How to define the beam-plate interaction?

1. What does an eccentricity do?

- When the beam has no eccentricity (see Model 1 below): the rigidity of the plate will locally be increased with the rigidity of the beam (= the sum of both rigidities).
- When the beam has an eccentricity (see Model 2 below): the beam and plate will work together as a T-section. The rigidity of this composed section will be higher than the sum of both rigidities.

In order to illustrate this, we compare the load distribution towards the end support lines and the centreline in 4 beam-plate models$^1$.

- Model 1: a beam in the middle, not eccentric
- Model 2: same beam in the middle, eccentric
- Model 3: no beam in the middle (or a beam with a very low stiffness in comparison to the plate)
- Model 4: a support line in the middle. The plates will behave as perfectly continuous.

The load distribution towards each part is expressed in percent [%].

<table>
<thead>
<tr>
<th>Model 1</th>
<th>Model 2</th>
</tr>
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<tbody>
<tr>
<td>22.5%-55%-22.5%</td>
<td>20%-60%-20%</td>
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</table>

<table>
<thead>
<tr>
<th>Model 3</th>
<th>Model 4</th>
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<tbody>
<tr>
<td>43.5%-13%-43.5%</td>
<td>20%-60%-20%</td>
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</table>

Conclusion:

- As expected, the beam in Model 2 acts stiffer then in Model 1. The beam in Model 2 draws more force to itself, then the beam in Model 1.
- With increasing beam stiffness, Models 1 and 2 will behave like Model 4. With decreasing beam stiffness, Models 1 and 2 will behave like Model 3.
- The percentages may vary depending on the length/width ratio of the plates and the plate type (1 directional, 2 directional, preslabs, ...).

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$^1$ 9 x 5.5m, 1R slab of 0.2m thick, simply supported on two opposite sides, 10kN/m$^3$
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2. Practical examples

2.1. Summary

The purpose of this paragraph is to give you an overview of common modelling problems regarding beam-plate interaction. Keep in mind that forces are not only transferred between beams mutually and plates mutually, but also between beams and plates! We strive to approach the stiffness and load transfer as well as possible. As you will notice, each approach has its pro’s and con’s.

In all cases below: both the beam reinforcement AND the plate reinforcement should be placed!

<table>
<thead>
<tr>
<th>REALITY</th>
<th>DIAMONDS</th>
<th>WITHOUT ECCENTRICITIES</th>
<th>WITH ECCENTRICITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1: Continuous plate, simply supported on beam</td>
<td></td>
<td>License 2D slabs required</td>
<td>License 2D slabs + 2D plates required</td>
</tr>
<tr>
<td><img src="image1.png" alt="Diagram" /></td>
<td><img src="image2.png" alt="Diagram" /></td>
<td><img src="image3.png" alt="Diagram" /></td>
<td><img src="image4.png" alt="Diagram" /></td>
</tr>
<tr>
<td>Note: this configuration makes only sense for a beam BETWEEN 2 plates! Not for a beam at the edge of a plate.</td>
<td></td>
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</tr>
<tr>
<td>Beam height = h</td>
<td>Top beam = bottom plate</td>
<td>Top beam = bottom plate</td>
<td></td>
</tr>
<tr>
<td>Disable moment transfer on bar ends if you want simply supported behaviour.</td>
<td>Allow only transfer of N in rigid links.</td>
<td>Allow only transfer of N in rigid links.</td>
<td></td>
</tr>
<tr>
<td>⚠️ Easy modelling</td>
<td>⚠️ Complex modelling</td>
<td></td>
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</tbody>
</table>

Case 2: Discontinuous plates, simply supported on beam

<table>
<thead>
<tr>
<th>REALITY</th>
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<th>WITH ECCENTRICITIES</th>
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<td><img src="image11.png" alt="Diagram" /></td>
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<td><img src="image13.png" alt="Diagram" /></td>
<td><img src="image14.png" alt="Diagram" /></td>
<td><img src="image15.png" alt="Diagram" /></td>
<td><img src="image16.png" alt="Diagram" /></td>
</tr>
</tbody>
</table>

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Case 3: Beam and plate poured together

- Top beam = bottom plate
  - Option 1: allow only transfer of N in rigid links.
  - Beam height = h
  - Allow only transfer of V along the plate edges
  - Disable moment transfer on bar ends if you want simply supported behaviour.

- Top beam = top plate
  - Option 2: allow only transfer of V along the plate edges
  - Disable moment transfer on bar ends if you want simply supported behaviour.

- Complex modelling
- Border effects
- High risk of instabilities

- Beam = T or L-section with total height H. An R-section would underestimate the stiffness.
- Effective width determined using EN 1992-1-1 §5.3.2.1.
- Beam height = H
- Easy modelling (more additional work to calculate the effective widths)
  - Bending moment can still be transferred from the plates to the beam. This will give torsion in the beams. Setting the torsional stiffness $J_t$ of the beams to a small value, will eliminate the torsion, but with the risk of large (angular) deformation.
  - Higher self-weight because of double section, but compensated by larger compression zone.

- Easy modelling
- Axial forces will occur in beams and plates!
  - Turn off the buckling check in eccentric beams (uncheck the checkboxes before the buckling lengths).

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2.2. Comparison between the methods of modelling

Regardless what approach you choose (with or without eccentricities), you expect similar results between both approaches. In this paragraph we compare both approaches using a realistic 2D-plate model (preslabs 200/50, beams R150/350, 15kN/m²) and mention some points of attention.

2.2.1. Case1: continuous plate, simply supported on beam

- The bending moment in the field is indeed comparable.
- A retaining moment occurs in the model without eccentricities, because the plates can still transfer forces to the beam and because of a border effect.

The border effect arises because of the compatibility of the deformations: the plate itself remains bearing in 2 directions. The deformation that the plate undergoes along the 4 orange cut lines, must remain compatible. This is not always that easy, resulting in ‘abnormalities’ in the internal forces. ‘Abnormalities’ is between quotation marks, because the border effects are something you don’t expect, but they are normal in this type of modelling. The only approach were they can be eliminated, is 1D modelling and simple load descent like in hand calculations. But hand calculations make a lot of simplifications, in a way that they are sometimes not comparable to the reality, while Diamonds shows a more realistic behaviour.
2.2.2. Case 2: discontinuous plate, simply supported on beam

- The bending moment in the field is indeed comparable.
- In both models border effects can be found. Again the border effects arise because of the compatibility of the deformations: although you applied hinges, the plate itself remains bearing in 2 directions. The deformation that the plate undergoes along the 4 orange cut lines, must remain compatible. This is not always that easy, resulting in ‘abnormalities’ in the internal forces. ‘Abnormalities’ is between quotation marks, because the border effects are something you don’t expect, but they are normal in this type of modelling. The only approach were they can be eliminated, is 1D modelling and simple load descent like in hand calculations. But hand calculations make a lot of simplifications, in a way that they are sometimes not comparable to the reality, while Diamonds shows a more realistic behaviour.
Note: for beams along the edge of a plate, it doesn’t matter if you apply the hinges on the border of the plate or on the rigid link. Both give similar results.

2.2.3. Case 3: beam and plate poured together

In this modelling, it hard to compare the internal forces. Both models do not have the same self-weight and axial forces will occur in the eccentricity model. So the cracked deformation (+ creep + extend theory to axial forces) is used to compare the stiffness between the two models.
In the image above we see that the 2 modelling approaches (with or without eccentricities) give similar results, yet not entirely the same. This is because it is hard to estimate/calculate the effective widths of the T- and L-sections.

Out of curiosity, let us add a model in which non-eccentric R-sections are used. While we had a maximum cracked deformation after creep of 18.7mm (see previous image), we now find a maximum of 31.2mm. Confirming the statement that using a non-eccentric R-section to simulate beam-plate poured together will underestimate the stiffness of the beams.
3. Non-standard eccentricities

The button  allows standard cases of eccentricities, like:

For non-standard eccentricities like the examples below, the button  should be used.

- Draw the elements (plate(s) and beam) on the correct level. Use the plate and beam axis to determine these levels, and thus the correct length of the rigid links.
- At the locations of the rigid links: draw a line, select the line and click on . The black continuous line you selected will be a dashed pink line now.
- The torsion effect is in the rigid links and will go to waste.
- This type of modelling is only advised for smaller models, not for large 3D projects.

Note: if plates are in different levels, you’ll need a 2D Plates + 3D Plates license!