Benchmark Example No. 1

Design of Slab for Bending

SOFiSTiK | 2018

VERiFiCATiON MANUAL
DCE-EN1: Design of Slab for Bending

VERiFiCATiON MANUAL, Version 2018-7
Software Version: SOFiSTiK 2018

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Front Cover

Project: New SOFiSTiK Office, Nuremberg | Contractor: WOLFF & MLLER, Stuttgart | Architecture: WABE-PLAN ARCHITEKTUR, Stuttgart | Structural Engineer: Boll und Partner. Beratende Ingenieure VBI, Stuttgart | MEP: GM Planen + Beraten, Griesheim | Lead Architect: Gerhard P. Wirth gpwirtharchitekten, Nuremberg | Vizualisation: Armin Dariz, BiMOTiON GmbH

Overview

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

1 Problem Description

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

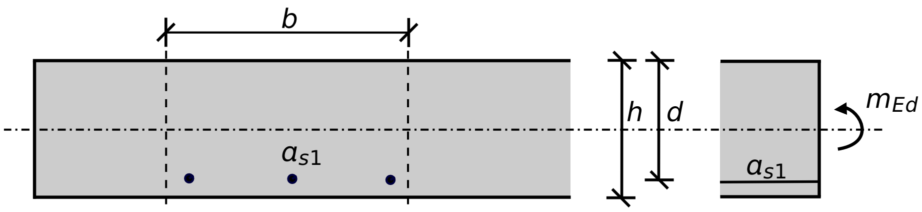

Figure 1: Problem Description

2 Reference Solution

This example is concerned with the design of sections for ULS, subject to pure flexure, such as beams or slabs. 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)

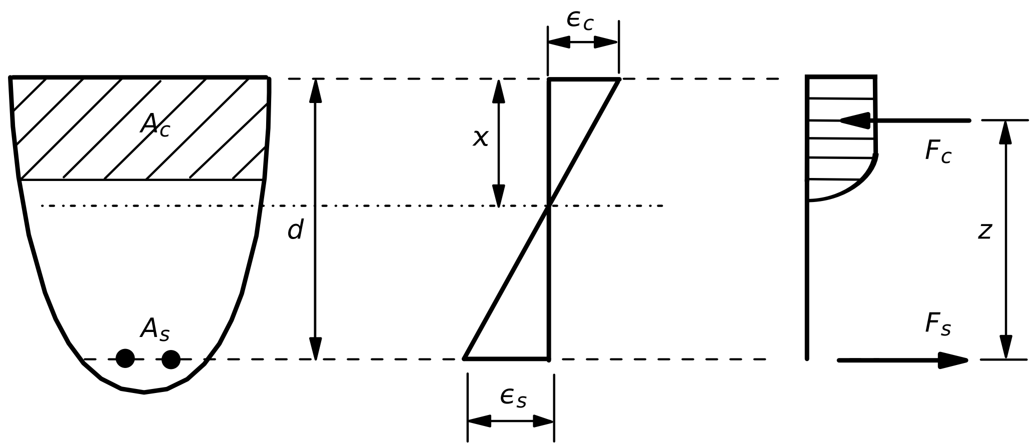

Figure 2: Stress and Strain Distributions in the Design of Cross-sections

In singly reinforced beams and slabs, 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).

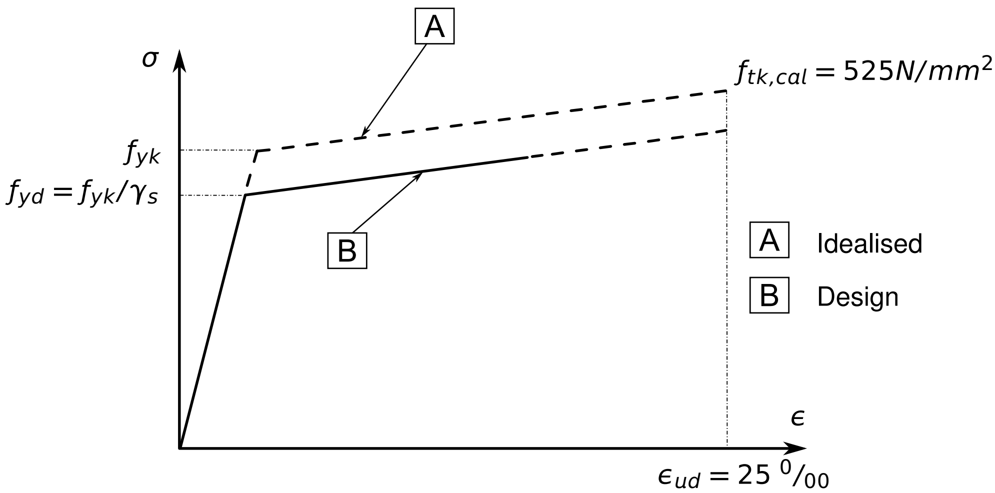

Figure 3: Idealised and Design Stress-Strain Diagram for Reinforcing Steel

3 Model and Results

The rectangular slab section, 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 $25\ kNm$. 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
$C\ 25/30$	$h = 20.0\ cm$	$m_{Ed} = 25\ kNm/m$
$B\ 500A$	$d = 17.0\ cm$	
	$b = 1.0\ m$	

Table 2: Results

	SOF.	General Chart [3]	ω—Table [3]	k_d—Table [3]
$a_{s1}\ [cm^2/m]$	3.334	3.328	3.334	3.333

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

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

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:

$M_{Ed} = m_{Ed} \cdot b = 25\ kNm; \qquad N_{Ed} = 0$
$M_{Eds} = M_{Ed} - N_{Ed} \cdot z_{s1} = 25\ kNm$

Design with respect to General Design Chart Bending with axial force for rectangular cross-sections:

$$\mu_{Eds} = \frac{M_{Eds}}{b \cdot d^2 \cdot f_{cd}} = \frac{25 \cdot 10^{-3}}{1.0 \cdot 0.17^2 \cdot 14.17} = 0.061$$

$$\epsilon = 25 \cdot 10^{-3}; \qquad \zeta = 0.97 \qquad \rightarrow \qquad \sigma_{s1d} = 456.52\ MPa$$

$$a_{s1} = \frac{1}{\sigma_{s1d}} \cdot \left(\frac{M_{Eds}}{\zeta \cdot d} + N_{Ed} \right) = 3.328\ cm^2/m$$

Tab. 9.1 [3]: General Chart for up to $C50/60$ - Cross-section without compression reinforcement

Design with respect to $\omega-$ (or μ_s-) Design Table for rectangular cross-sections:

$$\mu_{Eds} = \frac{M_{Eds}}{b \cdot d^2 \cdot f_{cd}} = \frac{25 \cdot 10^{-3}}{1.0 \cdot 0.17^2 \cdot 14.17} = 0.061$$

$\omega = 0.0632$ (interpolated) and $\sigma_{sd} = 456.52\ MPa$

Tab. 9.2 [3]: $\omega-$Table for up to $C50/60$ - Rectangular section without compression reinforcement

$$a_{s1} = \frac{1}{\sigma_{sd}} \cdot (\omega \cdot b \cdot d \cdot f_{cd} + N_{Ed}) = 3.334\ cm^2/m$$

Design with respect to k_d- Design Table for rectangular cross-sections:

$$k_d = \frac{d}{\sqrt{M_{Eds}/b}} = \frac{17}{\sqrt{25/1.0}} = 3.40$$

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

$k_s = 2.381$, $\kappa_s = 0.952$ (interpolated values)

$$a_{s1} = \left(k_s \cdot \frac{M_{Eds}}{d} + \frac{N_{Ed}}{\sigma_{s1d}} \right) \cdot \kappa_s = 3.333\ cm^2/m$$

[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 slab section under bending. Various 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.