Orthotropic direction and angle β – can be applied and manually set by the user via the *Edit Surface - Orthotropic* dialog.

Stiffness reduction factors – all types of stiffness reduction factors applicable, cf. Section 2.2.5, and also editable in the *Edit Surface - Orthotropic* dialog.

Equivalent thickness for self-weight computation – the value of d is automatically computed by RFEM as

$$d = \frac{A_{x'}}{a} \tag{3.45}$$

It can be also user-editable via the d or wt options in the *Edit Surface* dialog box.

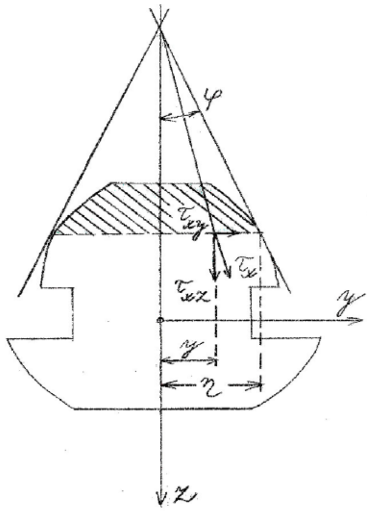


Figure 3.7: Definition of first statical moment of area

- $I^{\star}_{yy'}$ = second moment of area of a unit cross-section of width $1/(1-\nu^2)$ along the $y-y$ axis, but partially accounting for the discontinuously interacting ribs in the x-direction via

$$I^{\star}_{yy'} = \frac{ad_p^3}{12(1-\nu^2)\psi}, \quad \psi = a + b\left(\left(\frac{d_p}{d_r + d_p}\right)^3 - 1\right) \tag{3.7}$$

  The correction factor was proposed by Timoshenko & Woinowsky-Krieger [1]. Note that $\psi \to a$ for $d_r \to 0$, in which case $I^{\star}_{yy'} \to \frac{ad_p^3}{12(1-\nu^2)}$, i.e., the second moment of area of a constant-thickness plate of unit width.

  The introduction of the Poisson ratio is due to the anticlastic effect provided by the plate, as the T-beam flange remains continuous thorughout the whole surface. Thus it can be considered to have a stiffenning effect.

- $A^{\star}_{xx'}$ = cross-sectional area resisting the y-directional membrane force

$$A^{\star}_{xx'} = \frac{Ead_p}{1-\nu^2} \tag{3.8}$$

- $\beta_{y'}$ = Jurawski–Grashof coefficient of a unit cross-section of width 1 along the y-axis

$$\beta_{y'} = \frac{6}{5} = 1.2 \tag{3.9}$$

- I_k = torsional constant of the unidirectional ribbed plate, being the sum of the torsional rigidities of the slab $I_{k,slab} = \frac{d_p^3}{12}$ and the rib in the longitudinal x-direction $I_{k,rib} = \frac{k_1 C_{rib}}{4a}$, where C_{rib} is the x-directional torsional stiffness of the rib and k_1 its correction factor. The latter is the solution of the governing torsional equation for a rib, given by Timoshenko & Goodier [2], depending on the ratio of the rib height h and its width t, as

$$C_{rib} = k_1 h t^3, \quad k_1 = \frac{1}{3}\left(1 - \frac{192}{\pi^5}\frac{t}{h}\sum_{n=1,2,5,\ldots}\frac{1}{n^5}\tanh\frac{nh\pi}{2t}\right) \quad \text{if } h \geq t, \tag{3.10}$$

$$C_{rib} = k_1 t h^3, \quad k_1 = \frac{1}{3}\left(1 - \frac{192}{\pi^5}\frac{h}{t}\sum_{n=1,2,5,\ldots}\frac{1}{n^5}\tanh\frac{nt\pi}{2h}\right) \quad \text{if } h < t, \tag{3.11}$$

  RFEM calculates k_1 iteratively until a convergence in the sense that $\frac{k_{1,n}-k_{1,n-1}}{k_{1,n}} \leq \varepsilon = 10^{-5}$ is achieved, where n and $n-1$ denote two consecutive approximations. On the other hand, an approximate expression is was also given by Roark, see [3], and could be used for a quick hand-calculation

$$C_{rib} = ht^3\left[\frac{1}{3} - 0.21\frac{t}{h}\left(1 - \frac{t^4}{12h^4}\right)\right] \quad \text{for } h \geq t \tag{3.12}$$