Biaxial bending (rectangular cross-section)

– Doubly reinforced section –

Ref. EN 1992-1-1
Sec. 9.5
Sec. 5.8.9 – Exp. (5.39)
Sec. 6.1 – Figure 6.1

Geometry cross-section

Rectangular shape:
Width b = 400 mm (width in respect of minor axis x-x)
Height h = 650 mm (depth in respect of major axis y-y)

Cl. 9.5.1(1): b/h ≥ 0,25

Analysis - (biaxial bending with a ≠ 0)

See "a" in Exp. (5.39)

2nd order effects in each direction (x-x and y-y) taken into account:
– bending moment about x-x axis (ULS): M_{Edx} = 370 kNm ($\geq$ 0)
– bending moment about y-y axis (ULS): M_{Edy} = 70 kNm ($\geq$ 0)
– axial load on column (ULS): N_{Ed} = 700 kN (compressive).

Materials – characteristic/design strengths

Concrete

Strength class for concrete:
f_{ck} = 30 N/mm^2 = 30 MPa
$f_{cd} = \alpha_{cc} f_{ck}/\gamma_c$ = 1,00f_{ck}/1,50 = 20,00 N/mm^2

Table 3.1

Steel

Strength of reinforcement (Class C): ε_{uk} = 7,50% → $\varepsilon_{ud} = 0{,}9\varepsilon_{uk}$ = 6,75%

Table C.1 – Annex C

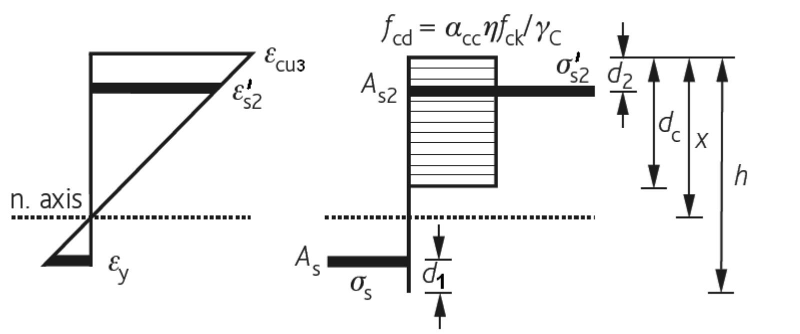
f_{yk} = 500 N/mm^2 = 500 MPa
$f_{yd} = f_{yk}/\gamma_s = f_{yk}/1{,}15 = 0{,}87 f_{yk}$ = 435 N/mm^2 = constant
E_s = 200 GPa; $\varepsilon_{yd} = f_{yd}/E_s$ = 0,002174 [-].

Cl. 3.2.7(2) b)

Stress-strain diagrams

Grade of concrete C30/37 with ε_{cu3} = 3,5/10^3, ε_{c3} = 1,75/10^3
η = 1,00, λ = 0,80.

Figure 3.5 – modified



a) Strain diagram b) Stress diagram

Durability and cover to reinforcement

Nominal cover to enclosing link:

$c_{nom} = c_{min} + \Delta c_{dev} = 30$ mm — **Exp. (4.1)**

Geometry

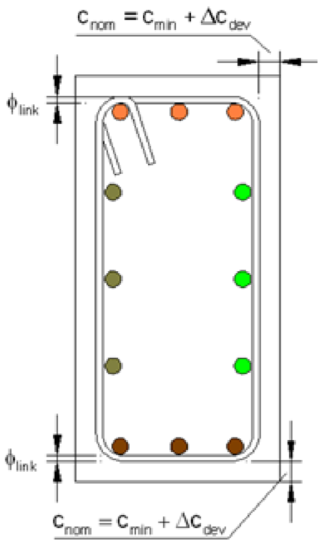
Maximum size of aggregate: $d_g = 25$ mm — **Cl. 8.2(2) – Note**

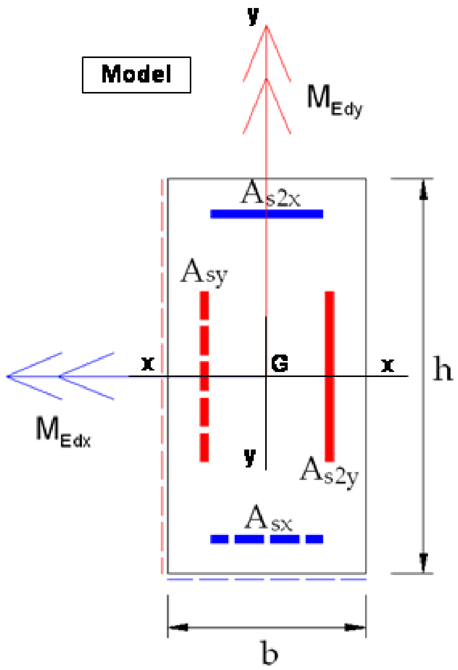
Diameter of enclosing link: $\phi_{link} = 10$ mm (shear requirements)

Main longitudinal reinforcement (provided)

[@section being considered]

Top steel: 5H18
vertical bars on the right side: 3H18
vertical bars on the left side: 3H18
Bottom steel: 5H18





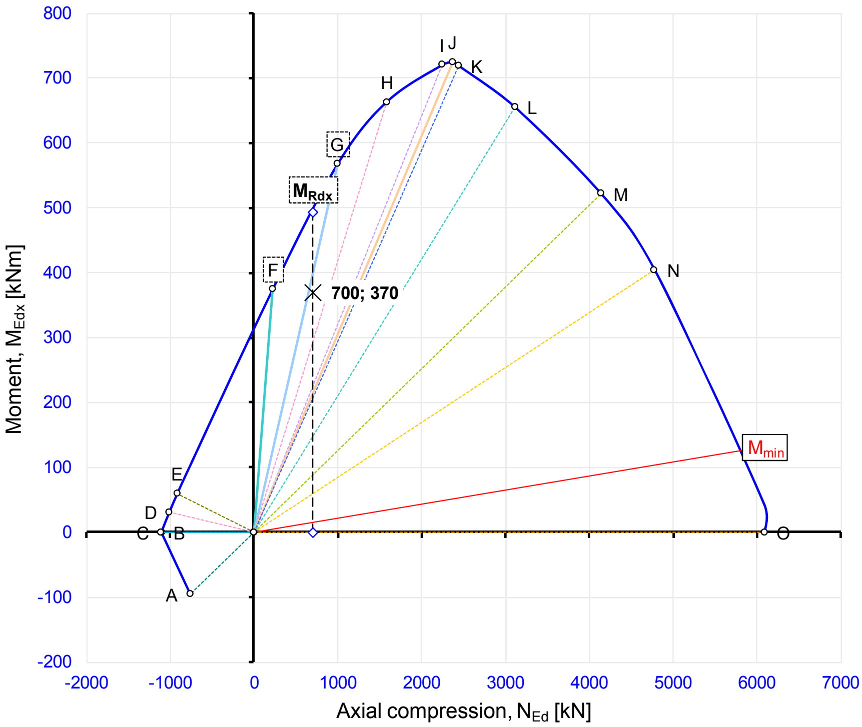
Areas of reinforcement – BRESLER Method

Sec. 5.8.9(4)

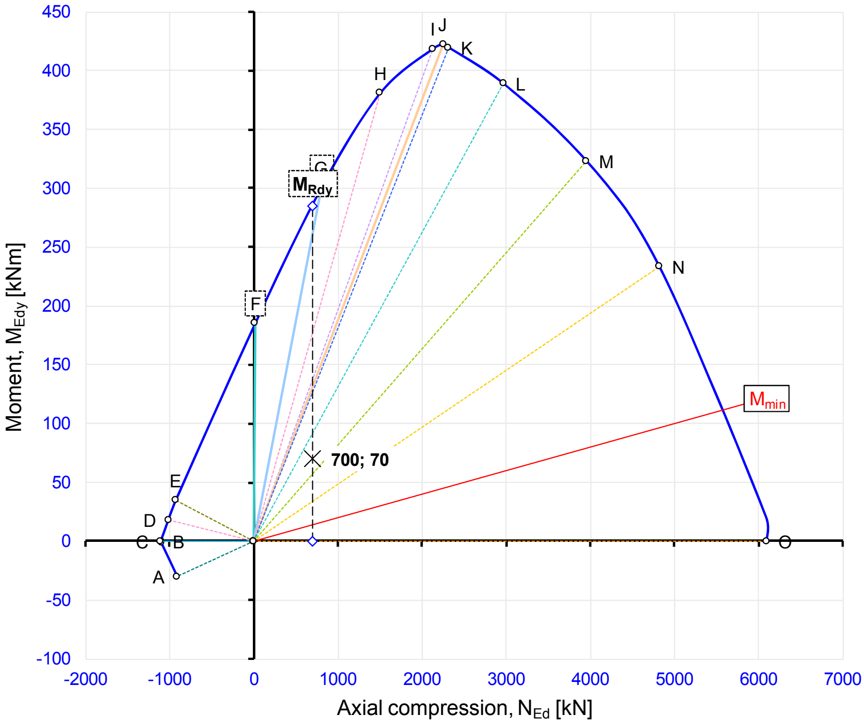
■ For bending moment about x-x axis :
Top: A_{s2x} = 5H18 = 1272 mm² (d_2 = 49 mm)
Bottom: A_{sx} = 5H18 = 1272 mm²
(d_1 = 49 mm → $d = h - d_1$ = 601 mm). — **Effective depth ⊥ x-x**

■ For bending moment about y-y axis:
Top: A_{s2y} = 3H18 + (1H18 + 1H18) = 1272 mm² (d_2 = 49 mm)
Bottom: A_{sy} = 3H18 + (1H18 + 1H18) = 1272 mm²
(d_1 = 49 mm → $d = h - d_1$ = 351 mm). — **Effective depth ⊥ y-y**

$M_{Rd,x}$: N_{Rd} interaction chart for b = 400 mm x h = 650 mm



Note: (biaxial bending with a ≠ 0).



$M_{Rd,y}$: N_{Rd} interaction chart for b = 650 mm x h = 400 mm

LEGENDA

A) $\varepsilon'_{s2} = -0{,}01;\ \varepsilon = 0\ @\ x = h$

B) $\varepsilon_s = \varepsilon'_{s2} = -\varepsilon_{ud}$

C) $\varepsilon_s = -\varepsilon_{ud};\ \varepsilon_c = 0$

D) $\varepsilon_s = -\varepsilon_{ud};\ \varepsilon_c = \varepsilon_{c3}$

E) $\varepsilon_s = -\varepsilon_{ud};\ \varepsilon_c = \varepsilon_{cu3}$

F) $\varepsilon_s = -0{,}01;\ \varepsilon_c = \varepsilon_{c3}$

G) $\varepsilon_s = -0{,}01;\ \varepsilon_c = \varepsilon_{cu3}$

H) $\varepsilon_s = -0{,}005;\ \varepsilon_c = \varepsilon_{cu3}$

I) $\varepsilon_s = -0{,}0025;\ \varepsilon_c = \varepsilon_{cu3}$

J) $\varepsilon_s = -\varepsilon_{yd} = -E_s / f_{yd};\ \varepsilon_c = \varepsilon_{cu3}$

K) $\varepsilon_s = -(\varepsilon_{yd} + 0{,}0001);\ \varepsilon_c = \varepsilon_{cu3}$

L) $\varepsilon_s = -0{,}0012;\ \varepsilon_c = \varepsilon_{cu3}$

M) $\varepsilon_s = -0{,}0002;\ \varepsilon_c = \varepsilon_{cu3}$

N) $\varepsilon_c = \varepsilon_{cu3};\ x = h$

O) $\varepsilon_s = \varepsilon'_{s2} = \varepsilon_c = \varepsilon_{c3}$

Reinforcement details

$A_{s,tot}$ = 5H18 + 5H18 + 3H18 + 3H18 = 4072 mm².

$A_{s,min}$ = MAX[0,10N_{Ed}/f_{yd}; 0,002bh] = 575 mm^2 ≤ $A_{s,tot}$ (satisfactory) — **Cl. 9.5.2(2) – Note**

$A_{s,max}$ = 0,04bh = 10400 mm^2 ≥ $A_{s,tot}$ (satisfactory). — **Cl. 9.5.2(3) – Note**

BRESLER Method

N_{Ed} = 700 kN (compressive).

N_{Rd} = bhf_{cd} + $A_{s,tot}f_{yd}$ = — **Cl. 5.8.9(4)**

= [(400)(650)(20,00) + (4072)(434,8)]/1000 = 6970 kN.

Biaxial bending for 0,1 ≤ N_{Ed}/N_{Rd} ≤ 1,0 (rectangular sections).

In this case:

N_{Ed}/N_{Rd} = 0,10 → a = 1,00 (biaxial bending with a ≠ 0). — **Cl. 5.8.9 – Exp. (5.39)**

With N_{Ed} = 700 kN (compressive):

$M_{Rd,x}$ = 493 kNm (ULS)

$M_{Rd,y}$ = 285 kNm (ULS)

M_{Edx} = 370 kNm (ULS)

M_{Edy} = 70 kNm (ULS)

$$\left(\frac{M_{Edx}}{M_{Rd,x}}\right)^a + \left(\frac{M_{Edy}}{M_{Rd,y}}\right)^a = (370/493)^{1,00} + (70/285)^{1,00} =$$ **Exp. (5.39)**

= 0,750 + 0,245 = 0,995 ≤ 1 (satisfactory)

(biaxial bending with a ≠ 0).

Note

$$\nu_d = \frac{N_{Ed}}{A_c f_{cd}} = \frac{N_{Ed}}{bhf_{cd}} = 0,135.$$