Column base: Open section column

COMPRESSION

Summary

The objective of this study is verification of CBFEM IDEA RS software with component method.

Description of verified connection: steel open section column is anchored with anchor bolts to concrete pad, the column is loaded with compressive force.

Inputs

Compressed column is designed as maximal 3rd class to avoid stability problems.

The study was performed for parameters: size of the column, dimensions of base plate, grade of concrete, dimensions of concrete pad.

Component method

Three components are examined: column flange and web in compression, concrete in compression including grout, welds.

All components are designed according to EN 1993-1-8.

Column flange and web in compression

Component “column flange and web in compression” is designed according to EN 1993-1-8 – 6.2.6.7.

Concrete in compression including grout

Component “concrete in compression including grout” is designed according to EN 1993-1-8 – 6.2.6.9 and EN 1992-1-1 – 6.7.

Two iterations of effective area are used to determine the resistance.

Fillet weld

The weld is closed around a cross-section of the column.

The thickness of the weld on the flanges is the same as the thickness of the weld on the web.

Design of the weld is done according to EN 1993-1-8 – 4.5.3.2(6).

Anchorage example – Steel column HEB 240:

$N_{Ed} = -1200\ \text{kN}$

Concrete pad dimensions: $a' = 1000\ \text{mm}$, $b' = 1500\ \text{mm}$, $h = 400\ \text{mm}$; concrete grade C20/25

Base plate dimensions: 330 x 440 x 20 mm, steel grade S235

$a = 330\ \text{mm};\ b = 440\ \text{mm};\ t_p = 20\ \text{mm}$

Anchor bolts: : 4 x M20, A_s = 245 mm^2, anchor head a = 60 mm, steel grade 8.8

Grout thickness: 30 mm

According to EN 1992-1-1 – 6.7 Partially loaded areas:

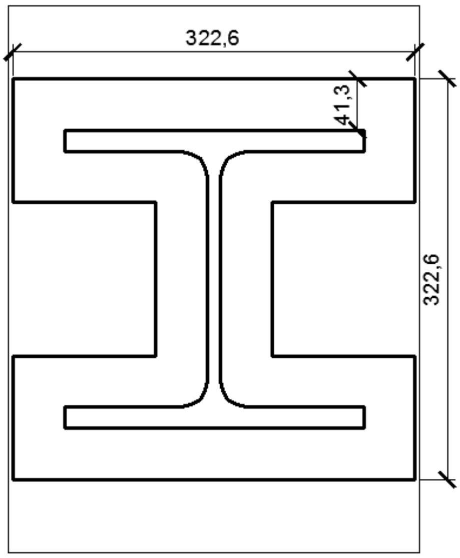
1st iteration:

$a_r = \min(x_1; x_2) = \min(335; 335) = 335\ \text{mm}$

$b_r = \min(y_1; y_2) = \min(380; 680) = 380\ \text{mm}$

$$a_1 = min\begin{Bmatrix} a + 2 \cdot a_r = 330 + 2 \cdot 335 = 1000\ \text{mm} \\ 5 \cdot a = 5 \cdot 330 = 1650\ \text{mm} \\ a + h = 330 + 400 = 730\ \text{mm} \\ 5 \cdot b_1 = 5 \cdot 840 = 4200\ \text{mm} \end{Bmatrix} = 730\ \text{mm}$$

$$b_1 = min\begin{Bmatrix} b + 2 \cdot b_r = 440 + 2 \cdot 380 = 1200\ \text{mm} \\ 5 \cdot b = 5 \cdot 440 = 2200\ \text{mm} \\ b + h = 440 + 400 = 840\ \text{mm} \\ 5 \cdot a_1 = 5 \cdot 730 = 3650\ \text{mm} \end{Bmatrix} = 840\ \text{mm}$$



$$k_j = \sqrt{\frac{a_1 \cdot b_1}{a \cdot b}} = \sqrt{\frac{730 \cdot 840}{330 \cdot 440}} = 2{,}055$$

$$f_{jd} = \frac{\beta_j \cdot k_j \cdot f_{ck}}{\gamma_c} = \frac{0{,}67 \cdot 2{,}055 \cdot 20}{1{,}5} = 18{,}358\ \text{MPa}$$

$$c = t_p \cdot \sqrt{\frac{f_y}{3 \cdot f_{jd} \cdot \gamma_{M0}}} = 20 \cdot \sqrt{\frac{235}{3 \cdot 18.358 \cdot 1{,}0}} = 41.3\ \text{mm}$$

$l_{eff} = 240 + 2 \cdot 41.3 = 322.6\ \text{mm}$ $\quad$ $l_{eff} = b + 2 \cdot c$

$b_{eff} = 17 + 2 \cdot 41.3 = 99.6\ \text{mm}$ $\quad$ $b_{eff} = t_f + 2 \cdot c$

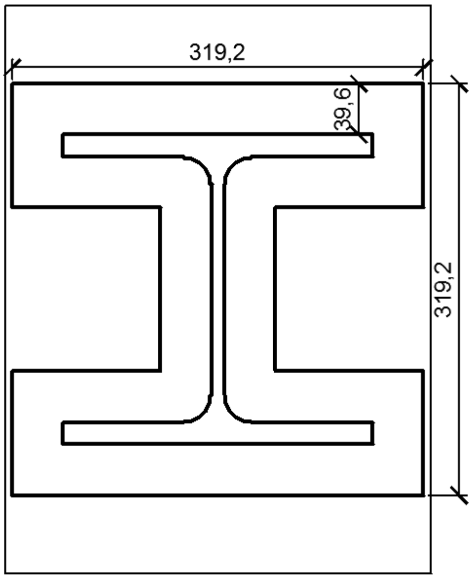
2nd iteration:

$a_r = \min(x_1; x_2) = \min(338.7; 338.7) = 338.7\ \text{mm}$

$b_r = \min(y_1; y_2) = \min(438.7; 738.7) = 438.7\ \text{mm}$

$$a_1 = min\begin{Bmatrix} a + 2 \cdot a_r = 322{,}6 + 2 \cdot 338.7 = 1000\ \text{mm} \\ 5 \cdot a = 5 \cdot 322.6 = 1613\ \text{mm} \\ a + h = 322.6 + 400 = 722{,}6\ \text{mm} \\ 5 \cdot b_1 = 5 \cdot 722.6 = 3613\ \text{mm} \end{Bmatrix} = 722.6\ \text{mm}$$

$$b_1 = min\begin{Bmatrix} b + 2 \cdot b_r = 322.6 + 2 \cdot 438.7 = 1200 \text{ mm} \\ 5 \cdot b = 5 \cdot 322.6 = 1613 \text{ mm} \\ b + h = 322.6 + 400 = 722.6 \text{ mm} \\ 5 \cdot a_1 = 5 \cdot 722.6 = 3613 \text{ mm} \end{Bmatrix} = 722.6 \text{ mm}$$



$$k_j = \sqrt{\frac{a_1 \cdot b_1}{a \cdot b}} = \sqrt{\frac{722.6 \cdot 722.6}{322.6 \cdot 322.6}} = 2.240$$

$$f_{jd} = \frac{\beta_j \cdot k_j \cdot f_{ck}}{\gamma_c} = \frac{0.67 \cdot 2.240 \cdot 20}{1.5} = 20.009 \text{ MPa}$$

$$c = t_p \cdot \sqrt{\frac{f_y}{3 \cdot f_{jd} \cdot \gamma_{M0}}} = 20 \cdot \sqrt{\frac{235}{3 \cdot 20.009 \cdot 1{,}0}} = 39.6 \text{ mm}$$

$l_{eff} = 240 + 2 \cdot 39.6 = 319.2$ mm $\boxed{l_{eff} = b + 2 \cdot c}$

$b_{eff} = 17 + 2 \cdot 39.6 = 96.2$ mm $\boxed{b_{eff} = t_f + 2 \cdot c}$

$A_{eff} = 72724.64 \text{ mm}^2$

$N_{Rd}^{-} = A_{eff} \cdot f_{jd} = 72724.64 \cdot 20.009 = 1455.147$ kN

Utilization: $\frac{N_{Ed}^{-}}{N_{Rd}^{-}} = \frac{1200}{1455.147} = 82.47\ \%$

Results by CBFEM Idea RS software

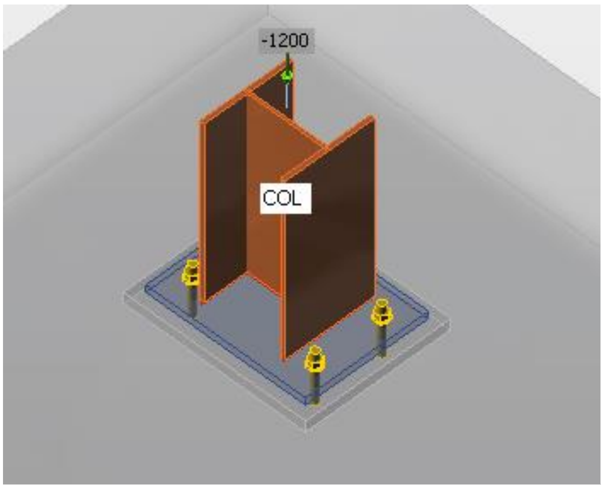
Combination of the advantages of finite element method and analytical component method.

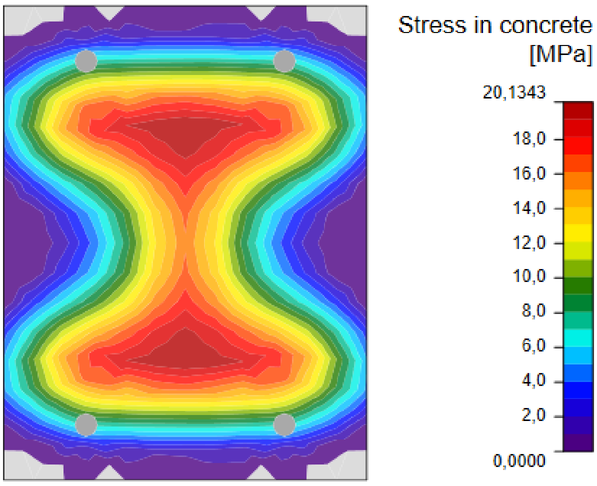
Shell elements, special spring and contact elements with characteristics according to the component method.

Elastic-plastic stress-strain diagram is used for material of shell elements. Assessment is based on the maximum strain given according to EN 1993-1-5 by value of 5%.

Bolts are modelled using special spring elements and assessment is carried out according to standard procedures described in EN 1993-1-8.

The results from Idea Connection software are shown below.





Code setting

Item	Value	Reference
γ_{M0}	1,00	EN 1993-1-1: 6.1
γ_{M1}	1,00	EN 1993-1-1: 6.1
γ_{M2}	1,25	EN 1993-1-1: 6.1

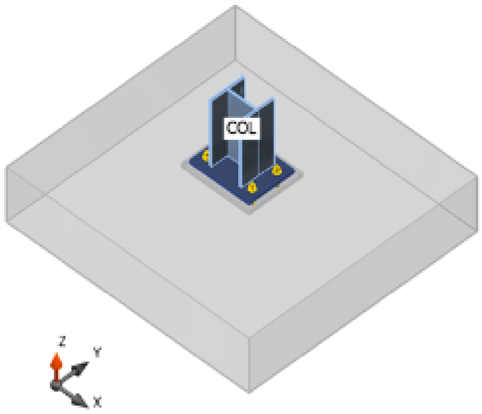
Material

Steel	S 235
Concrete	C25/30, C20/25

Verification_Compression

Beams and columns

Name	CrossSection	β – Direction [°]	γ - Pitch [°]	α - Rotation [°]	Offset ey [mm]	Offset ez [mm]
COL	HEA240	0,0	-90,0	0,0	0	0



Material

Steel	S 235
Concrete	C20/25
Bolts	M20 - 8.8 (DIN 934)

Load effects

Name	Member	Pos.	N [kN]	Vy [kN]	Vz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
LE1	COL	End	-1200,0	0,0	0,0	0,0	0,0	0,0

Summary

Name	Value	Check status
Analysis	Applied loads : 100,0%	OK
Plates	0,1 < 5%	OK
Bolts	0,0 < 100%	OK
Welds	48,9 < 100%	OK
Concrete block	62,6 < 100%	OK
Shear	0,0 < 100%	OK

Sensitivity study

Results of CBFEM Idea RS software were compared with the results of the component method. The comparison was focused on capacity and determination of the critical component.

The study was performed for parameters: size of the column, dimensions of base plate, grade of concrete, dimensions of concrete pad. The selected columns were HEB 200, HEB 300 and HEB 400. The base plate width and depth was chosen 100 mm, 150 mm and 200 mm larger than the column section, the base plate thickness was 15 mm, 20 mm and 25 mm. The concrete pad was from grade C16/20, C25/30 and C35/45. The concrete pad height was for all cases 800 mm and width and depth was 200 mm, 300 mm and 400 mm larger than the dimensions of the base plate. The parameters are summarized in tab. 1. Welds were the same around the whole column section. The fillet welds had the throat thickness a = 8 mm.

Table 1: Selected parameters

column section	HEB 200	HEB 300	HEB 400
base plate offset	100 mm	150 mm	200 mm
base plate thickness	15 mm	20 mm	25 mm
concrete grade	C16/20	C25/30	C35/45
concrete pad offset	200 mm	300 mm	400 mm

The resistances determined by component method are in tab. 2. One parameter was changed and the others were held constant at the middle value. N_{Rd} is the resistance of component "concrete in compression including grout", $F_{c,fc,Rd}$ is the resistance of component "column flange and web in compression" and $F_{c,weld}$ is the resistance of welds considering uniform distribution of stress. The coefficient lowering the compressive strength of concrete due to grout β_j = 0.67 was used.

Table 2: Component method

Column	**B.p. offset [mm]**	**B.p. thickness [mm]**	**Concrete grade**	**C.p. offset [mm]**	**N_{Rd} [kN]**	**2.$F_{c,fc,Rd}$ [kN]**	**$F_{c,weld}$ [kN]**
HEB 200	150	20	C25/30	300	1753	**1632**	2454
HEB 300	150	20	C25/30	300	**2352**	3126	3466
HEB 400	150	20	C25/30	300	**2579**	4040	3822
HEB 300	100	20	C25/30	300	**2296**	3126	3466
HEB 300	200	20	C25/30	300	**2408**	3126	3466
HEB 300	150	15	C25/30	300	**1909**	3126	3466
HEB 300	150	25	C25/30	300	**2795**	3126	3466
HEB 300	150	20	C16/20	300	**1789**	3126	3466
HEB 300	150	20	C35/45	300	**2908**	3126	3466
HEB 300	150	20	C25/30	200	**2064**	3126	3466
HEB 300	150	20	C25/30	400	**2517**	3126	3466

The model in Idea Connection was loaded by the compressive force equal to N_{Rd}, which was determined from the component method. The value of concrete block resistance was chosen as applied force divided by concrete block utilization obtained from the program. The same approach was used to get the resistance of welds $F_{c,weld}$: the applied force was divided by weld utilization of the most stressed weld. Note that the program uses nonlinear analysis and thus this approach to determine the resistances is not completely correct and precise. The same coefficient as in the analytical solution "Joint coefficient β_j" = 0,67 and the "Effective area – coefficient of max stress" = 0,38 were used.

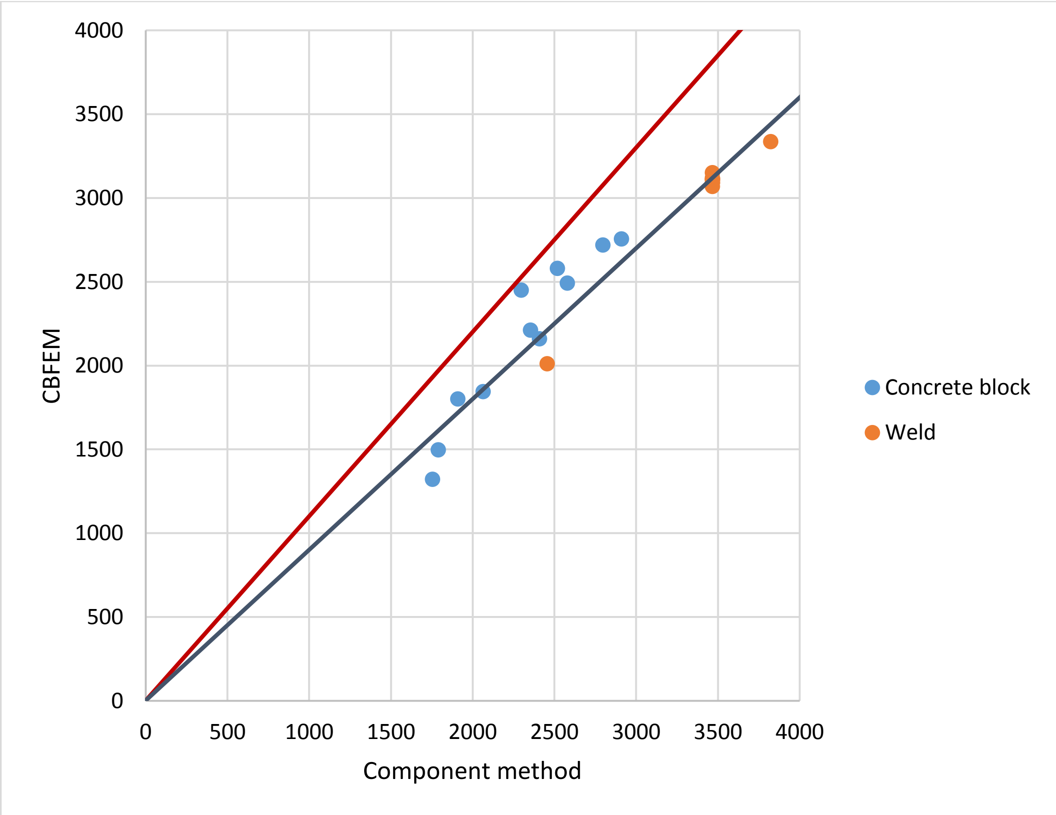
Table 3: CBFEM method

Column	B.p. offset [mm]	B.p. thickness [mm]	Concrete grade	C.p. offset [mm]	Concrete block [kN]	Plates [kN]	$F_{c,weld}$ [kN]
HEB 200	150	20	C25/30	300	**1321**	1860	2010
HEB 300	150	20	C25/30	300	**2211**	3516	3111
HEB 400	150	20	C25/30	300	**2492**	ok	3336
HEB 300	100	20	C25/30	300	**2450**	ok	3107
HEB 300	200	20	C25/30	300	**2160**	ok	3091
HEB 300	150	15	C25/30	300	**1801**	ok	3150
HEB 300	150	25	C25/30	300	**2719**	ok	3068
HEB 300	150	20	C16/20	300	**1497**	ok	3090
HEB 300	150	20	C35/45	300	**2756**	ok	3117
HEB 300	150	20	C25/30	200	**1845**	ok	3108
HEB 300	150	20	C25/30	400	**2579**	ok	3119

Reliability

Reliability of CBFEM software is provided in accordance with the strategy of EC considering partial safety factors.

Material safety factors according to EN 1993-1-8 are used for design resistance of the connection. For concrete γ_c = 1.5, for welds γ_{M2} = 1.25 and for plates γ_{M0} = 1.0.



Graph 1: Reliability graph

The red and blue lines correspond to the 110 % and 90 % value of resistance from component method, respectively. The points below the blue line have difference higher than 10 % but are on the safe side. The worst result on the unsafe side was by 6.71 % higher than according to the component method. All results of CBFEM weld resistance were around 90 % of component method results. This is caused by the fact that the stress in weld is the same on the flanges and the web in the case of component method but is higher at the flanges than at the web because of various stiffness in the case of CBFEM.

Recapitulation

Verification studies confirmed the accuracy of the CBFEM IDEA RS software. Results of this software were compared with the results of the component method recommended in EN 1993-1-8. Most of the results differences are below 10 %, which is a generally acceptable value, and nearly all results of CBFEM are safer than those obtained from component method.

Reliability of CBFEM software is provided in accordance with the strategy of EC considering partial safety factors.