SIMPLIFIED NUMERICAL MODEL DEVELOPMENT OF LIGHTWEIGHT-CONCRETE ENCASED COLD-FORMED STEEL ELEMENTS

By

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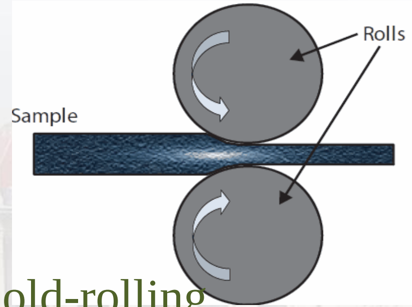
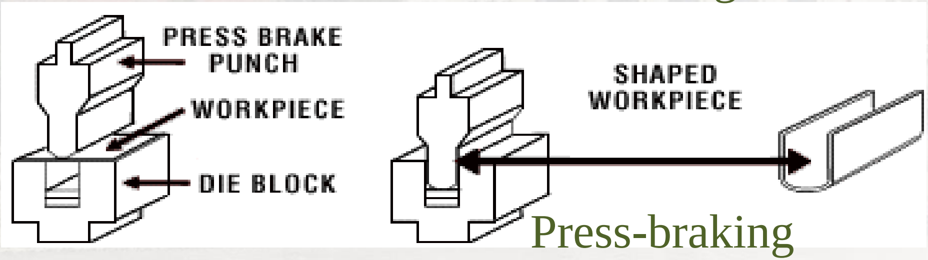
INTRODUCTION ABOUT COLD-FORMED STEEL SECTIONS

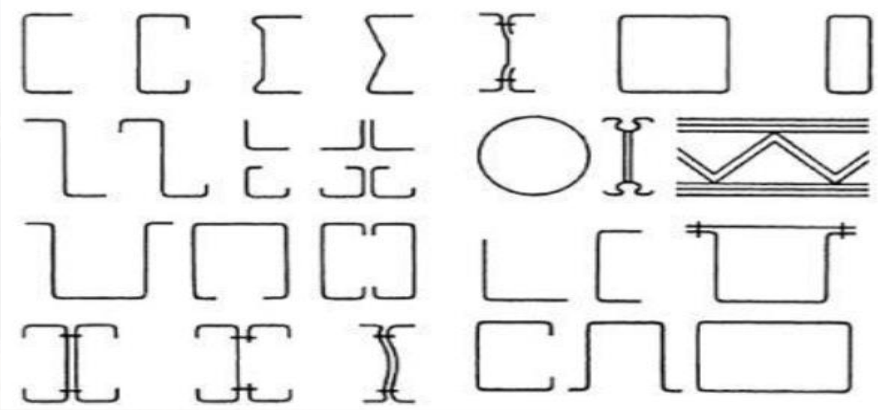


Cold-rolling



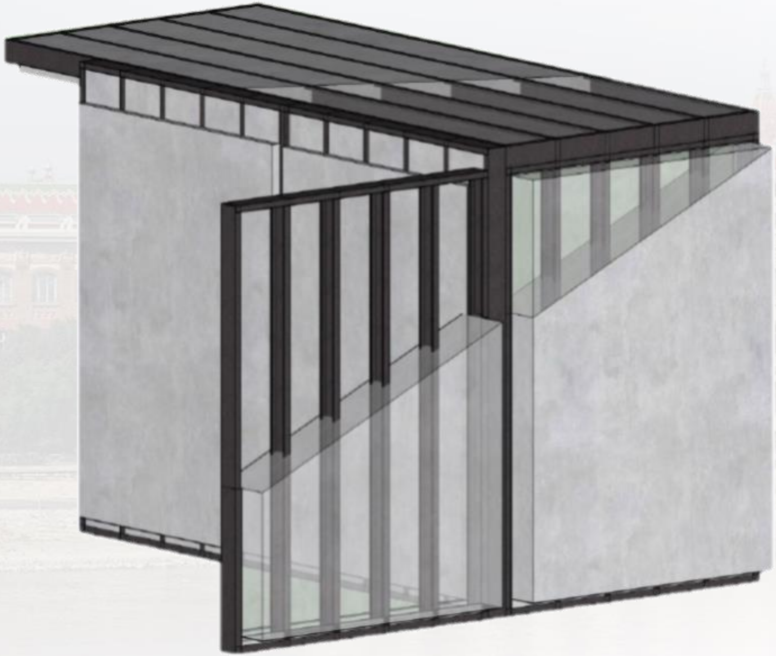
Press-braking

Bending brake

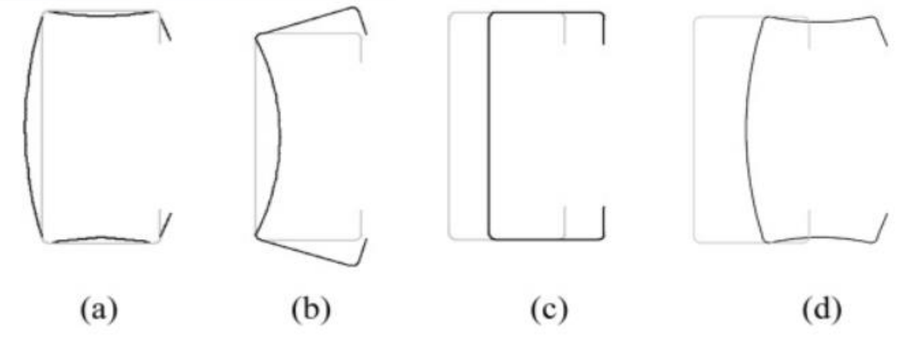


Cross sections

INTRODUCTION



Innovative building system [Hegyi and Dunai, 2016]

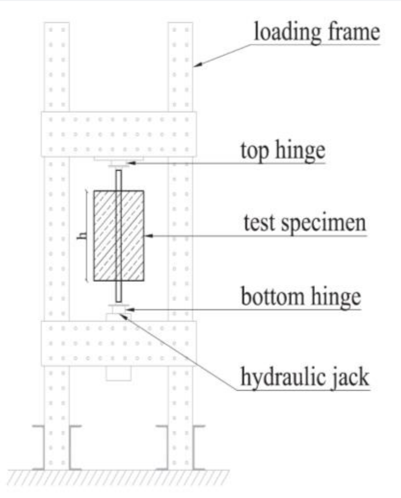


Buckling modes of cold-formed sections (CFS): (a) local, (b) distortional, (c) global and (d) local-flexural interactive modes [Ye et al., 2018]

EXPERIMENTAL TEST [Hegyi and Dunai, 2016]

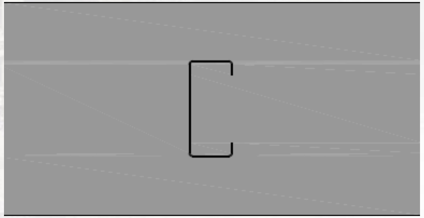
A: E= 115.36 MPa

X: E= 270.39 MPa



Loading frame of the member tests

Failure modes of unbraced elements: a) 300 mm; b) 600 mm; c) 2000 mm



Cross-section of braced elements

Local failure at the end of the braced specimen

specimen type	Number of specimens[a]	Ultimate load [kN]			Increment [%]	
		Unbraced – 0	Braced – A	Braced – X	Braced – A	Braced – X
C90-10-300	3/3/2	27.34	38.93	40.26	42	47
C90-10-600	3/2/3	27.34	37.80	37.44	38	37
C90-10-2000	3/3/3	17.76	34.44	33.57	94	89

POLYSTYRENE AGGREGATE CONCRETE (PAC)

Polystyrene concrete block

Expanded Polystyrene beads

E_c= [30-300] MPa

- Poor strength
- Light weight
- Low thermal conductivity

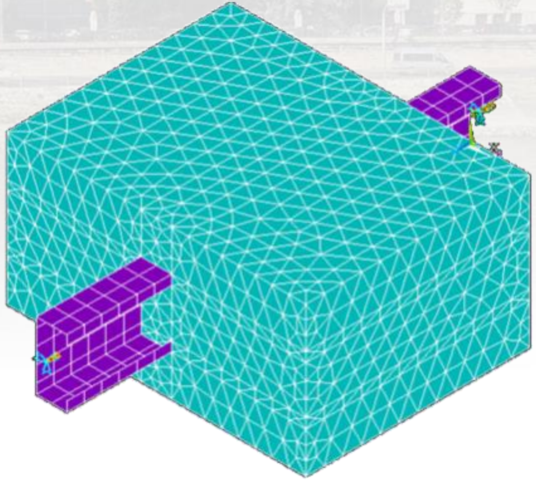
Research problem

CFS encased in lightweight-concrete are new elements → new structural system

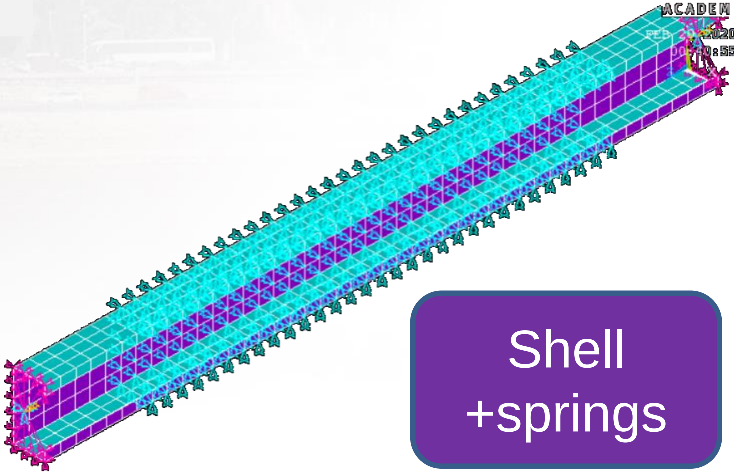
- → Checking by experimental test
- → Checking by numerical model
- → New design rules

Research aim

- Development of a simplified shell finite element model
- Validation of the model by test results
- Providing rules for the simplified model



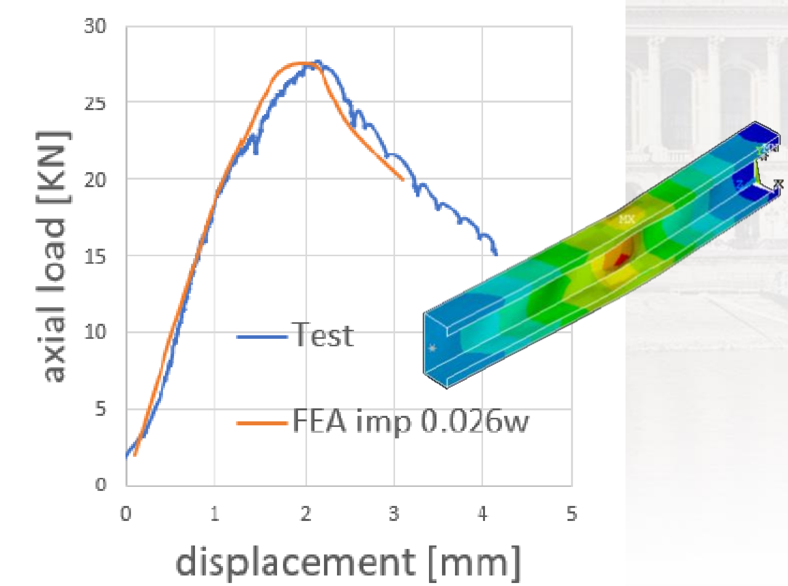
Shell
+solid



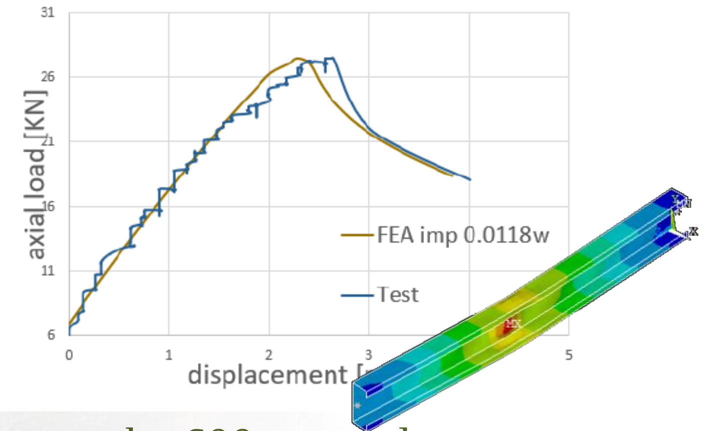
Shell
+springs

NUMERICAL MODEL DEVELOPMENT FOR UNBRACED SPECIMENS

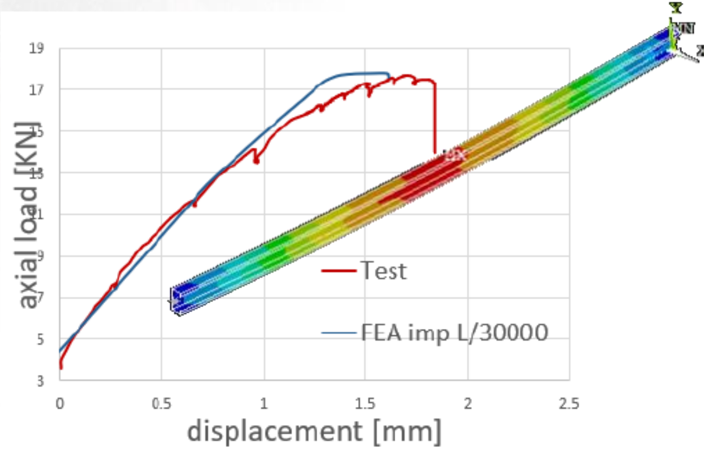
Experimental and numerical axial load–displacement curves of:



the 300 mm column



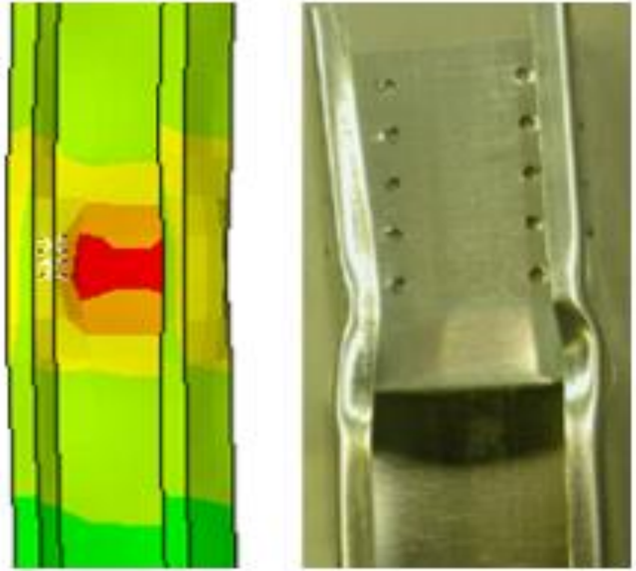
the 600 mm column



the 2000 mm column

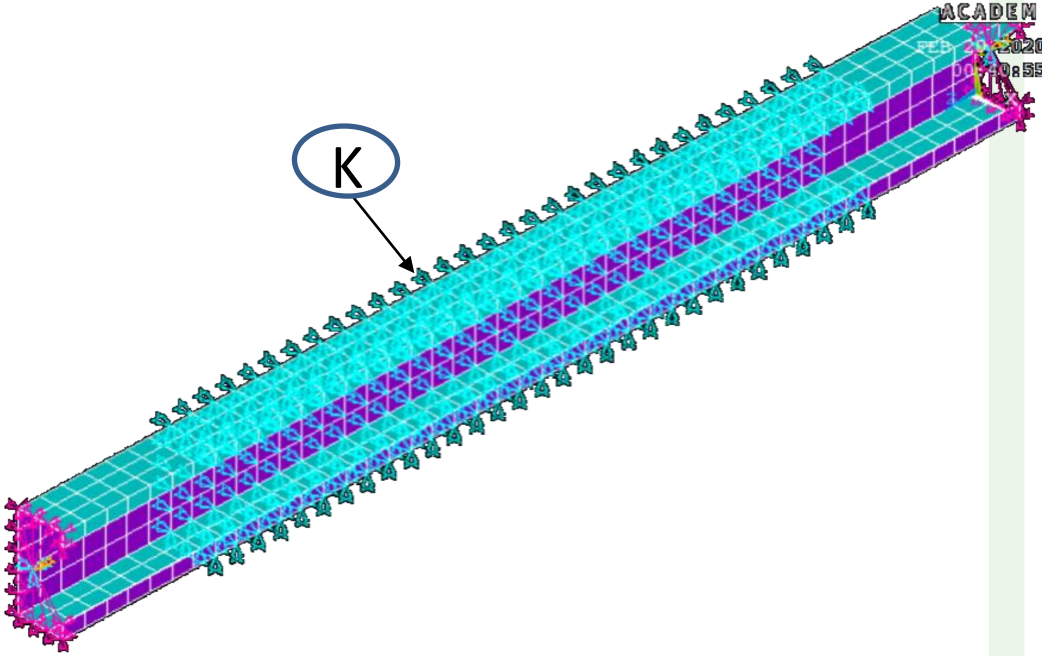
COMPARISON OF TESTS AND FEA ULTIMATE LOADS

Column length [mm]	Ultimate load [KN]		
	Test	**FEA**	**FEA/Test**
300	27.34	27.59	1.01
600	27.34	27.43	1.00
2000	17.76	17.80	1.00



Comparison of local failure mode between test and FEA for 300 mm specimens

Simplified numerical model development for braced specimens

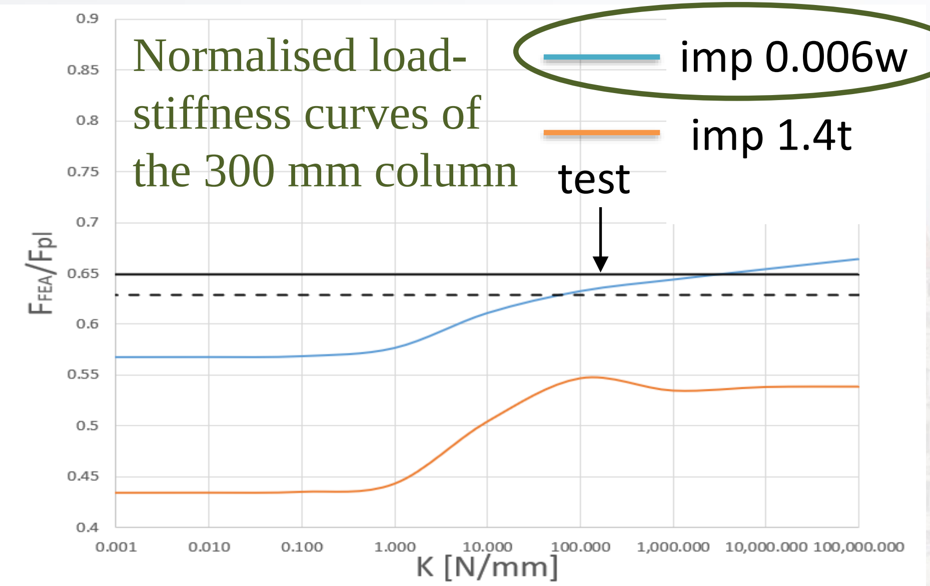


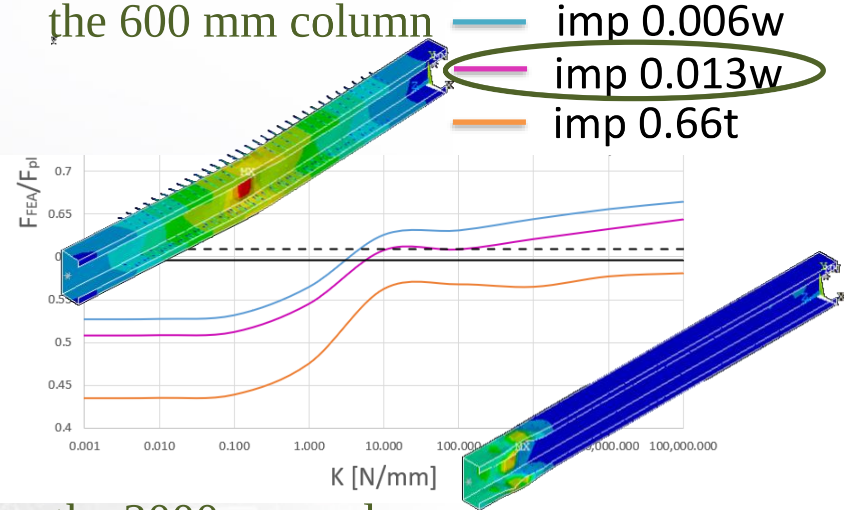
Applied load and restraint conditions for braced specimens

Parametric study:

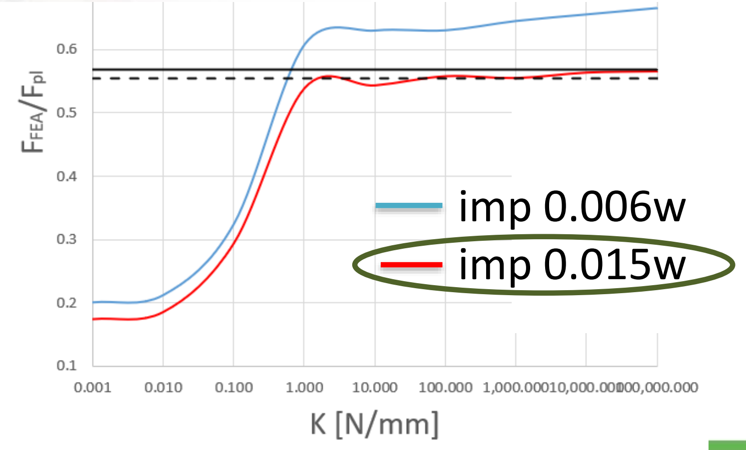
- Predict the bracing effect of concrete
- Determine the optimum range of bracing

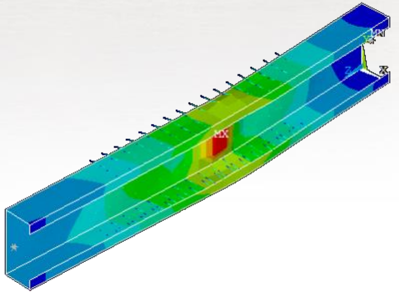
K = 0.001-100000 N/mm

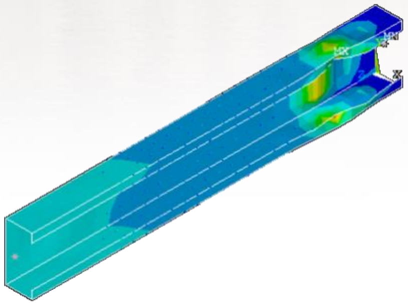


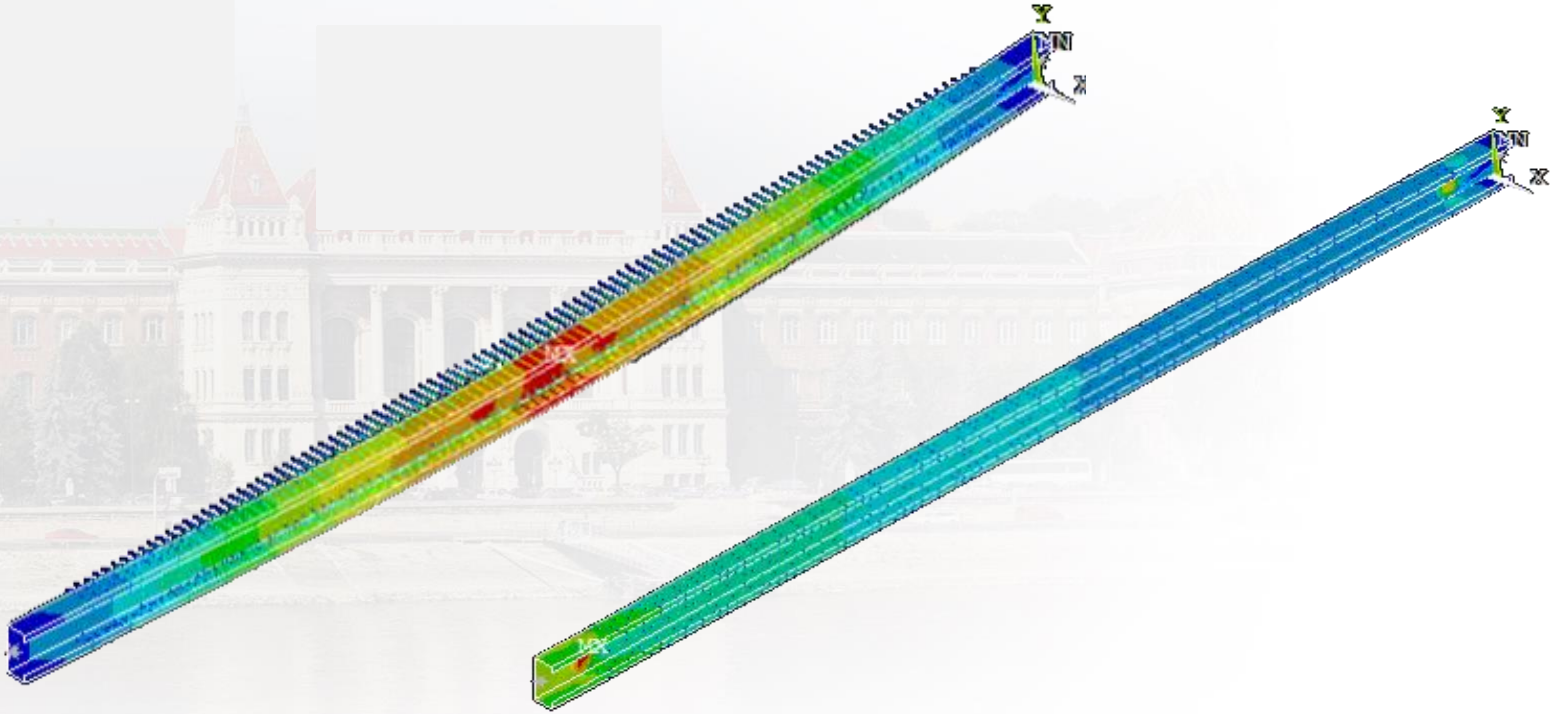


the 2000 mm column









Failure mode of the 2000 mm column

SPRING STIFFNESS FORMULA DEVELOPMENT FOR PAC BRACED MEMBERS

[Hegedűs and Kollár, 2006]

$$k_w = \frac{2\pi E_c}{(3-\upsilon_c)(1+\upsilon_c)}\sqrt{\frac{1}{l_x^2}+\frac{1}{l_y^2}}$$

$$w = A_0 \cdot \sin\frac{\pi x}{l_x} \cdot \sin\frac{\pi y}{l_y}$$

$$\longrightarrow \frac{D}{t}\left(\frac{\partial^4 w}{\partial x^4}+2\frac{\partial^4 w}{\partial x^2 \partial y^2}+\frac{\partial^4 w}{\partial y^4}\right)-\sigma_x\frac{\partial^2 w}{\partial x^2}-2\tau_{xy}\frac{\partial^2 w}{\partial x \partial y}-\sigma_y\frac{\partial^2 w}{\partial y^2}=\frac{k_w}{t}w$$

Internal compressed element model [Hegyi, 2016]

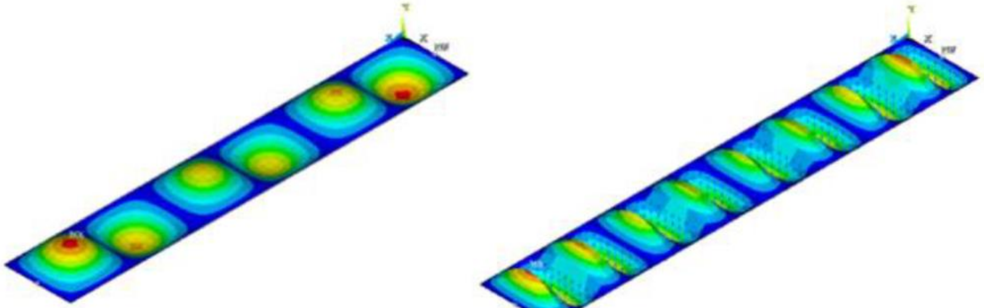
$$\sigma_{cr,p} = 4\frac{\pi^2 E_s}{12(1-\upsilon_s^2)(b/t)^2} - \frac{4680\ MPa}{b/t} + 2.35E_c + \sqrt{E_c.3025\ MPa}$$

Outstand compressed element model

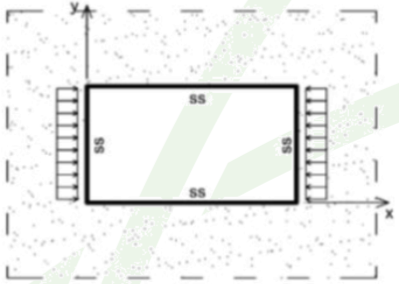
$$\sigma_{cr,p} = 0.43\frac{\pi^2 E_s}{12(1-\upsilon_s^2)(b/t)^2} + \frac{1200\ MPa}{b/t} + 2.22E_c + \sqrt{E_c.3390\ MPa} - 40MPa$$

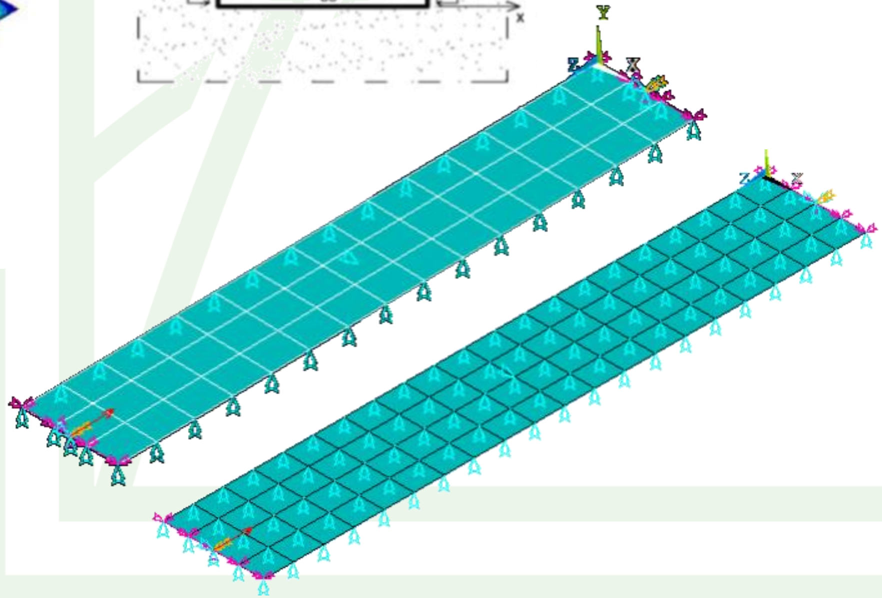
Spring stiffness formula development for PAC braced members

Internal compressed element model



Buckling mode of unbraced (left) and braced (right) internal compressed plates (b/t=50)





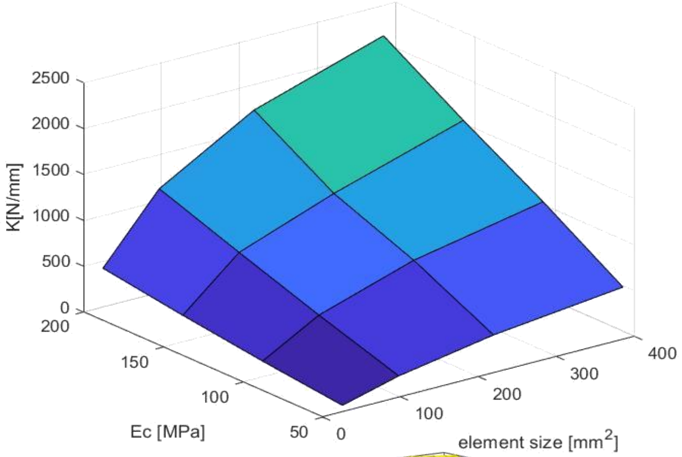
Applied load and boundary conditions for simply supported unbraced and braced plates

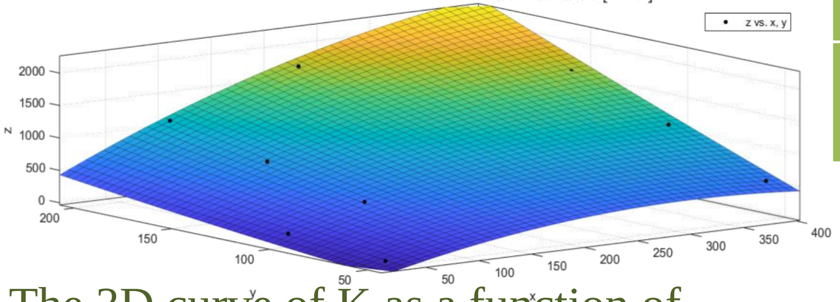
Parameter range of numerical investigation

Parameter	Range	
Plate slenderness (b/t)	Internal	Outstand
	50-250	20-60
Elastic modulus of PAC (E_c)	50-200 [MPa]	
Element size (A)	5-20 [mm]	

SPRING STIFFNESS FORMULA DEVELOPMENT FOR INTERNAL PLATES

$$K = a\left[\frac{N}{mm}\right] + b\left[\frac{N}{mm^3}\right].A + c\,[mm].E_C + d\left[\frac{N}{mm^5}\right].A^2 + e\left[\frac{1}{mm}\right].A.E_C + f\left[\frac{mm^3}{N}\right].{E_C}^2$$

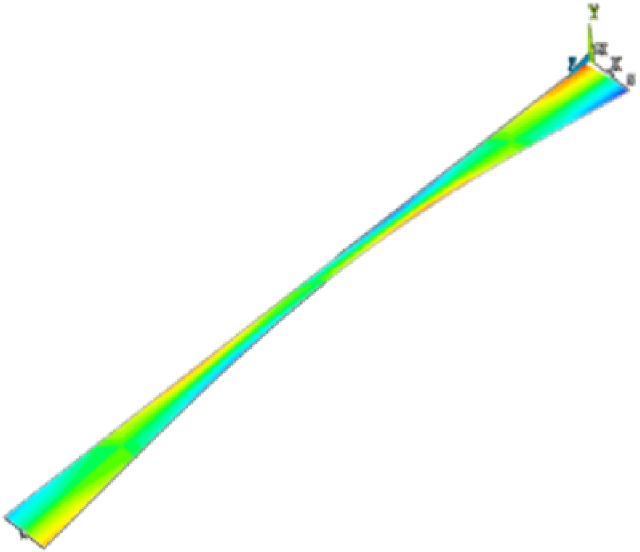


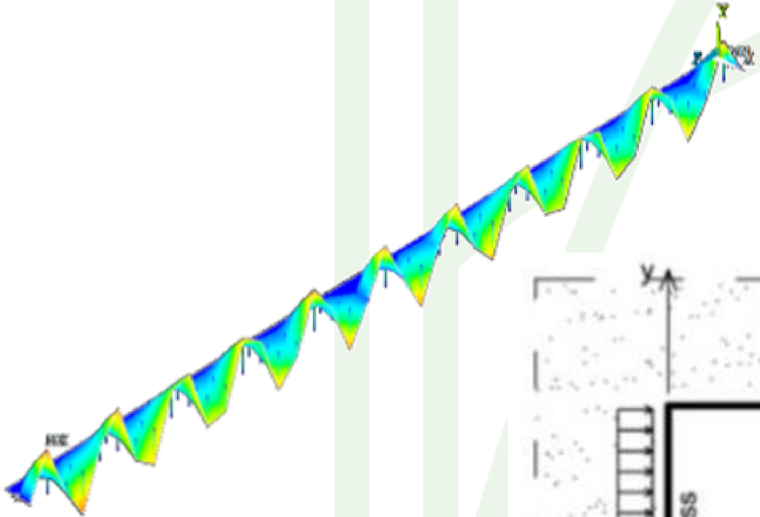


The 3D curve of K as a function of Ec and A (b/t=175)

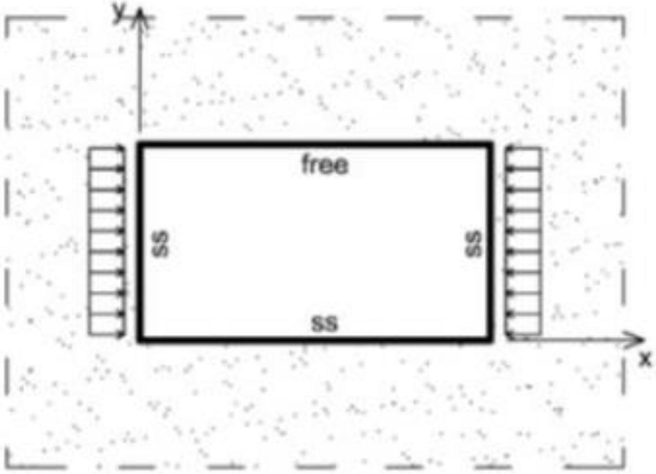
b/t	a $\left[\frac{N}{mm}\right]$	b $\left[\frac{N}{mm^3}\right]$	C [mm]	d $\left[\frac{N}{mm^5}\right]$	e $\left[\frac{1}{mm}\right]$	f $\left[\frac{mm^3}{N}\right]$
50	-203.2	5.231	1.942	-0.0236	0.02615	0.001267
100	-228.7	3.028	2.628	-0.00629	0.01938	0.0015
175	-197.3	3.147	2.002	-0.0068	0.02156	0.003725
250	-262.9	3.668	2.82	-0.00802	0.02174	0.001072

OUTSTAND COMPRESSED ELEMENT MODEL



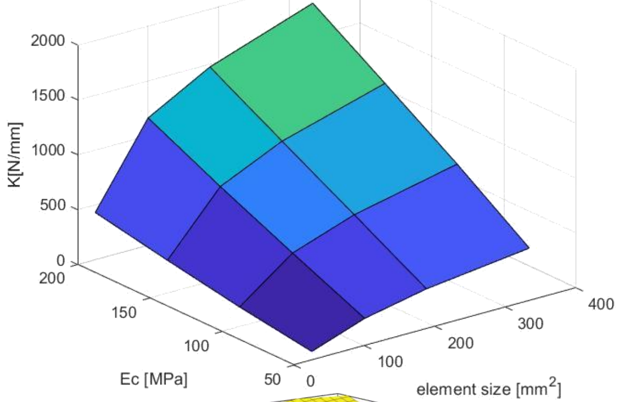


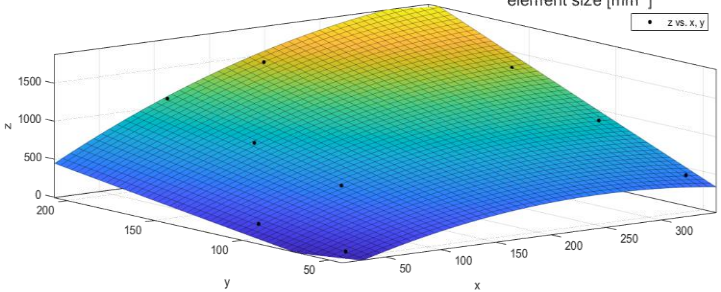
Buckling mode of unbraced (left) and braced (right) outstand compressed plates (b/t=20)



OUTSTAND COMPRESSED ELEMENT MODEL

$$K = a\left[\frac{N}{mm}\right] + b\left[\frac{N}{mm^3}\right].A + c\,[\mathrm{mm}].E_C + d\left[\frac{N}{mm^5}\right].A^2 + e\left[\frac{1}{mm}\right].A.E_C + f\left[\frac{mm^3}{N}\right].{E_C}^2$$





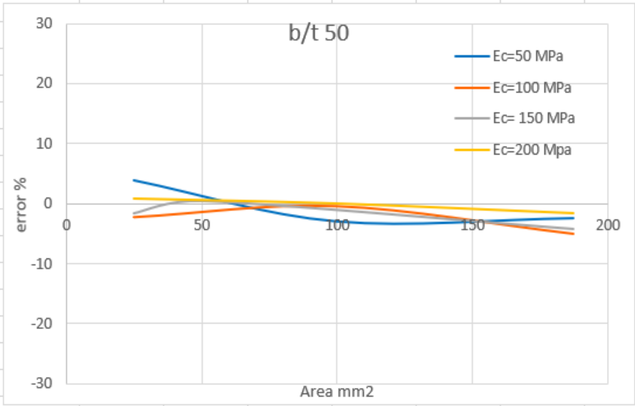
The 3D curve of K as a function of Ec and A (b/t=50)

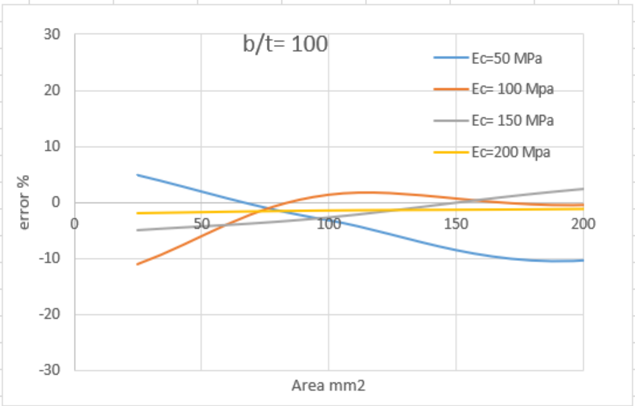
b/t	a $\left[\frac{N}{mm}\right]$	b $\left[\frac{N}{mm^3}\right]$	C [mm]	d $\left[\frac{N}{mm^5}\right]$	e $\left[\frac{1}{mm}\right]$	f $\left[\frac{mm^3}{N}\right]$
20	-190.1	5.984	1.726	-0.03303	0.02399	0.001433
35	-231.1	3.485	2.906	-0.00814	0.01683	0.0004
50	-255.9	3.879	2.891	-0.0096	0.01908	0.000625
60	-269.9	3.735	3.024	-0.00816	0.02133	0.00022

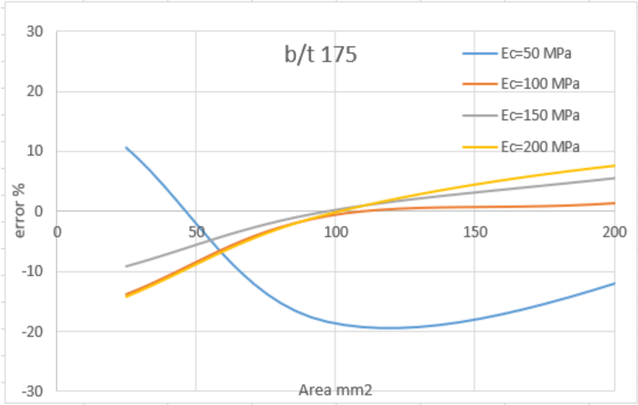
APPROXIMATING EQUATION SUGGESTION FOR SPRING STIFFNESS FORMULA

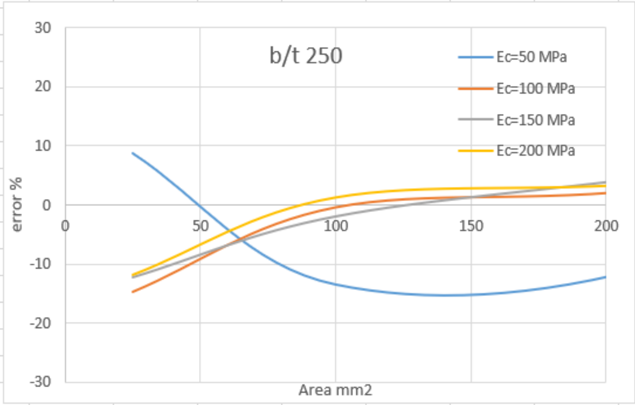
$$K= -200 \left[\frac{N}{mm}\right] + 4 \left[\frac{N}{mm^3}\right] A + 2.5\ [\mathrm{mm}]\ E_C + 0.009\left(- A^2 \left[\frac{N}{mm^5}\right] + A.E_C \left[\frac{1}{mm}\right] + E_C{}^2 \left[\frac{mm^3}{N}\right]\right)$$

The error of the simplified formula in case of internal plate





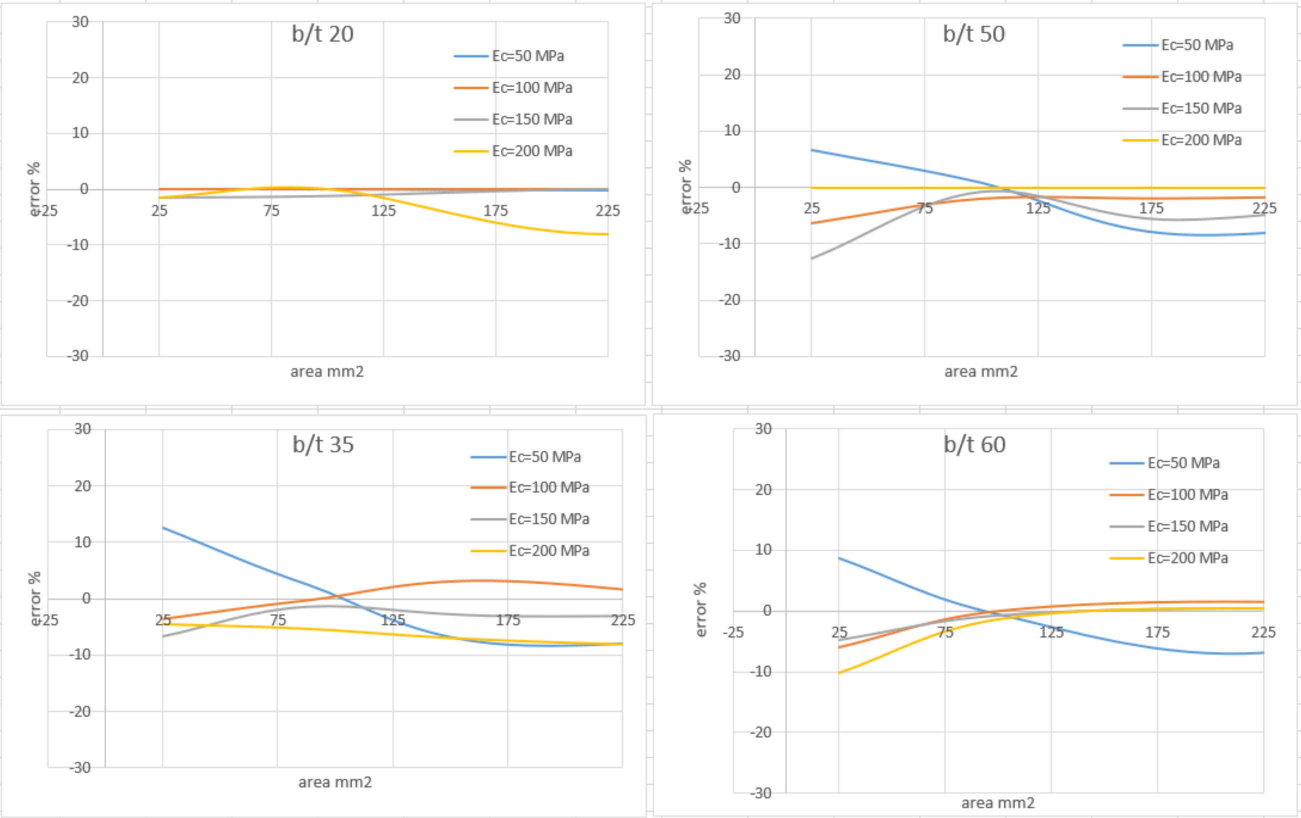




APPROXIMATING EQUATION SUGGESTION FOR SPRING STIFFNESS FORMULA

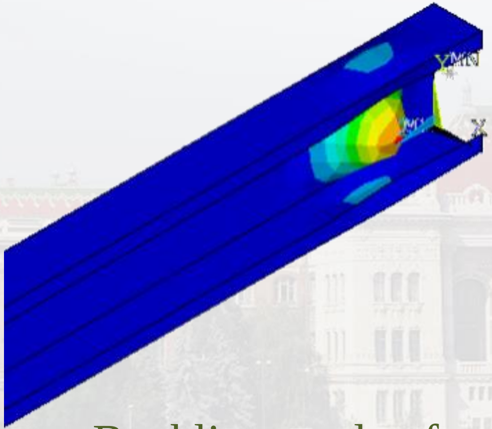
$$K = -200\left[\frac{N}{mm}\right] + 4\left[\frac{N}{mm^3}\right]A + 2.5\,[\mathrm{mm}]\,E_C + 0.009\left(-A^2\left[\frac{N}{mm^5}\right] + A.E_C\left[\frac{1}{mm}\right] + E_C{}^2\left[\frac{mm^3}{N}\right]\right)$$

The error of the simplified formula in case of outstand plate

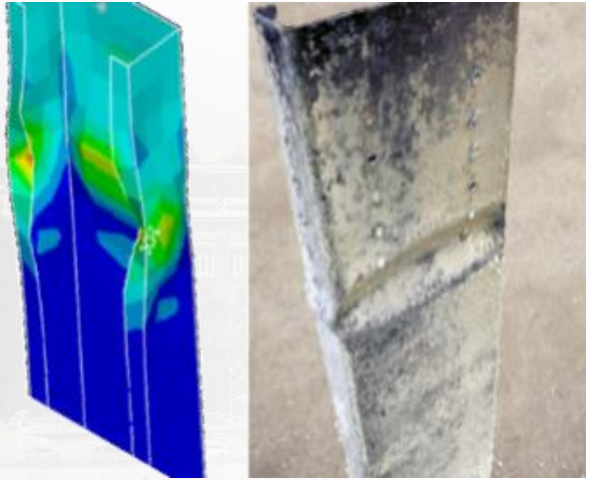


DESIGN RESISTANCE

Test-based design resistance EC 1993-1-3 2006 (A.6.3.2 (1))



Buckling mode of C90-0.9-600-A



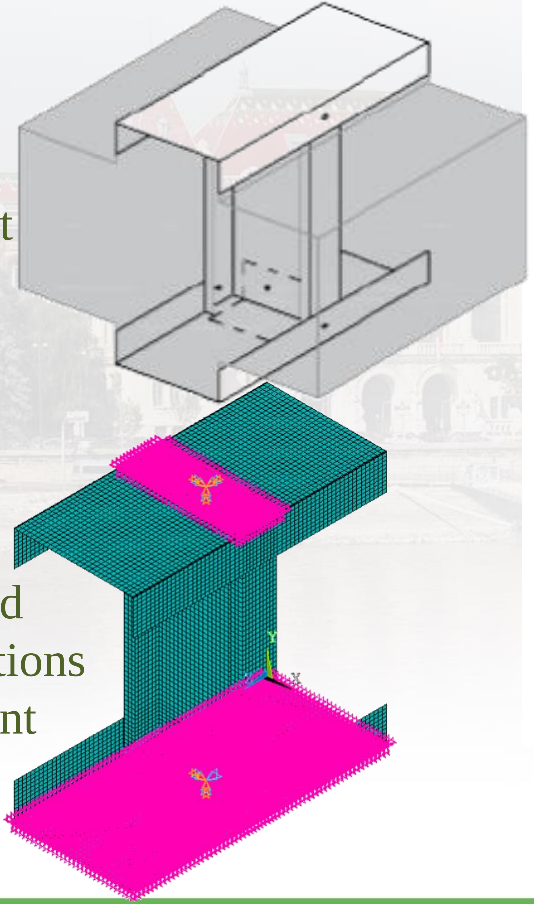
Comparison of local failure at the end of the braced specimen between test and FEA

Design values for α= *b*/66

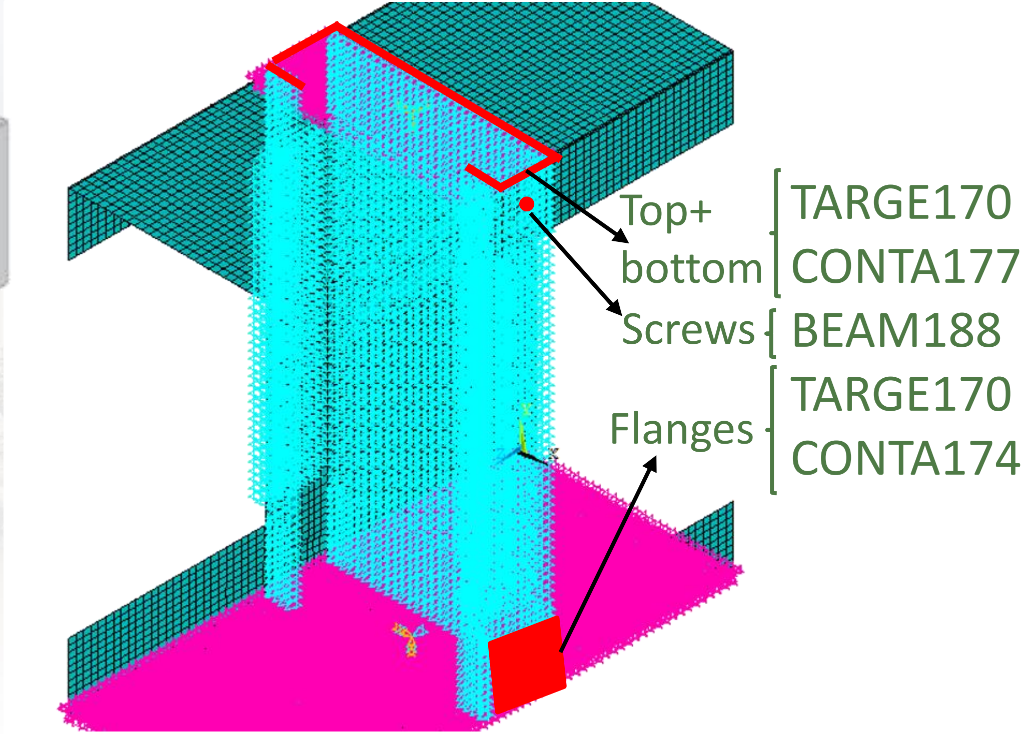
Specimens type	Test-based design resistance [KN]	Numerical design resistance [KN]		
		L=300 [mm]	L=600 [mm]	L=2000 [mm]
C90-0.9-A	26.50	27.22 (2.7%)	27.23 (2.7%)	27.16 (2.5%)
C90-0.9-X	26.50	27.17 (2.5%)	27.38 (3.3%)	27.46 (3.6%)
C140-0.9-WM	27.33	27.13 (0.7%)	27.37 (0.1%)	27.34 (0.0%)
C140-1.5-WM	63.24	59.40 (6.0%)	59.97 (5.1%)	59.87 (5.3%)

NUMERICAL MODEL DEVELOPMENT FOR COLUMN-END JOINTS

Column-end joint element build-up [Hegyi and Dunai, 2016]

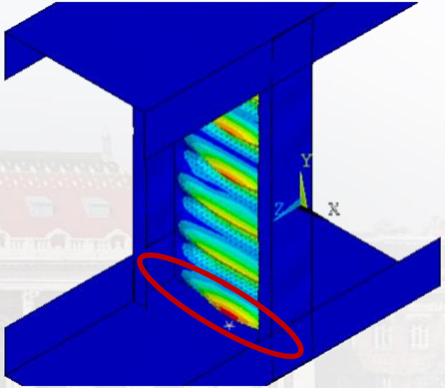


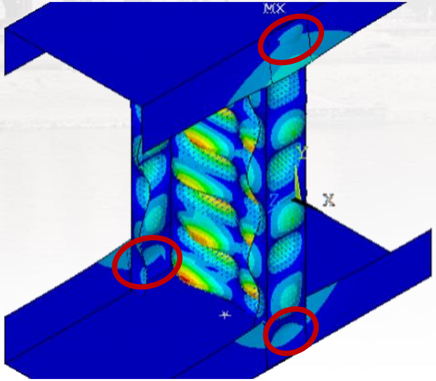
Applied load and boundary conditions for unbraced joint



Applied load and boundary conditions for braced joint

BUCKLING MODES





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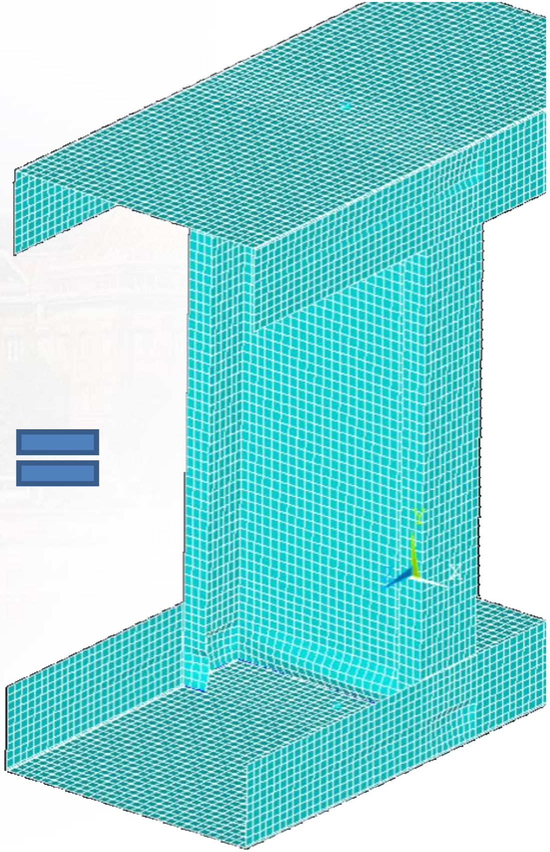
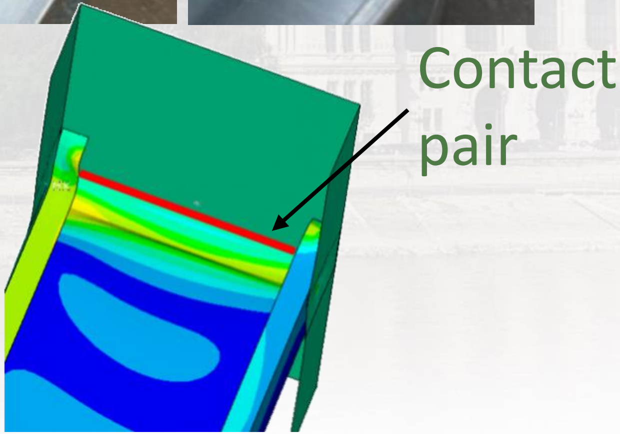
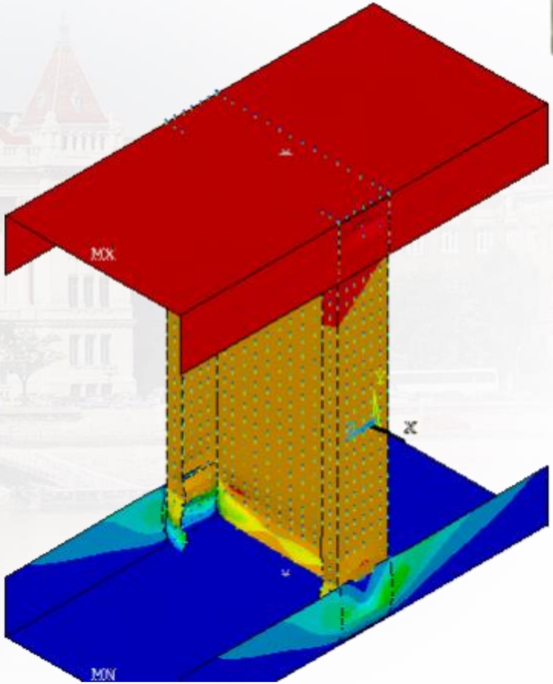
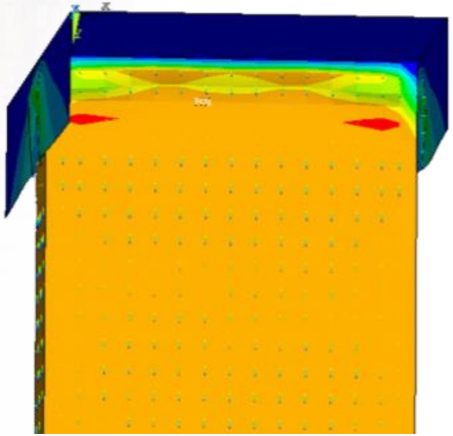


FAILURE MODES COMPARISON



Comparison of connection failure of the unbraced specimen between test and FEA





Comparison of connection failure of the braced specimen between test and FEA

CONCLUSIONS

- Simplified numerical models were developed for fully and partially-PAC filled CFS columns and joints.
- A simplified numerical formula was proposed to define the solid-replacement spring stiffness.
- Design equivalent geometrical imperfection amplitudes were suggested to predict the design resistance of PAC filled thin-walled columns and joints.
- Further studies

PUBLICATIONS

[1] ANALYSIS AND CROSS SECTION DEVELOPMENT OF COLD-FORMED STEEL RECTANGULAR HOLLOW FLANGE BEAMS, 15th International Miklos Ivanyi PhD & DLA Symposium, Pecs, Hungary.

[2] ANALYSIS AND CROSS SECTION DEVELOPMENT OF COLD-FORMED STEEL RECTANGULAR HOLLOW FLANGE BEAMS, Nathalie Eid, Attila László Joó, Pollack Periodica journal, published.

[3] NUMERICAL SIMULATION OF ULTRA-LIGHTWEIGHT-CONCRETE ENCASED COLD-FORMED STEEL STRUCTURES , Eurosteel 2021, Sheffield, UK, published.

[4] Simplified model of ultra-lightweight-concrete encased cold-formed steel structures Nathalie Eid, Attila László Joó, Advances in Civil Engineering, published.

Thank you for your listening!

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