6.2 Column web panel in shear

6.2.1 Description

The objective of this study is a verification of component based finite element method (CBFEM) of a beam-column joint with a class 4 column web with research FEM model (RFEM) and component method (CM).

6.2.2 Analytical model

The component column web panel in shear is described in cl. 6.2.6.1 EN1993-1-8:2006. The design method is limited to column web slenderness $d / t_w \leq 69\ \varepsilon$. Webs with higher slenderness are designed according to EN1993-1-5:2005 cl. 5 and Annex A. The shear resistance is made of shear buckling resistance of the web panel and resistance of the frame made of the flanges and stiffeners surrounding the panel. The buckling resistance of the web panel is based on the shear critical stress

$$\tau_{cr} = k_\tau \sigma_E \qquad (6.2.1)$$

where σ_E is the Euler critical stress of the plate

$$\sigma_E = \frac{\pi^2 E}{12(1-\nu^2)} \left(\frac{t_w}{h_w}\right)^2 \qquad (6.2.2)$$

The buckling coefficient k_τ is obtained in EN 1993-1-5 Annex A.3.

The slenderness of the web panel is

$$\bar{\lambda}_w = 0{,}76 \sqrt{\frac{f_{yw}}{\tau_{cr}}} \qquad (6.2.3)$$

The reduction factor χ_w may be obtained in EN 1993-1-5 cl. 5.3.

The shear buckling resistance of the web panel is

$$V_{bw,Rd} = \frac{\chi_w f_{yw} h_w t_w}{\sqrt{3}\gamma_{M1}} \qquad (6.2.4)$$

The resistance of the frame may be designed according to cl. 6.2.6.1 EN 1993-1-8:2006.

6.2.3 Research FEM model

Research FEM model (RFEM) is used to verify the CBFEM model. In the numerical model, 4-node quadrilateral shell elements with nodes at its corners are applied. Material and geometric nonlinear analysis with imperfections (GMNIA) is applied. Equivalent geometric imperfections are derived from the first buckling mode and the amplitude is set according to EN1993-1-5:2005 Annex C. A numerical model is shown in Fig. 6.2.1.

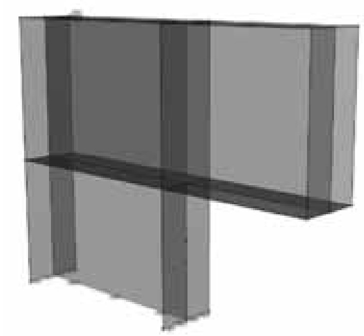

Fig. 6.2.1 Research FEM model of a beam-column joint with slender column panel

6.2.4 Design finite element model

The design procedure for slender plates is described in section 3.8. The buckling analysis is implemented in the software. The calculation of the design resistances is done according to design procedure. F_{CBFEM} is interpolated by the user until $\rho \cdot \alpha_{ult,k}/\gamma_{M1}$ is equal to 1.

A beam-column joint with a slender column web is studied. The height of the beam web is changing, thus the width of the column web panel is changing. The geometry of the examples is described in Tab. 6.2.1. The joint is loaded by bending moment.

Tab. 6.2.1 Examples overview

Example	Column flange		Column web		Beam	Material
	b_f	t_f	h_w	t_w	IPE	
	[mm]	[mm]	[mm]	[mm]		
IPE400	250	10	820	4	400	S235
IPE500	250	10	820	4	500	S235
IPE600	250	10	820	4	600	S235

6.2.5 Global behaviour and verification

The global behaviour of a beam-column joint with slender column web described by moment-rotation diagram in CBFEM model is shown in Fig. 6.2.2. Attention is focused to the main characteristics: design resistance and critical load. The diagram is completed with a point where yielding starts and resistance by 5 % plastic strain.

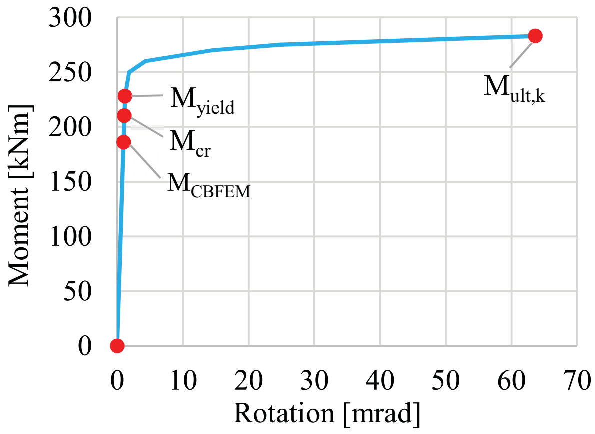

Fig. 6.2.2 Moment-rotation curve of example IPE600

6.2.6 Verification of resistance

The design resistance calculated by CBFEM is compared with RFEM and CM. The comparison is focused on the design resistance and critical load. The results are ordered in Tab. 6.2.2. The diagram in Fig. 6.2.3c shows the influence of the width of the column web on the resistances and critical loads in the examined examples.

Tab. 6.2.2 Design resistances and critical loads of RFEM, CBFEM and CM

Example	M_{cr}			α_{cr}	M			$\alpha_{ult,k}$	Difference	
	RFEM	CM	CBFEM	CBFEM	RFEM	CM	CBFEM	CBFEM	M_{CBFEM} / M_{RFEM}	M_{CBFEM} / M_{CM}
	[kNm]	[kNm]	[kNm]	[-]	[kNm]	[kNm]	[kNm]	[-]	[%]	[%]
IPE400	256	275	303	1,75	170	177	186	1	9	5
IPE500	216	234	236	1,31	177	194	180	1,29	2	8
IPE600	195	210	210	1,13	200	205	186	1,52	8	10

The results show good agreement in critical load and design resistance. The CBFEM model of the joint with a beam IPE600 is shown in Fig. 6.2.3a. The first buckling mode of the joint is shown in Fig. 6.2.3b.

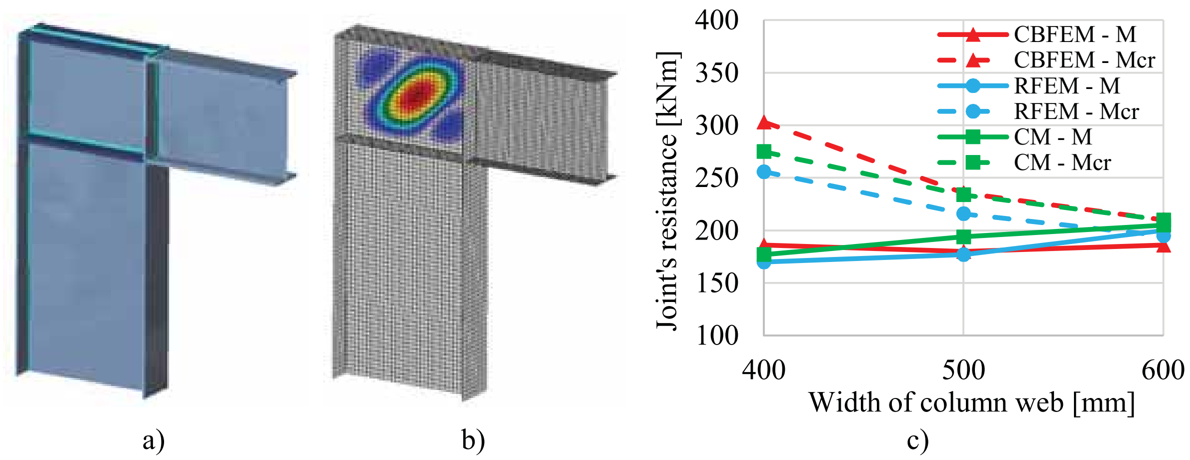

Fig. 6.2.3 a) CBFEM model b) First buckling mode
c) Influence of width of column web on resistances and critical loads

Verification studies confirmed the accuracy of the CBFEM model for prediction of a column web panel behaviour. Results of CBFEM are compared with the results of the RFEM and CM. The design procedure is verified on the RFEM model. Procedures predict similar global behaviour of the joint. The difference in design resistance is in all cases up to 10 %.

6.2.7 Benchmark example

Inputs

Beam

- Steel S235
- IPE600

Column

- Steel S235
- Flange thickness $t_f = 10$ mm
- Flange width $b_f = 250$ mm
- Web thickness $t_w = 4$ mm
- Web height $h_w = 820$ mm

Web stiffener

- Steel S235
- Stiffener thickness $t_w = 19$ mm
- Stiffener width $h_w = 250$ mm
- Stiffeners opposite to upper and lower flange

Outputs

- Load by 5 % plastic strain $M_{ult,k} = 283$ kNm
- Design resistance $M_{CBFEM} = 186$ kNm
- Critical buckling factor (for $M = 186$ kNm) $\alpha_{cr} = 1,13$
- Load factor by 5 % plastic strain $\alpha_{ult,k} = M_{ult,k} / M_{CBFEM} = 283/186 = 1,52$