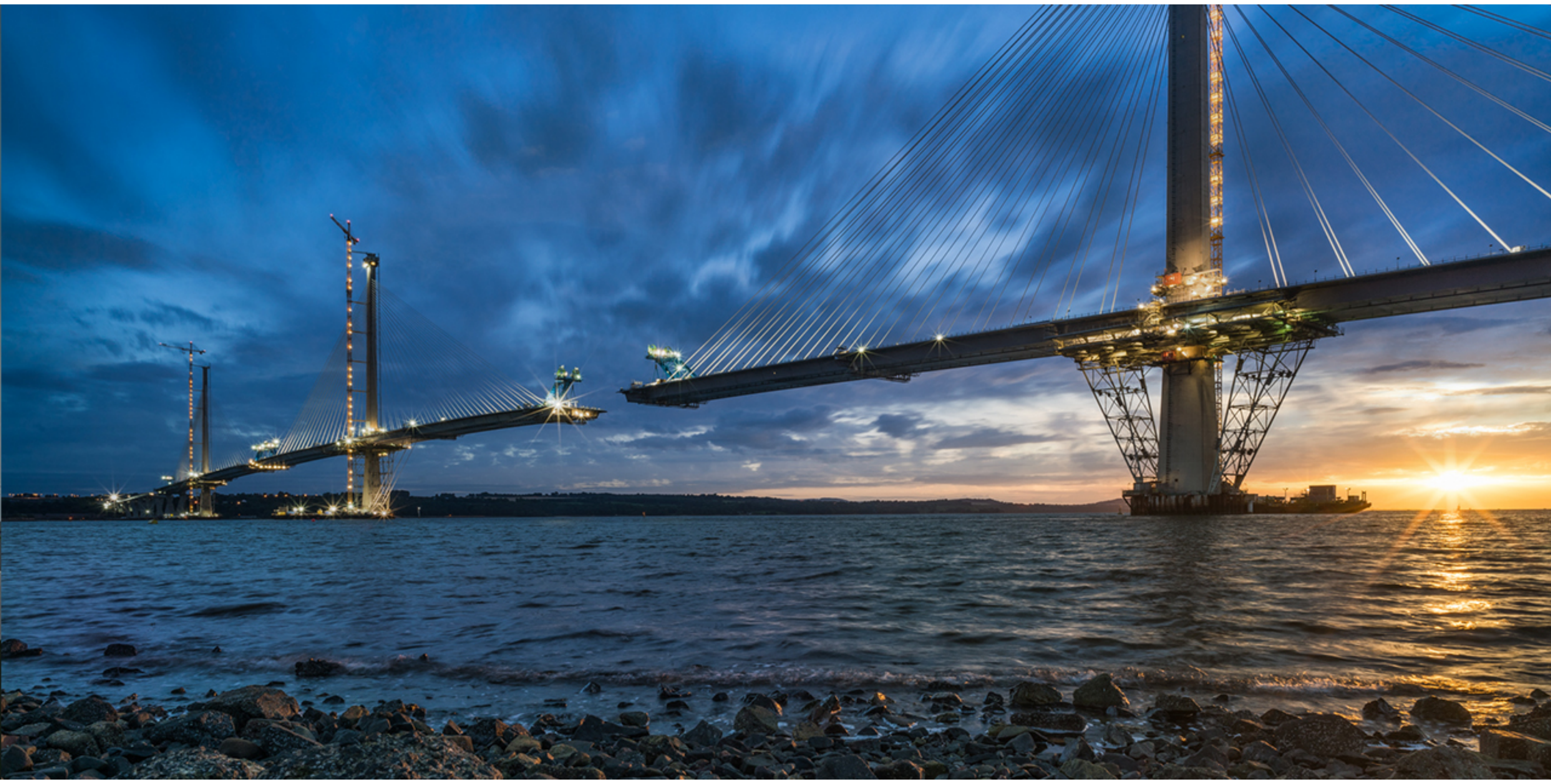

Benchmark Example No. 3

Design of a T-section for Bending

SOFiSTiK | 2020

VERiFiCATiON
DCE-EN3 Design of a T-section for Bending

VERiFiCATiON Manual, Service Pack 2020-14 Build 134

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Front Cover

Project: Queensferry Crossing | Photo: Bastian Kratzke

Overview	
Design Code Family(s):	DIN
Design Code(s):	DIN EN 1992-1-1
Module(s):	AQB
Input file(s):	t-beam_bending.dat

1 Problem Description

The problem consists of a T-beam section, as shown in Fig. 1. The cross-section is designed for an ultimate moment M_{Ed} and the required reinforcement is determined.

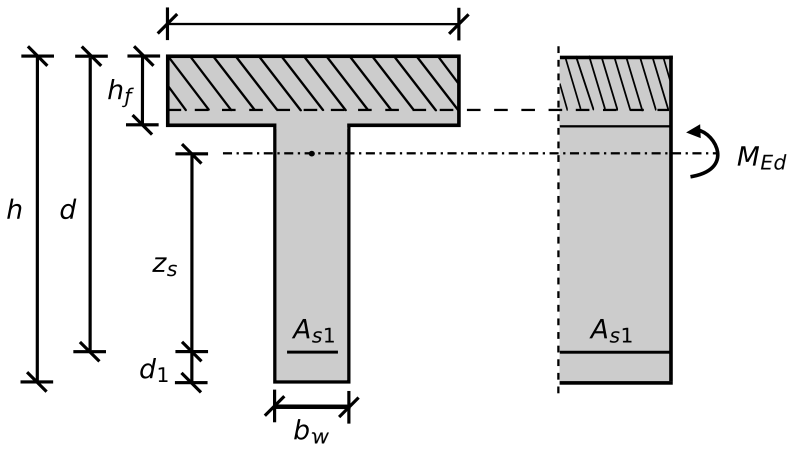

Figure 1: Problem Description

2 Reference Solution

This example is concerned with the design of sections for ULS, subject to pure flexure. 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, 3.2.7)
- Basic assumptions for section design (Section 6.1)
- Reinforcement (Section 9.3.1.1, 9.2.1.1)

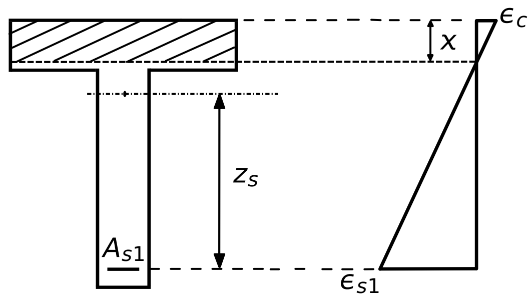

Figure 2: Stress and Strain Distributions in the Design of T-beams

In doubly reinforced rectangular beams, the conditions in the cross-section at the ultimate limit state, are assumed to be as shown in Fig. 2. 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).

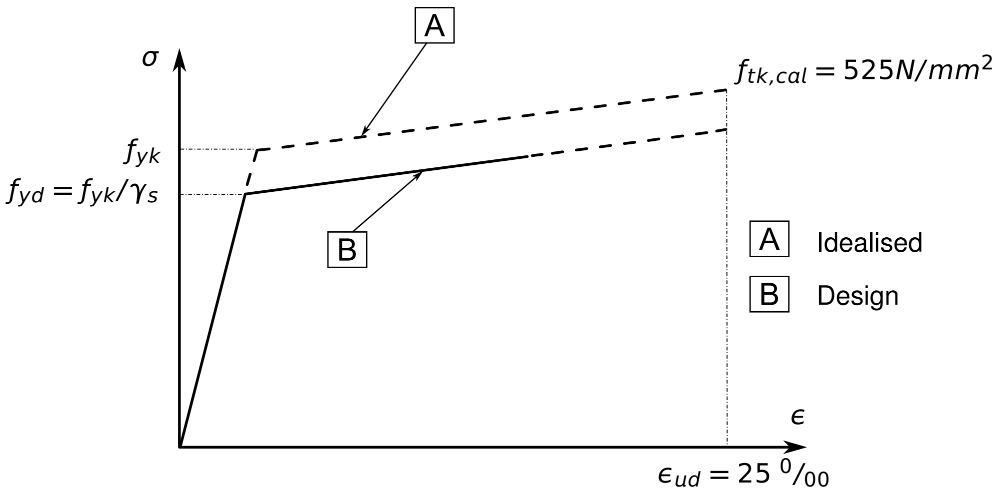

Figure 3: Idealised and Design Stress-Strain Diagram for Reinforcing Steel

3 Model and Results

The T-beam, with properties as defined in Table 1, is to be designed, with respect to DIN EN 1992-1-1:2004 (German National Annex) [1], [2], to carry an ultimate moment of $425\ kNm$. The calculation steps with different design methods [3] [4] [5] are presented below and the results are given in Table 2. Here, it has to be mentioned that these standard methods employed in order to calculate the reinforcement are approximate, and therefore deviations often occur.

Table 1: Model Properties

Material Properties	Geometric Properties	Loading
$C\,20/25$	$h = 65.0\ cm$	$M_{Ed} = 425\ kNm$
$B\,500A$	$d = 60.0\ cm$	
	$d_1 = 5.0\ cm$	
	$b = 30\ cm$	
	$b_{eff} = 258\ cm$	
	$h_f = 18\ cm$	

Table 2: Results

	SOF.	ω–Table [3]	k_d–Table [3]
$A_{s1}\ [cm^2/m]$	15.90	15.74	15.85

4 Design Process[1]

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

Material:

Concrete: $\gamma_c = 1.50$
Steel: $\gamma_s = 1.15$

(NDP) 2.4.2.4: (1), Tab. 2.1DE: Partial factors for materials

$f_{ck} = 20\ MPa$
$f_{cd} = \alpha_{cc} \cdot f_{ck}/\gamma_c = 0.85 \cdot 20/1.5 = 11.33\ MPa$

Tab. 3.1: Strength for concrete

3.1.6: (1)P, Eq. (3.15): $\alpha_{cc} = 0.85$ considering long term effects

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

3.2.2: (3)P: yield strength $f_{yk} = 500\ MPa$

3.2.7: (2), Fig. 3.8

Design Load:

$N_{Ed} = 0$

$M_{Eds} = M_{Ed} - N_{Ed} \cdot z_{s1} = 425\ kNm$

Design with respect to $\omega-$ (or μ_s-)Table for T-beams:

$$\mu_{Eds} = \frac{M_{Eds}}{b_{eff} \cdot d^2 \cdot f_{cd}} = \frac{425 \cdot 10^{-3}}{2.58 \cdot 0.60^2 \cdot 11.33} = 0.040$$

Tab. 9.4 [3]: $\omega-$Table for up to $C50/60$ - T-beam

Referring to the design table for T-beams for:

$\mu_{Eds} = 0.040$ and

$$\frac{h_f}{d} = \frac{0.18}{0.60} = 0.30; \quad \frac{b_{eff}}{b_w} = \frac{2.58}{0.30} = 8.6$$

$\rightarrow \omega_1 = 0.039$

$$A_{s1} = \frac{1}{f_{yd}} \cdot (\omega_1 \cdot b_{eff} \cdot d \cdot f_{cd} + N_{Ed}) = 15.74\ cm^2$$

Design with respect to k_d- Design Table for T-beams:

Alternatively, the k_d-Tables can be applied, demonstrated that the neutral line lies inside the flange.

$$k_d = \frac{d}{\sqrt{M_{Eds}/b}} = \frac{60}{\sqrt{425/2.58}} = 4.67$$

Tab. 9.3 [3]: k_d-Table for up to $C50/60$ - Rectangular section without compression reinforcement

Referring to the table for $k_d = 4.67$ and after interpolation

$\rightarrow k_s = 2.351; \quad \xi = 0.060\ ; \quad \kappa_s = 0.952$

$x = \xi \cdot d = 0.060 \cdot 60 = 3.6\ cm$ ¡ $h_f = 18\ cm$

k_d-Table is applicable since the neutral line lies inside the flange

$$A_{s1} = \left(k_s \cdot \frac{M_{Eds}}{d} + \frac{N_{Ed}}{\sigma_{s1d}} \right) \cdot \kappa_s = 15.85\ cm^2$$

[1] 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.

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

5 Conclusion

This example shows the calculation of the required reinforcement for a T-beam under bending. Two different reference solutions are employed in order to compare the SOFiSTiK results to. It has been shown that the results are reproduced with excellent accuracy.

6 Literature

[1] *DIN EN 1992-1-1/NA: Eurocode 2: Design of concrete structures, Part 1-1/NA: General rules and rules for buildings - German version EN 1992-1-1:2005 (D), Nationaler Anhang Deutschland - Stand Februar 2010*. CEN. 2010.

[2] F. Fingerloos, J. Hegger, and K. Zilch. *DIN EN 1992-1-1 Bemessung und Konstruktion von Stahlbeton- und Spannbetontragwerken - Teil 1-1: Allgemeine Bemessungsregeln und Regeln für den Hochbau*. BVPI, DBV, ISB, VBI. Ernst & Sohn, Beuth, 2012.

[3] K. Holschemacher, T. Müller, and F. Lobisch. *Bemessungshilfsmittel für Betonbauteile nach Eurocode 2 Bauingenieure*. 3rd. Ernst & Sohn, 2012.

[4] *Beispiele zur Bemessung nach Eurocode 2 - Band 1: Hochbau*. Ernst & Sohn. Deutschen Beton- und Bautechnik-Verein E.V. 2011.

[5] R. S. Narayanan and A. W. Beeby. *Designers' Guide to EN 1992-1-1 and EN 1992-1-2 - Eurocode 2: Design of Concrete Structures*. Thomas Telford, 2005.