Flexure

IN ACCORDANCE WITH

European Standards CEN/TC 250
Structural Eurocodes (EN 1992-1-1)

UK National Annex

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SPREADSHEETS
Structural Design

Carlo Sigmund

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Contents

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Section 1 Flexure_EC2_UKNA

1.1 General: FlexureRectangularBeamsAndSlabs.xls

This sheet allows for the design of a section of solid slab or a rectangular beam section. The spreadsheet calculates the area of longitudinal steel reinforcement in accordance with EN 1992-1-1:2004 Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings and BS NA EN 1992-1-1 (2004) (English): UK National Annex to Eurocode 2. Design of concrete structures. General rules and rules for buildings.

All applied loads and moments should be ultimate and positive, as positive moments induce tension in the bottom reinforcement (A_s). The user is required to input desired amounts of redistribution δ to the initial moments according to Cl. 5.5(4) "*Linear elastic analysis with limited redistribution*".

With respect to cantilevers, the additional tensile force in the longitudinal reinforcement due to shear (input $V_{Ed} \neq 0$) in the design section is calculated from Exp. (6.18) - Cl. 6.2.3(7).

With regard the concrete, the minimum strength used is C12/15 (Table 3.1). The spreadsheet allows input for grades of concrete up to C50/60. Input is self explanatory but, in order to facilitate use of this spreadsheet, some degree of automation has been introduced.

The rectangular stress block shown in EN 1992-1-1, Figure 3.5 "*Rectangular stress distribution*" is used.

Where more than one horizontal layer of bars are required per section, the user may choose to specify up to 4 separate layers per reinforcement in order to increase section strength. The spreadsheet takes automatic measures to ensure minimum spacing of reinforcement is met (Cl. 8.2(3) "*Spacing of bars*").

Combo-boxes to the right under "DETAILING" Excel® Form define minimum bar sizes to be used. Combo-box to the right under "PreCalculus" Excel® Form define concrete characteristic compressive strength at 28 days.

To ensure proper placing and compaction of concrete around reinforcement, a maximum steel content is also specified and checked. Thus the maximum area of tension reinforcement in a beam (or solid slab) should not exceed 4 per cent of the gross cross-sectional area of the concrete (Cl. 9.2.1.1).

⚠ No check is performed in order to control cracking of the concrete. Therefore the minimum area of tension reinforcement is checked (Exp. 9.1N, Cl. 9.2.1.1).

To avoid sudden failure it is important to ensure that the tension steel reaches its yield stress before the concrete fails in compression. Tests on beams have shown that the steel yields before the concrete crusches when the depth “x” to the NA (neutral axis) depth does not exceed $\sim 0,45d$ (with “d” effective depth of tension reinforcement) and hence that the steel in tension will reach its ultimate stress before the concrete fails in compression.

If the value $K = M/(bd^2 f_{ck})$ for a particular beam or slab was found to be greater then a particular limit K' it would indicate that the concrete above the NA was overstressed in compression. Therefore either the beam (or slab) would have to be increased in size, or compressive reinforcement would have to be introduced above the NA to assist the concrete. Compression reinforcement (A_{s2}) is checked and eventually calculated. No check is performed in order to control beam deflection.

1.2 Layout

The basic layout for **Flexure_EC2** sheet is shown on the following screen dump:

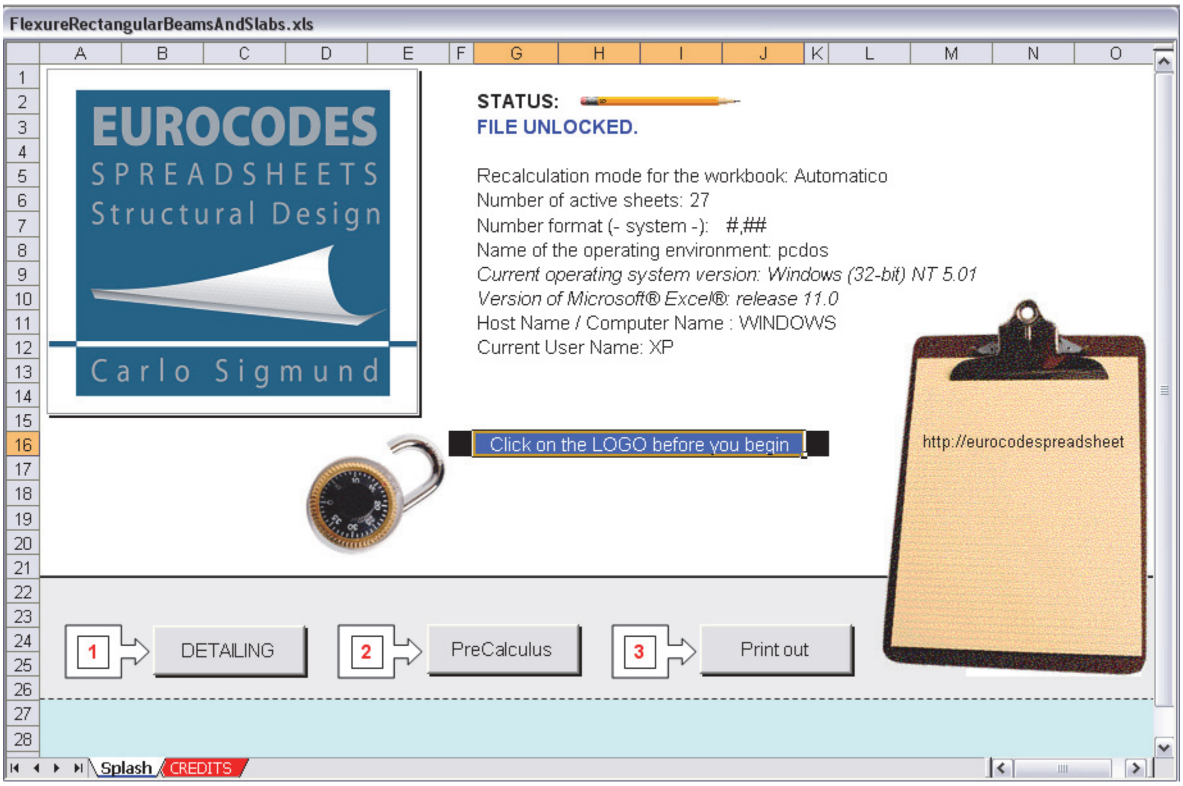


Figure 1.1 Sheet “Splash” from Excel® 2003.

PreCalculus Form:

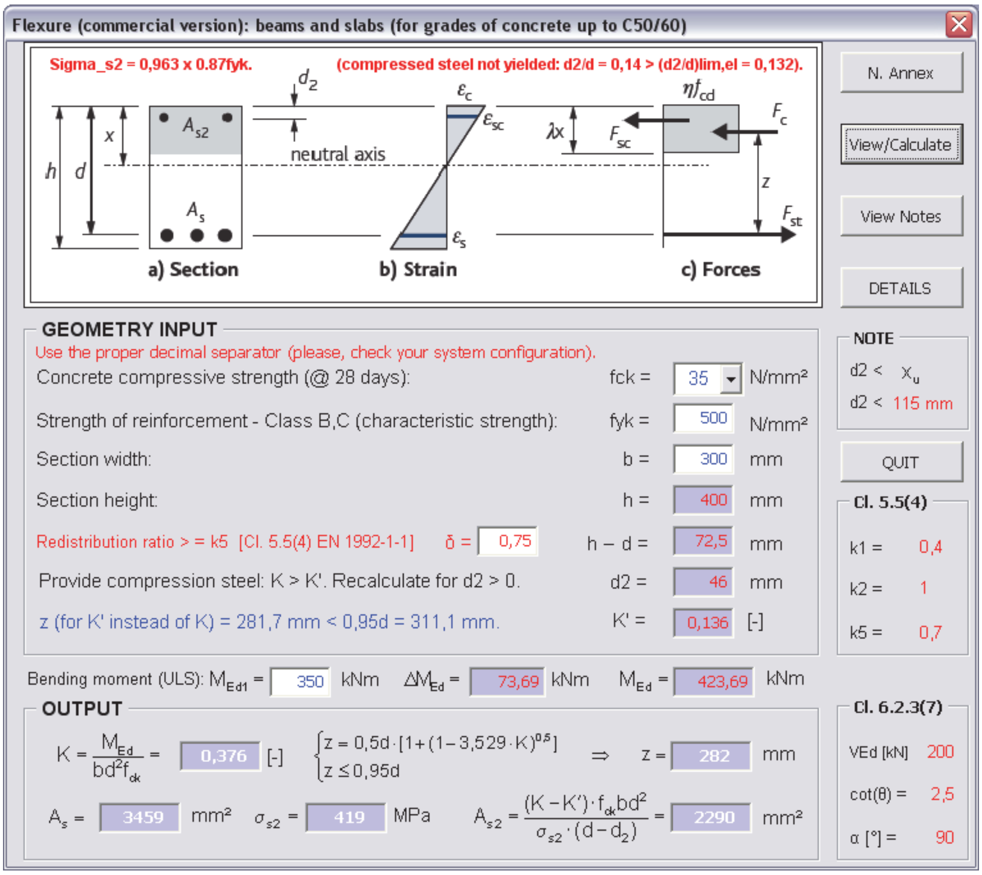


Figure 1.2 Input (white blank test boxes) and calculus (blue text boxes). Default value for δ = 1 (red).

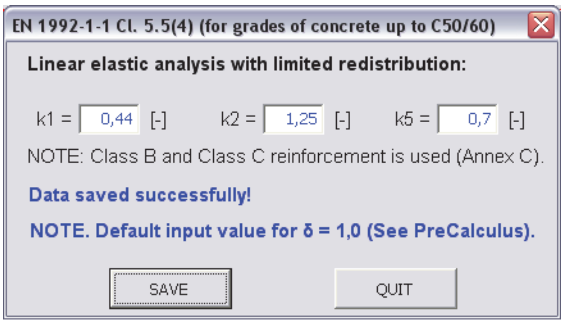


Figure 1.3 Input values k_1, k_2 and k_5. Default values (EN 1992-1-1).

View Notes Form:

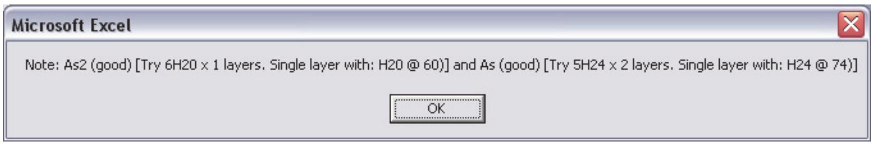


Figure 1.4 Example. Required compression and tensile reinforcement.

N. Annex Form:

DETAILS Form:

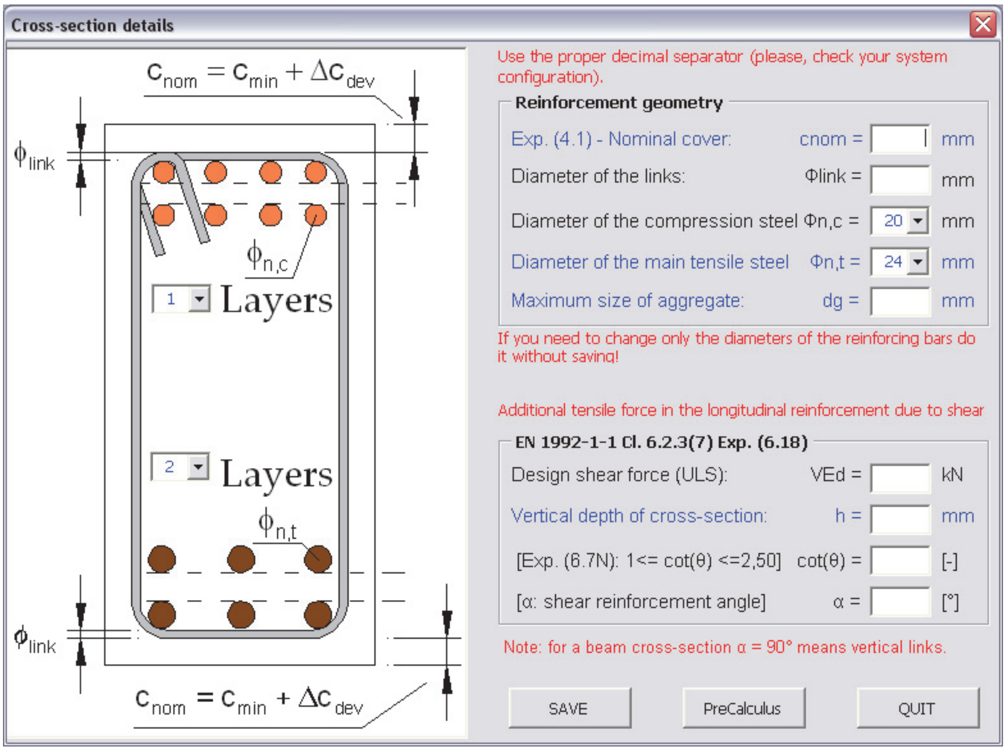
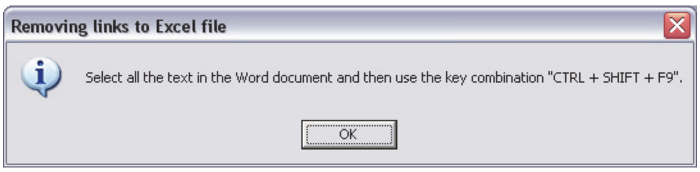


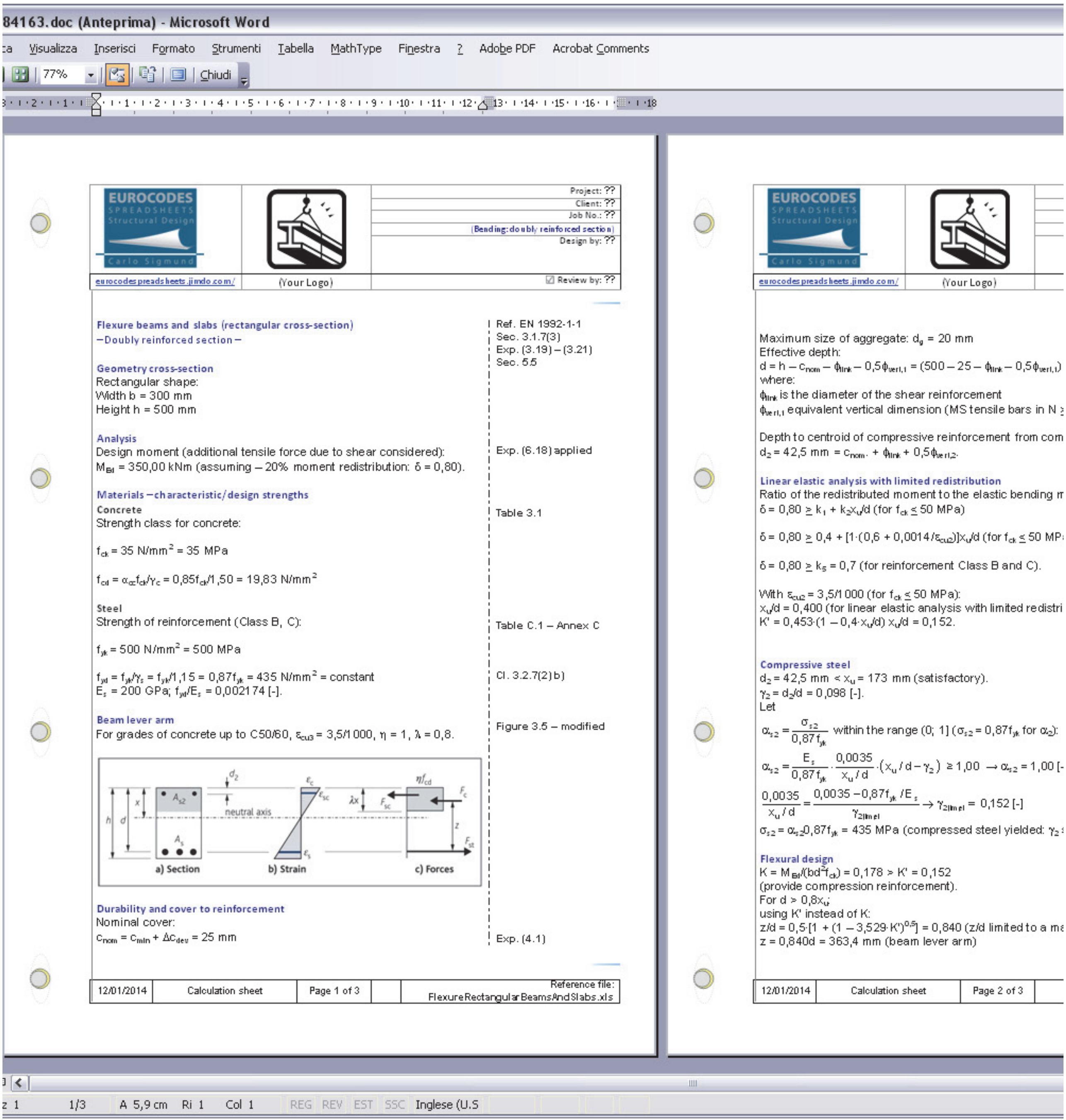
Figure 1.5 Coloured in blue the necessary inputs.

How to remove links to Excel file “FlexureRectangularBeamsAndSlabs.xls”:



1.3 Output - Word document (calculation sheet)

Example calculation sheet (output):



84163.doc (Anteprima) - Microsoft Word

EUROCODES SPREADSHEETS Structural Design Carlo Sigmund | (Your Logo) | Project: ?? Client: ?? Job No.: ?? (Bending: doubly reinforced section) Design by: ?? Review by: ??

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Flexure beams and slabs (rectangular cross-section)
– Doubly reinforced section –

Ref. EN 1992-1-1
Sec. 3.1.7(3)
Exp. (3.19) – (3.21)
Sec. 5.5

Geometry cross-section
Rectangular shape:
Width b = 300 mm
Height h = 500 mm

Analysis
Design moment (additional tensile force due to shear considered):
M_{Ed} = 350,00 kNm (assuming – 20% moment redistribution: δ = 0,80). — Exp. (6.18) applied

Materials – characteristic/design strengths
Concrete
Strength class for concrete: — Table 3.1

f_{ck} = 35 N/mm² = 35 MPa

$f_{cd} = \alpha_{cc} f_{ck}/\gamma_C = 0{,}85 f_{ck}/1{,}50$ = 19,83 N/mm²

Steel
Strength of reinforcement (Class B, C): — Table C.1 – Annex C

f_{yk} = 500 N/mm² = 500 MPa

$f_{yd} = f_{yk}/\gamma_s = f_{yk}/1{,}15 = 0{,}87 f_{yk}$ = 435 N/mm² = constant — Cl. 3.2.7(2)b)
E_s = 200 GPa; f_{yd}/E_s = 0,002174 [-].

Beam lever arm
For grades of concrete up to C50/60, ε_{cu3} = 3,5/1000, η = 1, λ = 0,8. — Figure 3.5 – modified

a) Section b) Strain c) Forces

Durability and cover to reinforcement
Nominal cover:
$c_{nom} = c_{min} + \Delta c_{dev}$ = 25 mm — Exp. (4.1)

12/01/2014 | Calculation sheet | Page 1 of 3 | Reference file: FlexureRectangularBeamsAndSlabs.xls

Maximum size of aggregate: d_g = 20 mm
Effective depth:
$d = h - c_{nom} - \phi_{link} - 0{,}5\phi_{vert,1} = (500 - 25 - \phi_{link} - 0{,}5\phi_{vert,1})$
where:
ϕ_{link} is the diameter of the shear reinforcement
$\phi_{vert,1}$ equivalent vertical dimension (MS tensile bars in N ...

Depth to centroid of compressive reinforcement from com...
d_2 = 42,5 mm = $c_{nom} + \phi_{link} + 0{,}5\phi_{vert,2}$.

Linear elastic analysis with limited redistribution
Ratio of the redistributed moment to the elastic bending m...
$\delta = 0{,}80 \geq k_1 + k_2 x_u/d$ (for $f_{ck} \leq 50$ MPa)

$\delta = 0{,}80 \geq 0{,}4 + [1 \cdot (0{,}6 + 0{,}0014/\varepsilon_{cu2})] x_u/d$ (for $f_{ck} \leq 50$ MP...

$\delta = 0{,}80 \geq k_5 = 0{,}7$ (for reinforcement Class B and C).

With ε_{cu2} = 3,5/1000 (for $f_{ck} \leq 50$ MPa):
x_u/d = 0,400 (for linear elastic analysis with limited redistri...
$K' = 0{,}453 \cdot (1 - 0{,}4 \cdot x_u/d)\, x_u/d = 0{,}152$.

Compressive steel
d_2 = 42,5 mm < x_u = 173 mm (satisfactory).
$\gamma_2 = d_2/d$ = 0,098 [-].
Let

$\alpha_{s2} = \dfrac{\sigma_{s2}}{0{,}87 f_{yk}}$ within the range (0; 1] ($\sigma_{s2} = 0{,}87 f_{yk}$ for α_2):

$\alpha_{s2} = \dfrac{E_s}{0{,}87 f_{yk}} \cdot \dfrac{0{,}0035}{x_u/d} \cdot (x_u/d - \gamma_2) \geq 1{,}00 \rightarrow \alpha_{s2} = 1{,}00$ [-...

$\dfrac{0{,}0035}{x_u/d} = \dfrac{0{,}0035 - 0{,}87 f_{yk}/E_s}{\gamma_{2lim\,el}} \rightarrow \gamma_{2lim\,el} = 0{,}152$ [-]

$\sigma_{s2} = \alpha_{s2} 0{,}87 f_{yk}$ = 435 MPa (compressed steel yielded: γ_2 ...

Flexural design
$K = M_{Ed}/(bd^2 f_{ck}) = 0{,}178 > K' = 0{,}152$
(provide compression reinforcement).
For d > 0,8x_u;
using K' instead of K:
$z/d = 0{,}5 \cdot [1 + (1 - 3{,}529 \cdot K')^{0{,}5}] = 0{,}840$ (z/d limited to a ma...
z = 0,840d = 363,4 mm (beam lever arm)

12/01/2014 | Calculation sheet | Page 2 of 3

Figure 1.6 Sample print with compression steel (Word® Office® must be installed on your system).

1.4 Flexure_EC2 (Beams and slabs) derived formulae

According to EN 1992-1-1 Sec. 3.1.6 "*Design compressive and tensile strengths*" the rectangular stress block shown in the Figure 1.7 below is used:

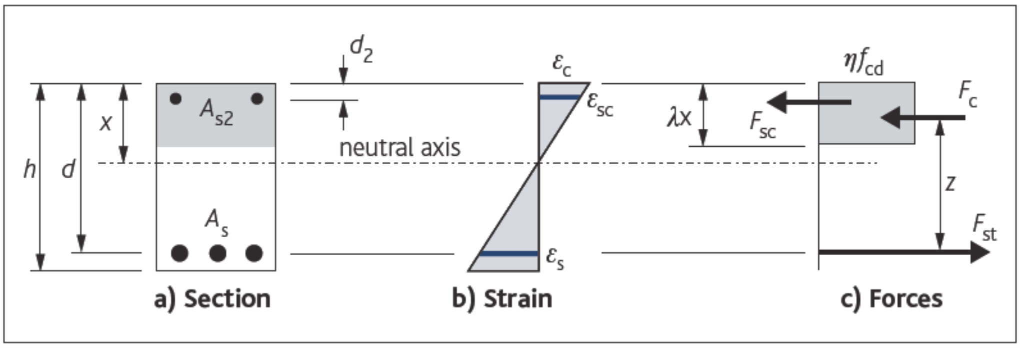

Figure 1.7 Strain and design forces in a section. A_s = tensile reinforcement. A_{s2} compression reinforcement. **Beam cross-section with height "h" and width "b".**

We know from theory of bending that when bending is induced in a rectangular beam the material fibres above the neutral axis are subjected to compressive stresses and those below to tensile stresses. Concrete has excellent qualities for resisting compression. However, its resistance to tension is so poor that it is ignored. Instead, steel reinforcement is introduced to resist tension.

For any beam to be adequate in bending, its internal moment of resistance must not be less than the externally applied bending moment. Therefore the design ultimate resistance moment M of a concrete beam (or slab) must be greater than or at least equal to the ultimate bending moment M_{Ed}.

SINGLY REINFORCED SECTIONS. For grade of concrete up to C50/60:[(1)]

$\varepsilon_{cu} = 3,5/1000$, $\eta = 1$ and $\lambda = 0,8$ (see figure above).

The ultimate design strength of concrete and steel are respectively:

$$f_{cd} = \alpha_{cc} f_{ck}/\gamma_c = 0,85 f_{ck}/1,5$$

$$f_{yd} = f_{yk}/\gamma_s = f_{yk}/1,15 = 0,87 f_{yk} .$$

For singly reinforced section, the design equation can be derived as follow (see Figure 1.8 below):

$$\begin{cases} F_c = (0,85 f_{ck}/1,5) \cdot b \cdot (0,8x) = 0,453 f_{ck} bx \\ F_{st} = 0,87 A_s f_{yk} \end{cases}$$

Considering moment about the centroid of the tension force:

(1) **Cm/n** means: f_{ck} = **m** [MPa] and $f_{ck,cube}$ = **n** [MPa].

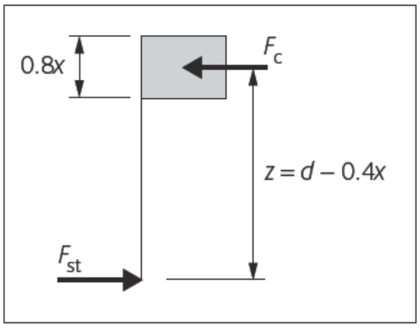

Figure 1.8 Singly reinforced beam lever arm "z".

$M = 0,453 f_{ck} b x$. With $z = d - 0,4x$ and $x = 2,5(d - z)$:

$M = 0,453 f_{ck} b 2,5(d - z) z$

$M = 1,1333 f_{ck} b(zd - z^2)$

Let $K = M/(bd^2 f_{ck})$,

$$K = \frac{M}{bd^2 f_{ck}} = \frac{1,1333 f_{ck} b(zd - z^2)}{bd^2 f_{ck}}$$

$$K = 1,1333\left[\frac{z}{d} - \left(\frac{z}{d}\right)^2\right].$$

Solving the quadratic equation, for the solution with the limit d > 0,8x:

$$\frac{z}{d} = 0,5[1 + \sqrt{1 - (3,529K)}].$$

Note The spreadsheet check and respect the limit $z < 0,95d$.

The area of reinforcement required ($M = M_{Ed}$) is:

$$A_s = \frac{M_{Ed}}{0,87 f_{yk} z}.$$

REDISTRIBUTION RATIO According to Cl. 5.5(4) the ratio x_u/d is restricted by the amount of redistribution carried out. Where x_u is the depth of the NA at ULS after redistribution. For $f_{ck} \leq 50$ MPa:

$\delta \geq k_1 + k_2 \frac{x_u}{d} \geq k_5$ where Class B and Class C reinforcement is used (see Annex C).

Note The values of k_1, k_2 and k_5 for use in a Country may be found in the National Annex. The user may choose to specify which values to be used in the calculation.

Assuming for example k_1 = 0,4 and k_2 = 1:

$$\delta \geq 0,4 + \frac{x_u}{d} \geq 0,7 \quad \rightarrow \quad \frac{x_u}{d} \geq 0,3 \quad \rightarrow \quad \frac{x_u}{d} \leq (\delta - 0,4) \text{ and}$$

for $\frac{x_u}{d} = 0,45 \quad \rightarrow \quad \delta \geq 0,45 + 0,4 = 0,85$. Assuming $x_u = 0,45d$:

$$M' = 0,453 f_{ck} b x_u z$$

$$M' = 0,453 f_{ck} b(0,45d) \cdot [d - (0,4 \cdot 0,45d)]$$

$$M' = 0,167 f_{ck} b d^2$$

Therefore (for k_1 = 0,4 and k_2 = 1):

$K' = \frac{M'}{f_{ck} b d^2} = 0,167$ (see also Table below):

δ	1	0,95	0,9	0,85	0,8	0,75	0,7
% redistribution	0	5	10	15	20	25	30
K'	0,208	0,195	0,182	0,167	0,153	0,137	0,120

Table 1.1 Limits on K' with respect to redistribution ratio δ for k_1 = 0,4 and k_2 = 1,0. Note - Cl. 5.5(4).

COMPRESSION REINFORCEMENT. The majority of beam used in practice are singly reinforced, and these beams can be designed the formula mentioned above. In some cases, compression reinforcement is added in order to:

1. increase section strength (i.e. where $K > K'$)
2. to reduce long term deflection
3. to decrease curvature/deformation at ultimate limit state (ULS).

With reference to Figure 1.7, we need to consider an extra compression force:

$$F_{sc} = A_{s2} \sigma_{s2}$$

where σ_{sc} is the stress value of the compression steel: $0 \leq \sigma_{sc} \leq 0,87 f_{yk} = f_{yd}$. From the proportion of the strain distribution diagram:

$$\frac{\varepsilon_{s2}}{x_u - d_2} = \frac{\varepsilon_{cu3}}{x_u} \quad \rightarrow \quad \frac{\varepsilon_{s2}}{x_u - d_2} = \frac{0,0035}{x_u} \quad \rightarrow \quad \frac{\varepsilon_{s2}}{\frac{x_u}{d} - \frac{d_2}{d}} = \frac{0,0035}{\frac{x_u}{d}} . \qquad \textbf{(Eq. 1-1)}$$

Let $\gamma_{s2, lim, el} = (d_2/d)_{lim, el}$ for $\varepsilon_{s2} = \frac{0,87 f_{yk}}{E_s}$:

$$\gamma_{s2, lim, el} = \frac{x_u}{d} \cdot \left(0,0035 - \frac{0,87 f_{yk}}{E_s}\right) / 0,0035 . \qquad \textbf{(Eq. 1-2)}$$

For $f_{yk} = 500\ MPa$, $E_s = 200000\ MPa$ and $x_u/d = 0,45$: $\gamma_{s2,\,lim,\,el} = 0,170$.

If $\gamma_2 = d_2/d > \gamma_{s2,\,lim,\,el}$, then it is necessary to calculate the strain ε_{s2} from the Eq. 1-1:

$$\frac{\varepsilon_{s2}}{\frac{x_u}{d}-\gamma_2} = \frac{0,0035}{\frac{x_u}{d}} \quad \rightarrow \quad \varepsilon_{s2} = 0,0035 \cdot \frac{\frac{x_u}{d}-\gamma_2}{\frac{x_u}{d}}. \qquad \textbf{(Eq. 1-3)}$$

Let $\alpha_{s2} = \frac{\sigma_{s2}}{0,87f_{yk}}$ within the range $0 < \alpha_{s2} \le 1$ with $\varepsilon_{s2} = \frac{\alpha_{s2}0,87f_{yk}}{E_s}$:

$$\alpha_{s2} = \frac{E_s}{0,87f_{yk}} \cdot 0,0035 \cdot \frac{\frac{x_u}{d}-\gamma_2}{\frac{x_u}{d}}. \qquad \textbf{(Eq. 1-4)}$$

Therefore, for $\gamma_2 = d_2/d > \gamma_{s2,\,lim,\,el}$ it is $0 < \alpha_{s2} < 1$ (compression steel not yielded).
For $\gamma_2 \le \gamma_{s2,\,lim,\,el}$ it is $\alpha_{s2} = 1 \quad \rightarrow \quad \sigma_{s2} = 0,87f_{yk}$ (compression steel yielded).

The area of tension reinforcement can be considered in two parts:

1. the first part to balance the compressive force above del NA (concrete)
2. the second part to balance the force in the compression steel.

When a compression reinforcement is required ($K > K'$) then:

$$A_s = \text{FIRST PART} + \text{SECOND PART} = \frac{K'f_{ck}bd^2}{0,87f_{yk}z} + A_{s2} \cdot \alpha_{s2}$$

where

$$\frac{z}{d} = 0,5[1+\sqrt{1-(3,529K')}]$$ (in this case using K' instead of K).

Note The spreadsheet check and respect the limit z < 0,95d.

Taking moments about the centroid of the tension force (see Figure 1.7):

$$\begin{cases} M = M' + \sigma_{s2}A_{s2}(d-d_2) \\ M = K'f_{ck}bd^2 + \sigma_{s2}A_{s2}(d-d_2) \end{cases}$$

Rearranging:

$$A_{s2} = \frac{(K-K')f_{ck}bd^2}{\sigma_{s2}(d-d_2)} = \frac{(K-K')f_{ck}bd^2}{(\alpha_{s2} \cdot 0,87f_{yk})(d-d_2)}.$$

1.5 Verification tests

FLEXURERECTANGULARBEAMSANDSLABS.XLS. 5.09 MB. Created: 16 December 2013. Last/Rel.-date: 16 December 2013. Sheets:

- Splash
- CREDITS.

EXAMPLE 1-A- Pre-dimensioning of a rectangular section with compression reinforcement - **test1**

Given: A rectangular concrete beam (width b = 350 mm, height = 300 mm) is required to resist an ultimate moment of M_{Ed} = 214 kNm (assuming – 20% moment redistribution: δ = 0,80). If the beam is compose of grade 35 concrete and high yield (HY) reinforcement, determine the area of the steel required.

Solution: According to Figure 1.7 let us assume: $d_2 = 46 \text{ mm}$ and an effective depth $d = 228 \text{ mm}$.

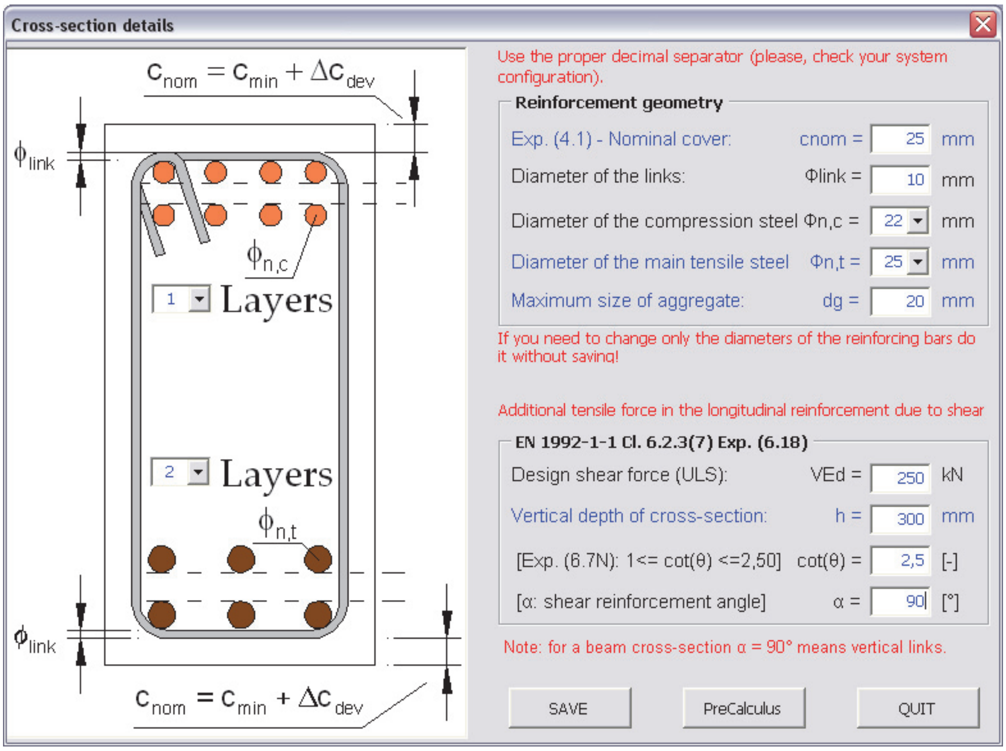

Figure 1.9 Cross-section details with d_2 = 46 mm and d = 227,5 mm.

Ratio of the redistributed moment to the elastic bending moment:

$\delta = 0,80 \geq k_1 + k_2 x_u / d$ for $f_{ck} \leq 50 \text{ MPa}$. Let us assume $k_1 = 0,4$, $k_2 = 1$ and $k_5 = 0,7$

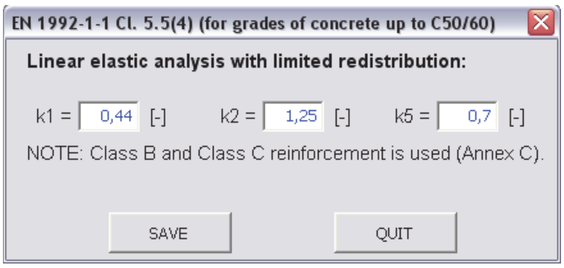

Figure 1.10 Cl. 5.5(4) for grade of concrete up to f_{ck} = 50 MPa.

$\delta = 0,80 \geq 0,4 + [1 \cdot (0,6 + (0,0014)/\varepsilon_{cu2})] \cdot x_u/d$

$\delta \geq k_5 = 0,7$ (for reinforcement Class B and C).

With $\varepsilon_{cu2} = 0,0035$ (for $f_{ck} \leq 50$ MPa):

$x_u/d = 0,40$ for linear elastic analysis with limited redistribution):

$K' = 0,453 \cdot [1-(0,4 \cdot x_u/d)] \cdot x_u/d = 0,152$.

COMPRESSIVE STEEL. $d_2 = 46$ mm $< x_u = 0,40 \cdot 228 = 91$ mm (satisfactory).

$\gamma_2 = d_2/d = 0,202$. Let

$$\alpha_{s2} = \frac{\sigma_{s2}}{0,87f_{yk}} = \frac{E_s}{0,87f_{yk}} \cdot \frac{0,0035}{x_u/d} \cdot (x_u/d - \gamma_2) = \frac{200000}{435} \cdot \frac{0,0035}{0,40} \cdot (0,40-0,202) = 0,80$$

$$\frac{0,0035}{x_u/d} = \frac{0,0035-0,87f_{yk}/E_s}{\gamma_{s2,lim,el}} \quad \rightarrow \quad \frac{0,0035}{0,40} = \frac{0,0035-435/200000}{\gamma_{s2,lim,el}} \quad \rightarrow \quad \gamma_{s2,lim,el} = 0,151$$

$\gamma_2 > \gamma_{s2,lim,el}$ compressed steel not yielded:

$\sigma_{s2} = \alpha_{s2} \cdot (0,87f_{yk}) = 0,80 \cdot 0,87 \cdot 500 = 348$ MPa

FLEXURAL DESIGN.

$$K = \frac{M_{Ed}}{bd^2f_{ck}} = \frac{214 \cdot 10^6}{350(228)^2(35)} = 0,336 > K' = 0,152$$ (provide compression reinforcement).

For $d > 0,8x_u$ using K' instead K:

$z/d = 0,5 \cdot [1+(1-3,529 \cdot K')^{0,5}] = 0,5 \cdot [1+(1-3,529 \cdot 0,152)^{0,5}] = 0,840 \leq 0,95$.

Beam lever arm:

$z = 0,840d = 0,84 \cdot 228 = 192$ mm.

AREA OF THE COMPRESSION REINFORCEMENT REQUIRED:

$$A_{s2} = \frac{(K-K')f_{ck}bd^2}{\sigma_{s2}(d-d_2)} = \frac{(0,336-0,152)(35)(350)(228)^2}{(348)(228-46)} = 1850 \text{ mm}^2$$

Try 5H22 x 1 layers. Single layer with: H22 @ 65 mm.

PERCENTAGE AREA OF THE COMPRESSION REINFORCEMENT PROVIDED:

$\rho_{s2} = 100 \cdot A_{s2}/(bd) = 100 \cdot 1900/[(350)(228)] = 2,38\% \leq 4bh/100 = A_{s,max}$ (satisfactory).

AREA OF TENSION REINFORCEMENT REQUIRED:

With $z = 192$ mm $\leq 0,95d$:

$$A_s = \frac{K'f_{ck}bd^2}{0,87f_{yk}z} + A_{s2} \cdot \alpha_{s2} = \frac{K'f_{ck}bd^2}{0,87f_{yk}z} + \frac{(K-K')f_{ck}bd^2}{\sigma_{s2}(d-d_2)} \cdot \alpha_{s2} = \frac{K'f_{ck}bd^2}{0,87f_{yk}z} + \frac{(K-K')f_{ck}bd^2}{0,87f_{yk}(d-d_2)}$$

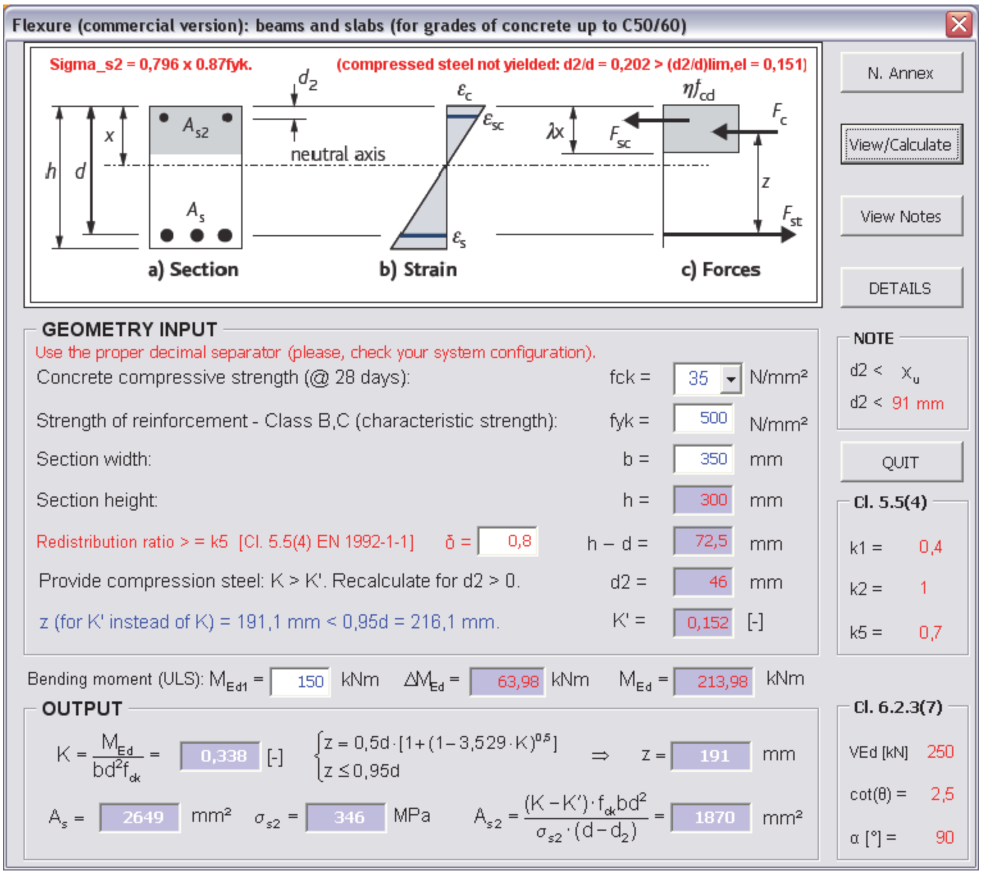

Figure 1.11 PreCalculus Excel® form: procedure for a quick pre-calculation: using UK Annex of EC2.

$$A_s = \frac{K' f_{ck} b d^2}{0,87 f_{yk} z} + \frac{(K - K') f_{ck} b d^2}{\sigma_{s2}(d - d_2)} \cdot \alpha_{s2} = \frac{(0,152)(35)(350)(228)^2}{0,87(500)(192)} + (1850) \cdot 0,80 = 2639 \text{ mm}^2$$

Try 3H25 x 2 layers. Single layer with: H25 @ 128 mm.

PERCENTAGE AREA OF THE COMPRESSION REINFORCEMENT PROVIDED:

$$\rho_{s2} = 100 \cdot A_{s2}/(bd) = 100 \cdot 1900/[(350)(228)] = 3,69\,\% \le 4bh/100 = A_{s,max} \text{ (satisfactory).}$$

1.6 Excel VBa Code (main)

```
Private Sub Cmb_Calculus_Click()
'----------------------------------------------------------
Dim fy As Variant
Dim b As Variant
Dim h As Variant
Dim d1 As Variant
Dim d2 As Variant
Dim Kpr As Variant
Dim fck As Variant
Dim M1 As Variant
```

```
Dim delta As Variant
Dim k2 As Variant


Dim Alfa2 As Variant
Dim sigma2 As Variant
Dim xu As Variant Dim Gamma2 As Variant
Dim Gamma2Lim As Variant
Dim d2max As Variant

Dim Mprint As Variant


Dim K As Variant
Dim z As Variant
Dim DeltaM As Variant
Dim M As Variant
Dim A As Variant
Dim NUM As Variant
Dim DEN As Variant
Dim A2 As Variant

Dim T As Double
Dim T1 As Double
Dim NIRQ As Double
Dim NIRQ1 As Double

Dim z1 As Variant

'----------------------------------------------------------


'----------------------------------------------------------
******Check input
'----------------------------------------------------------

        fck = Worksheets("frmB").Range("A16").Value
        k2 = Worksheets("frmB").Range("G8").Value
        k1 = Worksheets("frmB").Range("G7").Value

        h = Worksheets("frmB").Range("M6").Value
        d1 = Worksheets("frmB").Range("M7").Value
        d2 = Worksheets("frmB").Range("M8").Value
        DeltaM = Worksheets("frmB").Range("M9").Value


        M = 1 * M1 + 1 * DeltaM
        Mprint = M / (10 ^ 6)
        Worksheets("frmB").Range("M11").Value = Round(Mprint, 2)
        TextBox_M = Worksheets("frmB").Range("P11").Value


        Worksheets("frmB").Range("E11").Value = delta

        xu = (delta - k1) / k2
        Kpr = 0.453 * xu * (1 - 0.4 * xu)

        'Kpr = Worksheets("frmB").Range("H14").Value
        'TextBox_Kpr = Worksheets("frmB").Range("J14").Value
        TextBox_Kpr = Round(Kpr, 3)

        TextBox_h = Worksheets("frmB").Range("M6").Value
        TextBox_d1 = Worksheets("frmB").Range("M7").Value
        TextBox_d2 = Worksheets("frmB").Range("M8").Value
        TextBox_DeltaM = Worksheets("frmB").Range("S9").Value
```

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```
        TextBox_k1 = Worksheets("frmB").Range("E7").Value
        TextBox_k2 = Worksheets("frmB").Range("E8").Value
        TextBox_k5 = Worksheets("frmB").Range("E9").Value

        TextBox_VEd = Worksheets("Linked").Range("C59").Value
        TextBox_cotT = Worksheets("Linked").Range("C60").Value
        TextBox_Alfa = Worksheets("Linked").Range("C61").Value

'----------------------------------------------------------


    If ((fy * b * h * d1 * Kpr * M = 0) Or (d2 + d1 >= h) Or (d2 >= xu * (h - d1)) Or
       (Alfa2 < 0)) Or ((h <= d1) Or (h <= d2)) Then
    TextBox_Alert = "Please check your input!"
    TextBox_Alert2 = "Enter values that are consistent and positive."
    TextBox_K = "[--]"
    TextBox_z = "[--]"
    TextBox_A = "[--]"
    TextBox_A2 = "[--]"
    TextBox_d2max = "[--]"
    TextBox_sigma2 = "[--]"
    Else
        '----------------------------------------------------------

        K = M / (b * fck * (h - d1) ^ 2)
        T = (1 - 3.529 * K)
        T1 = (1 - 3.529 * Kpr)
        '----------------------------------------------------------
        If K <= Kpr Then
        '----------------------------------------------------------
            If (1 - 3.529 * K) < 0 Then
            TextBox_K = "[--]"
            TextBox_z = "[--]"
            TextBox_A = "[--]"
            TextBox_A2 = "[--]"
            TextBox_d2max = "[--]"
            TextBox_sigma2 = "[--]"
            TextBox_Alert = "Please, check your input!"
            TextBox_Alert2 = "Case Not Applicable: geometry inadequate."
            Else
        '----------------------------------------------------------



                If 0.5 * (h - d1) * (1 + Sqr(T)) > 0.95 * (h - d1) Then
                    TextBox_Alert = "Note: singly reinforced section with K =< K' = " &
       Round(Kpr, 3) & "."
                    TextBox_Alert2 = "z limited to a maximum of 0,95d = " & Round(0.95 *
       (h - d1), 1) & " mm."
                    z = 0.95 * (h - d1)
                    TextBox_z = Round(z, 0)
                    A = M / (0.87 * fy * z)
                    TextBox_A = Round(A, 0)
                    A2 = 0
                    TextBox_A2 = Round(A2, 0)
                    TextBox_K = Round(K, 3)
                    TextBox_sigma2 = "[--]"
                    TextBox_d2max = Round(xu * (h - d1), 0) & " mm"
                    TextBox_S = ""
                    TextBox_F = ""
                Else
                    TextBox_Alert = "Note: singly reinforced section with K <= K' = " &
       Round(Kpr, 3) & "."
                    z = 0.5 * (h - d1) * (1 + Sqr(T))
                    TextBox_z = Round(z, 0)
```

```
              TextBox_Alert2 = "z (for K = " & Round(K, 3) & ") = " & Round(z, 1) &
" mm < 0,95d = " & Round(0.95 * (h - d1), 1) & " mm."
              A = M / (0.87 * fy * z)
              TextBox_A = Round(A, 0)
              A2 = 0
              TextBox_A2 = Round(A2, 0)
              TextBox_K = Round(K, 3)
              TextBox_sigma2 = "[--]"
              TextBox_d2max = Round(xu * (h - d1), 0) & " mm"
              TextBox_S = ""
              TextBox_F = ""
          End If


  Worksheets("Linked").Range("C43").Value = Round((0.5 * (1 + Sqr(T))), 2) 'single
  Worksheets("Linked").Range("C44").Value = Round((0.5 * (h - d1) * (1 + Sqr(T))),
1) 'single



  '----------------------------------------------------------
      End If
  '----------------------------------------------------------
  Else
  '----------------------------------------------------------
      If (1 - 3.529 * Kpr) < 0 Then
      TextBox_K = "[--]"
      TextBox_z = "[--]"
      TextBox_A = "[--]"
      TextBox_A2 = "[--]"
      TextBox_d2max = "[--]"
      TextBox_sigma2 = "[--]"
      TextBox_Alert = "Please, check your input!"
      TextBox_Alert2 = "Case Not Applicable: geometry inadequate."
      Else
  '----------------------------------------------------------


  Gamma2 = d2 / (h - d1)
  Gamma2Lim = (xu) * (0.0035 - (0.87 * fy / 200000)) / 0.0035
  d2max = xu * (h - d1)
  TextBox_d2max = Round(d2max, 0) & " mm"

  If (Gamma2 <= Gamma2Lim) Then
      Alfa2 = 1
      TextBox_F = "(compressed steel yielded: d2/d = " & Round(Gamma2, 3) & " <=
(d2/d)lim,el = " & Round(Gamma2Lim, 3) & ")."
      sigma2 = 0.87 * fy
      TextBox_sigma2 = Round(sigma2, 0)
      TextBox_S = "Sigma_s2 = 1,00 x 0.87fyk."
  Else
      Alfa2 = (200000 / (0.87 * fy)) * (0.0035 / xu) * (xu - Gamma2)
      TextBox_F = "(compressed steel not yielded: d2/d = " & Round(Gamma2, 3) & " >
(d2/d)lim,el = " & Round(Gamma2Lim, 3) & ")."
      sigma2 = Alfa2 * 0.87 * fy
      TextBox_sigma2 = Round(sigma2, 0)
      TextBox_S = "Sigma_s2 = " & Round(Alfa2, 3) & " x 0.87fyk."
  End If

          If 0.5 * (h - d1) * (1 + Sqr(T1)) > 0.95 * (h - d1) Then
              TextBox_Alert = "Provide compression steel: K > K'. Recalculate for d2
> 0."
              TextBox_Alert2 = "z (for K' instead of K) limited to a maximum of
0,95d = " & Round(0.95 * (h - d1), 1) & " mm."
              z = 0.95 * (h - d1)
```

```
                TextBox_z = Round(z, 0)
                A2 = ((K - Kpr) * fck * b * (h - d1) ^ 2) / (Alfa2 * 0.87 * fy * (h - 
d1 - d2))
                TextBox_A2 = Round(A2, 0)
                A = ((K - Kpr) * fck * b * (h - d1) ^ 2) / (0.87 * fy * (h - d1 - d2)) 
+ (Kpr * fck * b * (h - d1) ^ 2) / (0.87 * fy * z)
                TextBox_A = Round(A, 0)
                TextBox_K = Round(K, 3)

            Else
                TextBox_Alert = "Provide compression steel: K > K'. Recalculate for d2 
> 0."
                z = 0.5 * (h - d1) * (1 + Sqr(T1))
                TextBox_z = Round(z, 0)
                TextBox_Alert2 = "z (for K' instead of K) = " & Round(z, 1) & " mm < 
0,95d = " & Round(0.95 * (h - d1), 1) & " mm."
                A2 = ((K - Kpr) * fck * b * (h - d1) ^ 2) / (Alfa2 * 0.87 * fy * (h - 
d1 - d2))
                TextBox_A2 = Round(A2, 0)
                A = ((K - Kpr) * fck * b * (h - d1) ^ 2) / (0.87 * fy * (h - d1 - d2)) 
+ (Kpr * fck * b * (h - d1) ^ 2) / (0.87 * fy * z)
                TextBox_A = Round(A, 0)
                TextBox_K = Round(K, 3)

            End If


  Worksheets("Linked").Range("D43").Value = Round((0.5 * (1 + Sqr(T1))), 2) 'double
  Worksheets("Linked").Range("D44").Value = Round((0.5 * (h - d1) * (1 + Sqr(T1))), 
1) 'double


  '---------------------------------------------------------
      End If


  '---------------------------------------------------------
  End If
  '---------------------------------------------------------

  Worksheets("Linked").Range("C30").Value = b
  Worksheets("Linked").Range("C31").Value = h
  Worksheets("Linked").Range("C32").Value = M / (10 ^ 6)
  Worksheets("Linked").Range("C35").Value = fy
  Worksheets("Linked").Range("C38").Value = (h - d1)
  Worksheets("Linked").Range("C39").Value = d2
  Worksheets("Linked").Range("C41").Value = Round(K, 3)
  Worksheets("Linked").Range("C45").Value = Round(A2, 0)
  Worksheets("Linked").Range("C47").Value = Round(A, 0)
  ' fine scrittura output
  '--------------------------------------------------------

End If
```

1.7 References

BRITISH STANDARDS INSTITUTION. The structural use of concrete – Part 1: Code of practice for design and construction, BS 8110–1:1997

EN 1992-1-1:2004. Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings. Brussels: CEN/TC 250 - Structural Eurocodes, December 2004 (DAV)

EN 1992-1-1:2004/AC:2010. Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings. Brussels: CEN/TC 250 - Structural Eurocodes, December 2010Reinforced Concrete Design to Eurocode, Bill Mosley, John Bungey and Ray Hulse, Palgrave Macmillan. 7th Edition

BS NA EN 1992-1-1 (2004) (English): UK National Annex to Eurocode 2. Design of concrete structures. General rules and rules for buildings

JRC Scientific and Technical Reports. Bridge Design to Eurocodes Worked examples. Worked examples presented at the Workshop “Bridge Design to Eurocodes”, Vienna, 4-6 October 2010. Support to the implementation, harmonization and further development of the Eurocodes. Editors A. Athanasopoulou, M. Poljansek, A. Pinto G., Tsionis, S. Denton

MPA The Concrete Centre. Worked Examples to Eurocode 2: Volume 1. Practical Design to Eurocode 2. 2013

Reinforced Concrete Design to Eurocode, Bill Mosley, John Bungey and Ray Hulse, Palgrave Macmillan. 7th Edition.

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