Benchmark Example No. 11

Shear at the interface between concrete cast
VERIFICATION
DCE-EN11 Shear at the interface between concrete cast

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The user of the program is solely responsible for the applications. We strongly encourage the user to test the correctness of all calculations at least by random sampling.

Front Cover
Project: Queensferry Crossing | Photo: Bastian Kratzke
1 Problem Description

The problem consists of a T-beam section, as shown in Fig. 1. The cross-section is designed for shear, the shear at the interface between concrete cast at different times is considered and the required reinforcement is determined.

![Figure 1: Problem Description](image)

2 Reference Solution

This example is concerned with the shear design of T-sections, for the ultimate limit state. The content of this problem is covered by the following parts of DIN EN 1992-1-1:2004 [1]:

- Design stress-strain curves for concrete and reinforcement (Section 3.1.7, 3.2.3)
- Guidelines for shear design (Section 6.2)

![Figure 2: Indented Construction Joint - Examples of Interfaces](image)

The design stress-strain diagram for reinforcing steel considered in this example, consists of an inclined top branch, as presented in Fig. 3 and as defined in DIN EN 1992-1-1:2004 [1] (Section 3.2.7).
3 Model and Results

The T-section, with properties as defined in Table 1, is to be designed for shear, with respect to DIN EN 1992-1-1:2004 (German National Annex) [1], [2]. The reference calculation steps [3] are presented in the next section and the results are given in Table 2.

Table 1: Model Properties

<table>
<thead>
<tr>
<th>Material Properties</th>
<th>Geometric Properties</th>
<th>Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>C 20/25</td>
<td>$h = 135.0 \text{ cm}$</td>
<td>$V_z = 800 \text{ kN}$</td>
</tr>
<tr>
<td>B 500A</td>
<td>$h_f = 29\text{ cm}$</td>
<td>$M_y = 2250 \text{ kNm}$</td>
</tr>
<tr>
<td></td>
<td>$d_1 = 7.0 \text{ cm}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$b_w = 40 \text{ cm}$, $b_{eff} = 250 \text{ cm}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$A_{s1} = 1.0 \text{ cm}^2$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$z_s = 95.56 \text{ cm}$</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Results

<table>
<thead>
<tr>
<th>$\alpha_s$ [cm²/m]</th>
<th>SOF.</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>state I</td>
<td>7.00</td>
<td>7.07</td>
</tr>
<tr>
<td>state II only $V$</td>
<td>4.86</td>
<td>4.90</td>
</tr>
<tr>
<td>state II $V + M$</td>
<td>4.99</td>
<td>4.99</td>
</tr>
</tbody>
</table>
4 Design Process

Design with respect to DIN EN 1992-1-1:2004 (NA) [1] [2].

Material:

Concrete: $\gamma_c = 1.50$

Steel: $\gamma_s = 1.15$

$f_{ck} = 25 \text{ MPa}$

$f_{cd} = a_{cc} \cdot f_{ck} / \gamma_c = 0.85 \cdot 25 / 1.5 = 14.17 \text{ MPa}$

$f_{yk} = 500 \text{ MPa}$

$f_{yd} = f_{yk} / \gamma_s = 500 / 1.15 = 434.78 \text{ MPa}$

$\sigma_{sd} = 456.52 \text{ MPa}$

$$\tau = \frac{T_y}{b_w} = \frac{V \cdot S}{I_y \cdot b_w}$$

where $S$ is the static moment of the separated area

$S = h_w \cdot b_w \cdot (z_s - h_w / 2) = 0.18058 \text{ m}^3$

$$\tau = \frac{0.8 \cdot 0.18058}{0.16667 \cdot 0.4} = 2.1669 \text{ MPa}$$

$$T_y = \frac{0.8 \cdot 0.18058}{0.16667} = 0.8676 \text{ MN/m} = 866.76 \text{ kN/m}$$

$$T_y = 866.76 / 2 = 433.38 \text{ kN/m}$$

State I:

Design Load:

$$V_{Edi} = T_y = 433.38 \text{ kN/m}$$

$$\nu_{Edi} = \tau = 2.1669 \text{ MPa}$$

$$V_{Rd,c} = \left[ C_{Rd,c} \cdot k \cdot \left(100 \cdot \rho_1 \cdot f_{ck}\right)^{1/3} + 0.12 \cdot \sigma_{cp} \right] \cdot b_w \cdot d$$

$$V_{Rd,c} = C_{Rd,c} \cdot k \cdot \left(100 \cdot \rho_1 \cdot f_{ck}\right)^{1/3} + 0.12 \cdot \sigma_{cp}$$

$$\rho_1 = \frac{A_{sl}}{b_w d} = 0.0 \rightarrow \nu_{Rd,c} = 0.0$$

with a minimum of

$$V_{Rd,c,min} = (\nu_{min} + 0.12 \cdot \sigma_{cp}) \cdot b_w \cdot d$$

$$V_{Rd,c,min} = \nu_{min} + 0.12 \cdot \sigma_{cp}$$

$$\nu_{min} = \left(0.0375 / \gamma_c\right) \cdot k^{3/2} \cdot f_{ck}^{1/2} = 0.20833 \text{ MPa}$$

The tools used in the design process are based on steel stress-strain diagrams, as defined in [1] 3.2.7:(2), Fig. 3.8, which can be seen in Fig. 3.

The sections mentioned in the margins refer to DIN EN 1992-1-1:2004 (German National Annex) [1], [2], unless otherwise specified.
Shear at the interface between concrete cast

6.2.5 (1): Eq. 6.23: The design shear stress at the interface should satisfy this

\( V_{Edi} \leq V_{Rdi} \)

\( V_{Rdi} = c \cdot f_{ctd} + \mu \cdot \sigma_n + \rho \cdot f_yd \cdot (1.2 \cdot \mu \cdot \sin \alpha + \cos \alpha) \)

and \( V_{Rdi} \leq 0.5 \cdot V \cdot f_{cd} \)

\( V_{Rdi, max} = 0.5 \cdot V \cdot f_{cd} = 4.9585 \, MPa \)

c = 0.50 and \( \mu = 0.9 \) for indented surface

\( f_{ctd} = 0.85 \cdot 1.80 / 1.5 = 1.02 \)

\( V_{Rdi} = 0.5 \cdot 1.02 + 0 + \frac{a_s}{0.2 \cdot 1.0} \cdot 435 \cdot (1.2 \cdot 0.9 \cdot 1 + 0) \)

\( V_{Rdi} = 0.51 + \frac{a_s}{0.2} \cdot 469.56 = 2.1669 \)

\( a_s = 7.07 \, cm^2/m \)

**State II only shear force \( V \):**

Design Load:

From the calculated inner lever arms for the two states we get a ratio:

\( \frac{z_I}{z_{II}} = 0.7664 \)

The associated design shear flow \( V_{Edi} \) is:

\( V_{Edi} = 0.7664 \cdot 433.38 = 332.15 \, kN/m \)

and \( V_{Edi} = 332.15/0.2 = 1.66 \, MPa \)

Following the same calculation steps as for state II we have:

\( V_{Rd,c} = 0.20833 \, MPa \) (as above)

\( V_{Edi} > V_{Rd,c} \rightarrow \) shear reinforcement is required

\( V_{Edi} \leq V_{Rdi} \)

\( V_{Rdi} = c \cdot f_{ctd} + \mu \cdot \sigma_n + \rho \cdot f_yd \cdot (1.2 \cdot \mu \cdot \sin \alpha + \cos \alpha) \)

\( V_{Rdi} = 0.5 \cdot 1.02 + 0 + \frac{a_s}{0.2 \cdot 1.0} \cdot 435 \cdot (1.2 \cdot 0.9 \cdot 1 + 0) \)

\( V_{Rdi} = 0.51 + \frac{a_s}{0.2} \cdot 469.56 = 1.66 \)

\( a_s = 4.90 \, cm^2/m \)
State II shear force $V$ and moment $M$:

$$M_{Eds} = 2250 \text{ kNm}$$

$$\mu_{Eds} = \frac{M_{Eds}}{b_{eff} \cdot d^2 \cdot f_{cd}} = \frac{2250 \cdot 10^{-3}}{2.5 \cdot 1.28^2 \cdot 14.17} = 0.03876$$

$$\omega = 0.03971 \text{ and } \xi = 0.9766 \text{ (interpolated)}$$

$$A_{sl} = \frac{1}{\sigma_{sd}} \cdot (\omega \cdot b \cdot d \cdot f_{cd} + N_{Ed}) = 39.44 \text{ cm}^2$$

$$z = \max\{d - c_{V,l} - 30 \text{ mm}; ~ d - 2 \cdot c_{V,l}\}$$

$$z = \max\{1160; ~ 1190\} = 1190 \text{ mm}$$

Design Load:

$$T_V = V / z = 800 / 1.19 = 672.268 \text{ kN/m}$$

$$T_V = 672.268 / 2 = 336.134 \text{ kN/m}$$

$$V_{Edi} = 336.134 \text{ kN/m}$$

and $$V_{Edi} = 336.134 / 0.2 = 1.68 \text{ MPa}$$

$$\nu_{Rd,c} = C_{Rd,c} \cdot k \cdot (100 \cdot \rho_1 \cdot f_{ck})^{1/3} + 0.12 \cdot \sigma_{cp}$$

$$C_{Rd,c} = 0.15 / \gamma_c = 0.1$$

$$k = 1 + \sqrt{\frac{200}{d}} = 1 + \sqrt{\frac{200}{1280}} = 1.3953 < 2.0$$

$$\rho_1 = \frac{A_{sl}}{b_{wd}} = \frac{39.44}{40 \cdot 128} = 0.007703 < 0.02$$

$$\nu_{Rd,c} = 0.1 \cdot 1.3953 \cdot (100 \cdot 0.007703 \cdot 25)^{1/3} + 0$$

$$\nu_{Rd,c} = 0.373229 \text{ MPa}$$

$$V_{Edi} > \nu_{Rd,c} \Rightarrow \text{ shear reinforcement is required}$$

$$\nu_{Rdi} = c \cdot f_{ctd} + \mu \cdot \sigma_n + \rho \cdot f_{yd} \cdot (1.2 \cdot \mu \cdot \sin \alpha + \cos \alpha)$$

$$\nu_{Rdi} = 0.5 \cdot 1.02 + 0 + \frac{a_s}{0.2 \cdot 1.0} \cdot 435 \cdot (1.2 \cdot 0.9 \cdot 1 + 0)$$

$$\nu_{Rdi} = 0.51 + \frac{a_s}{0.2} \cdot 469.56 = 1.68$$

$$a_s = 4.99 \text{ cm}^2/m$$
5 Conclusion

This example shows the calculation of the required reinforcement for a T-section under shear at the interface between concrete cast at different times. It has been shown that the results are reproduced with excellent accuracy. Small deviations occur because AQUA calculates (by using FEM analysis) the shear stresses more accurate compared to the reference example.

6 Literature


