Vigh L G

Influence of flange-to-web connection on the patch load resistance of I beams

Proc. of SDSS' Rio 2010 International Colloquium on Stability and Ductility of Steel Structures. Rio de Janeiro, 2010. pp. 705-712. (ISBN: 978-85-285-0137-7).

Abstract

Current design methods for calculating transverse load resistance of web plates neglect the effect of the flange-to-web connection. This simplification is on the conservative side and in deep plate girders its influence is practically negligible. However, in case of hot-rolled or extruded profiles, the fillet corner shaping through its geometry, rigidity and strength may highly increase the patch load resistance. Using non-linear numerical analysis, the author completed a parametric study on simply supported girders subjected to transverse load in order to study a) the effect of the connection and b) the capacity in interaction of transverse load and bending. The study clearly confirms the beneficial influence of the curved corners. To take this effect into account the author proposes a modification in the Eurocode formulation. The results of the simulation prove the validity of the proposed method.

Keywords: patch load, steel and aluminium I-beams, curved flange-to-web connection, non-linear numerical simulation, interaction of bending and transverse load resistance, Eurocode

Further info

This file contains the slides of the conference presentation.

If you are interested in the full paper, please email the author directly with the request:

geri@vbt.bme.hu

Vigh L G, Influence of flange-to-web connection on the patch load resistance of I beams, Proc. of SDSS' Rio 2010 International Colloquium on Stability and Ductility of Steel Structures. Rio de Janeiro, 2010. pp. 705-712. (ISBN: 978-85-285-0137-7).

References

[1] EN 1993-1-5:2005 Eurocode 3 – Design of steel structures – Part 1-5: Plated structural elements, Final Draft, CEN, Brussels, 2005.

[2] EN 1999-1-1:2007 Eurocode 9 – Design of aluminium structures – Part 1-1: General structural rules, CEN, Brussels, 2007.

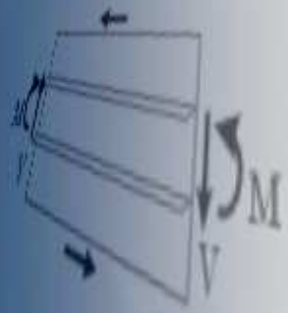
[3] Vigh, L.G., Virtual and real test based analysis and design of non-conventional thin-walled metal structures, PhD dissertation, Budapest University of Technology and Economics, 2006.

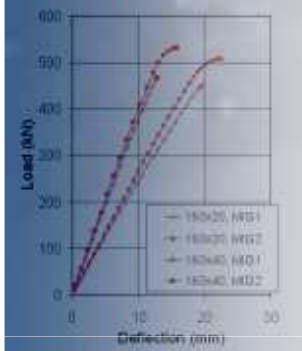
[4] Roberts, T.M., “Slender plate girders subjected to edge loading”, Proc. Inst. Civil Engineers, Part 2, Vol. 71, 805-819, Sept. 1981.

[5] Lagerqvist, O. and Johansson, B., “Resistance of I-girders to Concentrated Loads”, Journal of Construction Steel Research, 39 (2), 87-119, 1996.

[6] Kövesdi, B., Kuhlmann, U., Dunai, L., “Combined shear and patch loading of girders with corrugated webs”, Periodica Polytechnica Civil Engineering, 2010. (submitted for publication)

[7] ANSYS Structural Analysis Guide, Online Documentation ANSYS Inc., 2005.





SDSS' Rio 2010
Stability and Ductility of Steel Structures

Rio de Janeiro, Brazil
8-10 September 2010

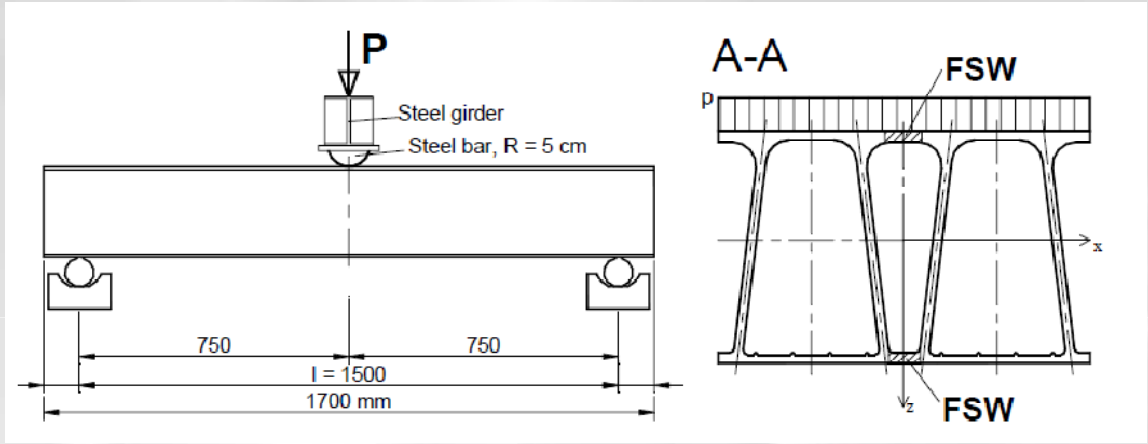
Influence of flange-to-web connection on the patch load resistance of I beams

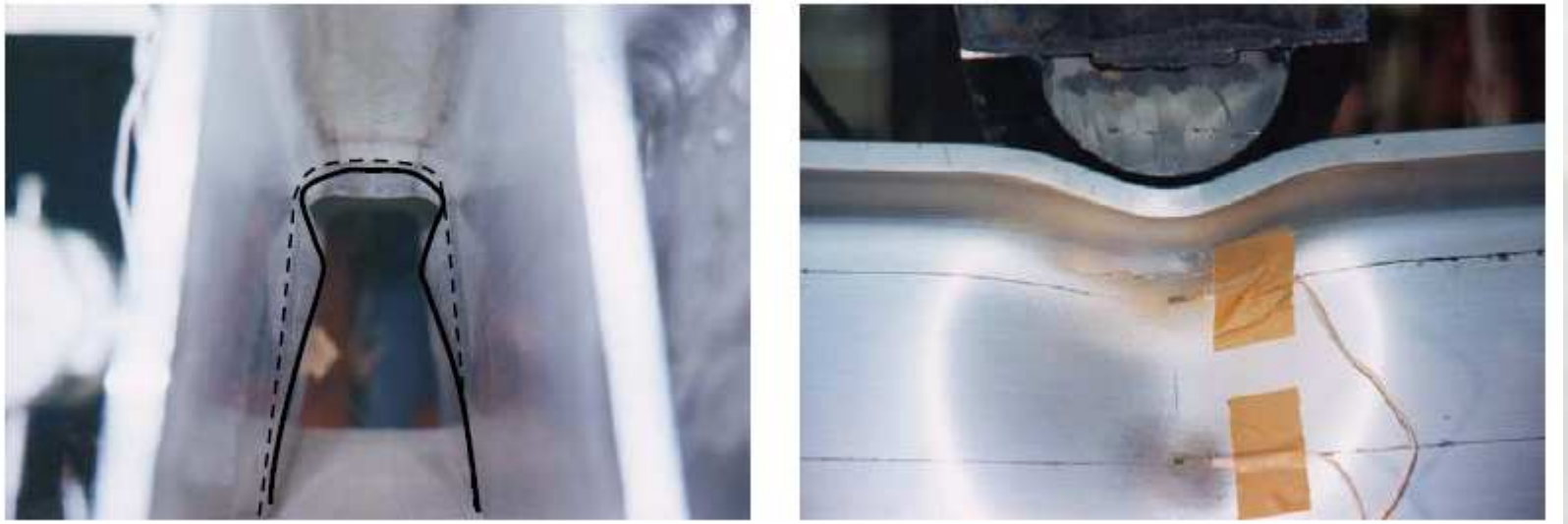
László Gergely Vigh, PhD,
Associate Professor
Budapest University of Technology and Economics,
Dept. of Structural Engineering, Hungary

Thanks are due to:
OTKA T049305 project of the Hungarian National Science Foundation

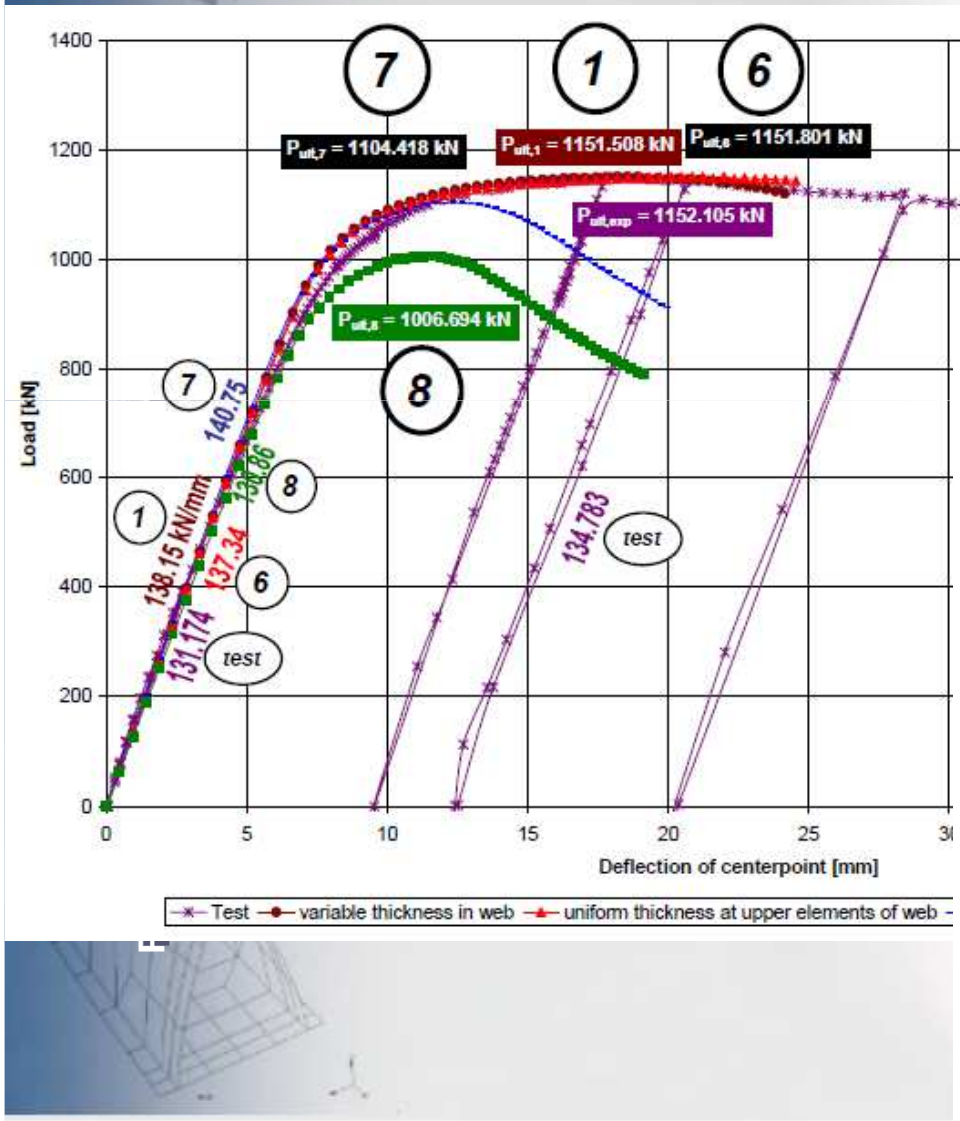
Problem statement

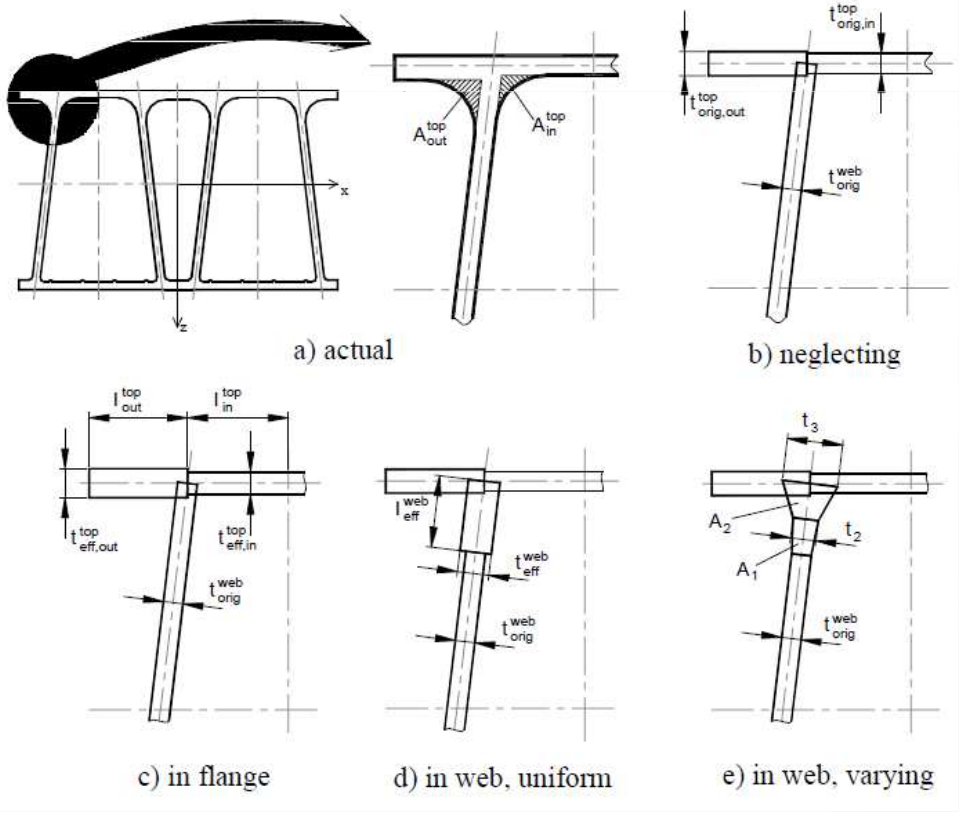
- **validation test:**

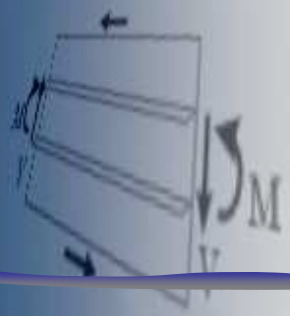




Problem statement

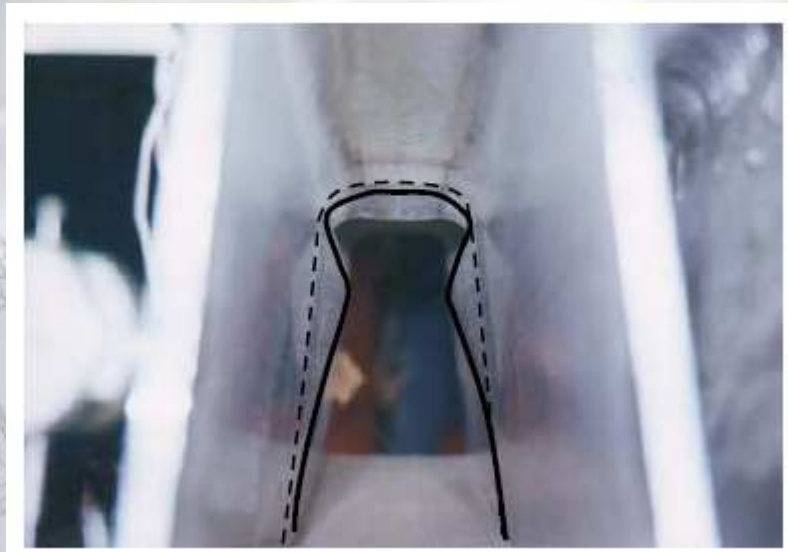


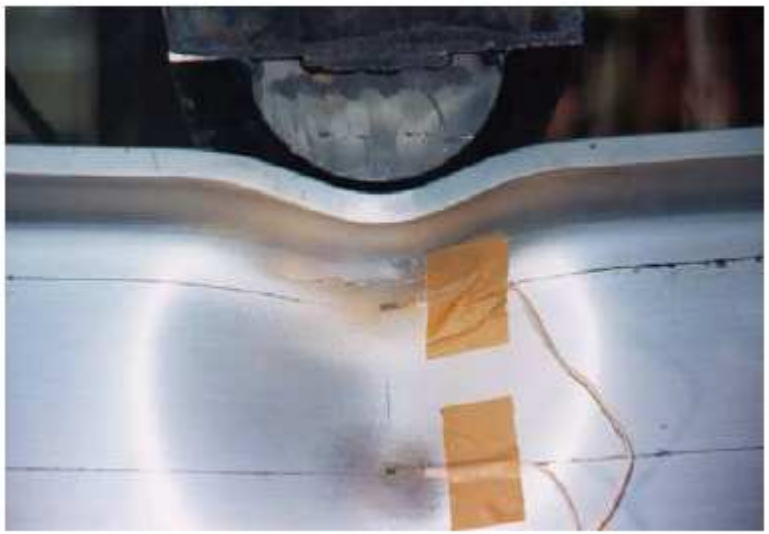


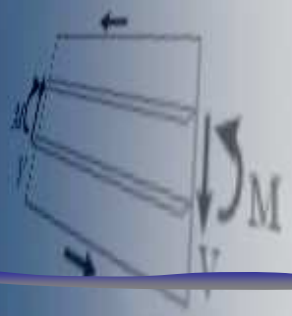


Problem statement

- **As per EC3-1-5 and EC9-1, patch load resistance depends on:**
  - load case
  - web and flange material properties
  - web dimensions/aspect ratio
  - web thickness
  - flange dimensions
  - loaded length







Standard Eurocode method

- **bending resistance:**

steel: $M_{c,Rd} = W_{pl}\dfrac{f_y}{\gamma_{M0}}$ aluminium: $M_{c,Rd} = \alpha_{M,1} W_{el}\dfrac{f_o}{\gamma_{M1}}$

- **transverse load resistance:**

critical load: $F_{cr} = 0.9 k_F E \dfrac{t_w^3}{h_w} = 0.9\left[6 + 2\left(\dfrac{h_w}{a}\right)^2\right] E\dfrac{t_w^3}{h_w}$

dimensionless parameters: $m_1 = \left(f_{of} b_f\right)/\left(f_{ow} t_w\right)$; $m_2 = 0.02\left(h_w / t_f\right)^2$

effective loaded length: $l_y = s_s + 2t_f\left(1 + \sqrt{m_1 + m_2}\right) \le a$

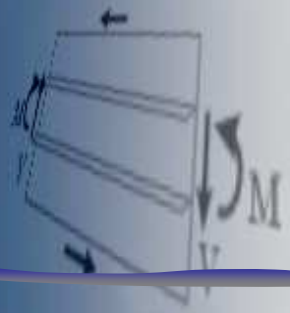
slenderness: $\lambda_F = \sqrt{\dfrac{l_y t_w f_{ow}}{F_{cr}}}$

reduction factor: $\chi_F = 0.5/\lambda_F \le 1.0$

transverse load resistance: $F_{Rd} = \chi_F l_y \dfrac{f_{ow}}{\gamma_{M1}}$

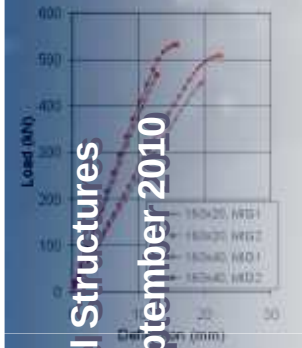
- **interaction:**

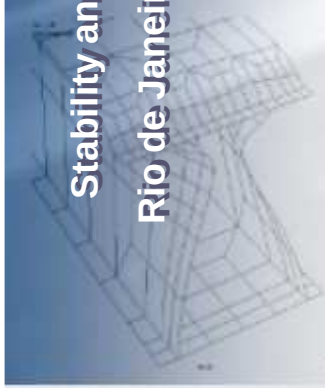
$$\frac{F_{Ed}}{F_{Rd}} + 0.8\frac{M_{Ed}}{M_{c,Rd}} \le 1.4$$



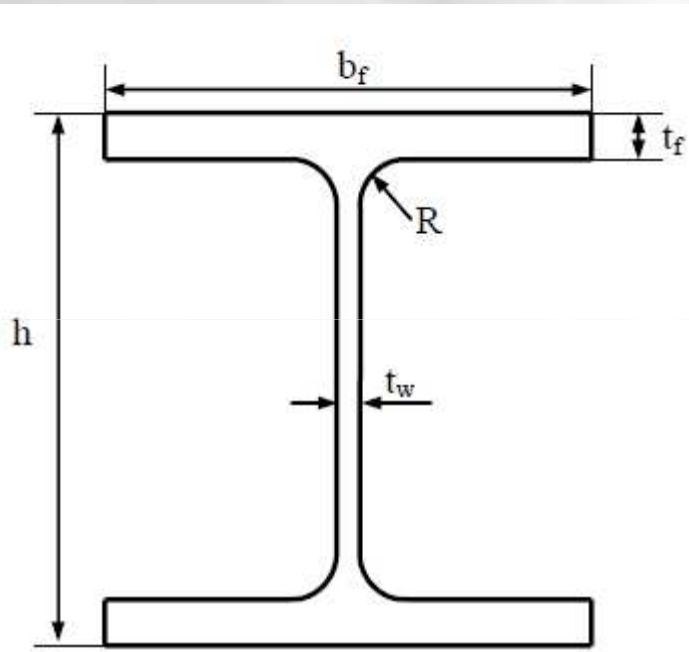
Problem statement

- **And what about**
  - flange-to-web joint? – out of consideration in current codes
- **Why?**
  - calibration of semi-empirical formulations:
    Lagerqvist et al: 388 test specimen (358 welded deep girders)
- **What and how big influence?**
  - ‘clear height’
  - effective loaded length
  - plastic hinge capacity of the flange

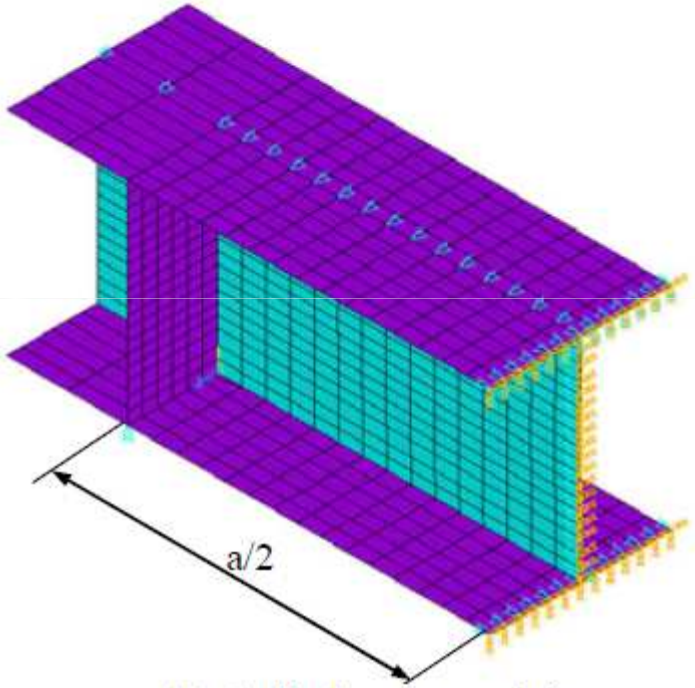




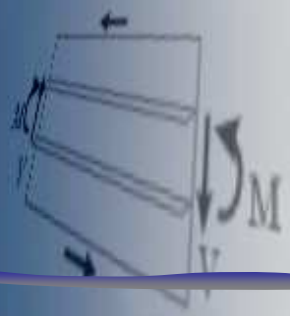
Parametric study – model



a) cross-section

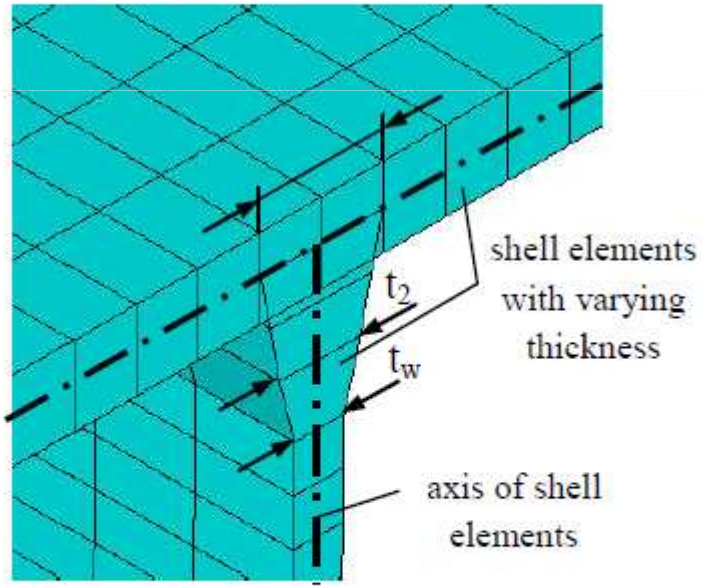


b) shell-element model



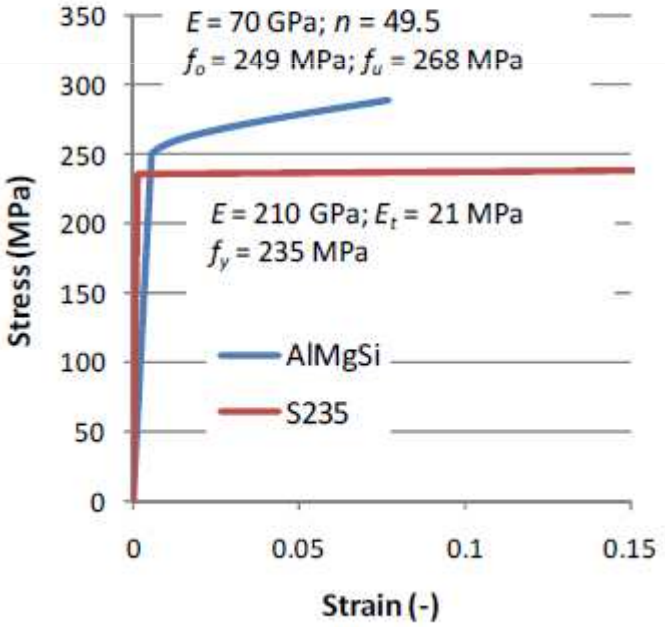
Parametric study – model

- **GMNIA**
  - material and geometrical non-linear imperfect analysis
  - one-bow eq. geometrical imperfection

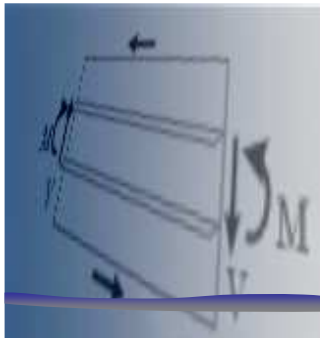


Note: these are not body elements

a) approximation of curved corners



b) material models



Parametric study

"HEA 100" / "HEA 100-75"

h	b_f	t_f	t_w	r	s_s	a	$F_{Rd,FEM}$ Steel	$F_{Rd,FEM}$ Alu
[mm]							[kN]	
96	100 (St) 75 (Al)	8	5	0	0	150	112.9	101.5
						300	106.1	93.9
						500	95.2	83.5
						750	81.5	71.9
					50	300	139.3	129.9
						500	123.8	118.6
						750	104.1	91.7
					200	300	211.0	209.4
						500	147.0	154.8
						750	124.0	112.4
				12	0	150	135.8	130.3
						300	125.0	116.7
						500	109.7	101.9
						750	93.0	84.4
					50	150	189.9	184.2
						300	155.0	154.7
						500	134.0	135.3
						750	110.9	99.5
					200	300	223.0	246.8
						500	148.0	168.2
						750	127.0	121.9
				18	0	500	123.0	116.8
						750	103.2	94.6
				24	0	150	187.2	190.7
						300	159.0	163.2
						500	137.7	134.7
						750	114.2	106.9

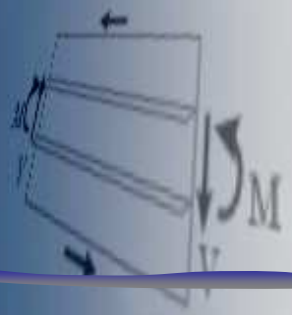
"HEA 200" / "HEA 200-100"

h	b_f	t_f	t_w	r	s_s	a	$F_{Rd,FEM}$ Steel	$F_{Rd,FEM}$ Alu
[mm]							[kN]	
190	200 (St) 100 (Al)	10	6.5	0	0	500	204.0	158.8
						1200	180.0	131.6
						2000	149.0	103.6
					50	500	256.1	204.8
						1200	231.0	173.3
						2000	188.0	122.8
					200	500	391.0	346.3
						1200	325.0	230.7
						2000	212.0	135.5
				18	0	500	245.0	200.7
						1200	212.0	163.8
						2000	173.8	124.2
					50	500	303.4	251.6
						1200	269.6	207.9
						2000	205.2	139.7
					200	500	417.0	401.3
						1200	329.0	256.3
						2000	222.0	150.7
				27	0	500	282.2	240.1
						1200	243.0	194.5
						2000	197.0	142.4
				36	0	500	331.1	288.4
						1200	283.7	231.7
						2000	221.0	164.8

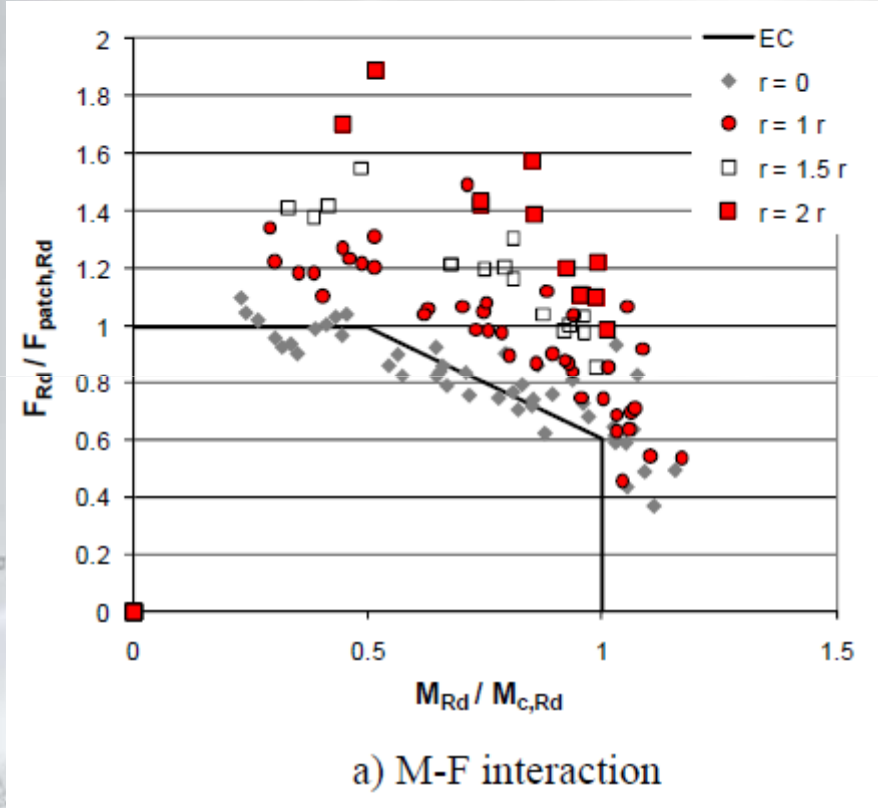
"HEA 300" / "HEA 300-140"

h	b_f	t_f	t_w	r	s_s	a	$F_{Rd,FEM}$ Steel	$F_{Rd,FEM}$ Alu
[mm]							[kN]	
290	300 (St) 140 (Al)	14	8.5	0	0	1000	371.8	277.3
						2000	334.5	233.4
						3000	293.0	195.3
					50	1000	441.0	333.2
						2000	402.0	286.8
						3000	350.6	230.2
					200	1000	645.0	---
						2000	598.8	386.9
						3000	435.0	262.6
				27	0	1000	460.1	355.5
						2000	404.2	300.0
						3000	348.1	244.3
					50	1000	537.9	419.0
						2000	482.0	355.7
						3000	409.8	270.9
					200	1000	691.0	622.3
						2000	641.0	441.4
						3000	463.0	293.9
				40.5	0	1000	535.7	434.0
						2000	471.5	362.4
						3000	404.1	286.5
				54	0	1000	626.5	529.7
						2000	558.0	437.4
						3000	465.0	338.1

h – total section height; b_f – flange width; t_f – flange thickness; t_w – web thickness; r – radius of corner; s_s – loaded length; a – span (= length of unstiffened web panel); $F_{Rd,FEM}$ – FEM load capacity



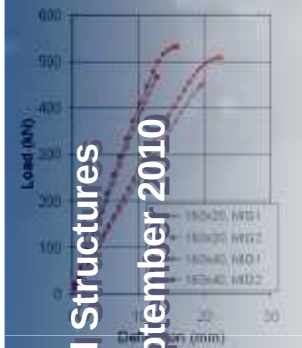
Results

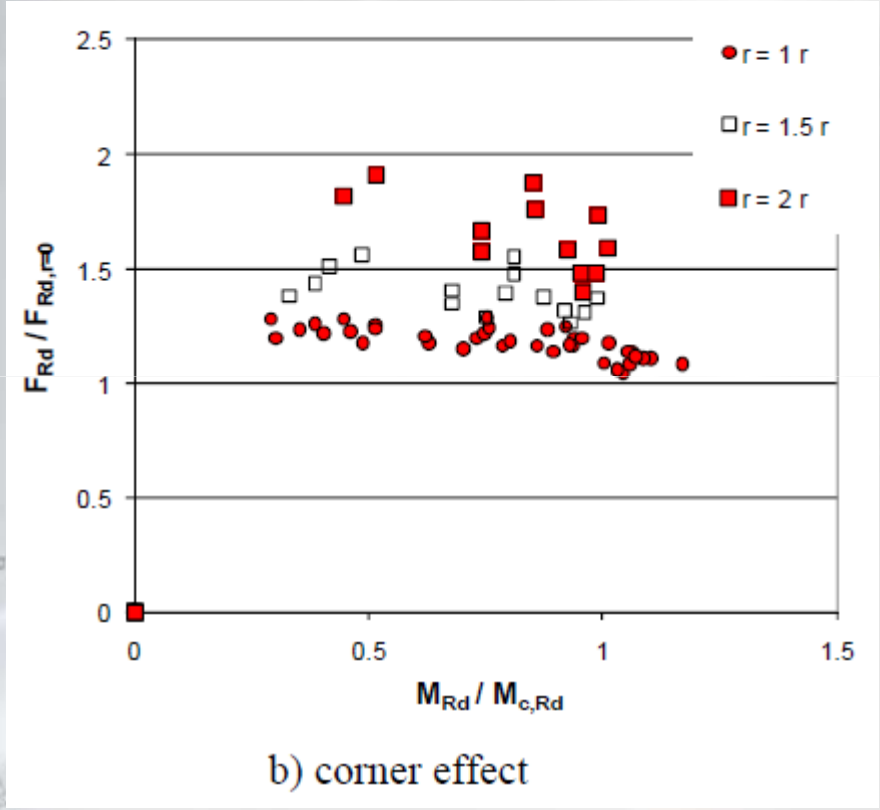


a) M-F interaction

- **Reliability**
  - numerical model is conservative?
  - zero radius – normal radius as reference?
  - zero loaded length cases to exclude?

Results





b) corner effect

- **Effect of curved corners**
  - quantitative change: significant increase in capacity
  - qualitative change in behaviour

Table 2: Comparison to $r = 0$.

r =	Steel		Alu	
	%	avg %	%	avg %
r	5 - 24	16	8 - 29	20
1.5 r	27 - 44	36	32 - 57	46
2 r	40 - 67	54	49-91	74

Standard Eurocode method

- **bending resistance:**

steel: $M_{c,Rd} = W_{pl} \frac{f_y}{\gamma_{M0}}$ aluminium: $M_{c,Rd} = \alpha_{M,1} W_{el} \frac{f_o}{\gamma_{M1}}$

- **transverse load resistance:**

critical load: $F_{cr} = 0.9 k_F E \frac{t_w^3}{h_w} = 0.9 \left[6 + 2 \left(\frac{h_w}{a} \right)^2 \right] E \frac{t_w^3}{h_w}$

dimensionless parameters: $m_1 = (f_{of} b_f)/(f_{ow} t_w)$; $m_2 = 0.02 (h_w / t_f)^2$

effective loaded length: $l_y = s_s + 2 t_f \left(1 + \sqrt{m_1 + m_2}\right) \le a$

slenderness: $\lambda_F = \sqrt{\frac{l_y t_w f_{ow}}{F_{cr}}}$

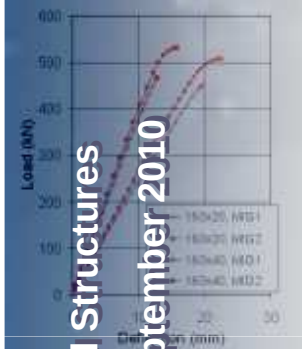
reduction factor: $\chi_F = 0.5 / \lambda_F \le 1.0$

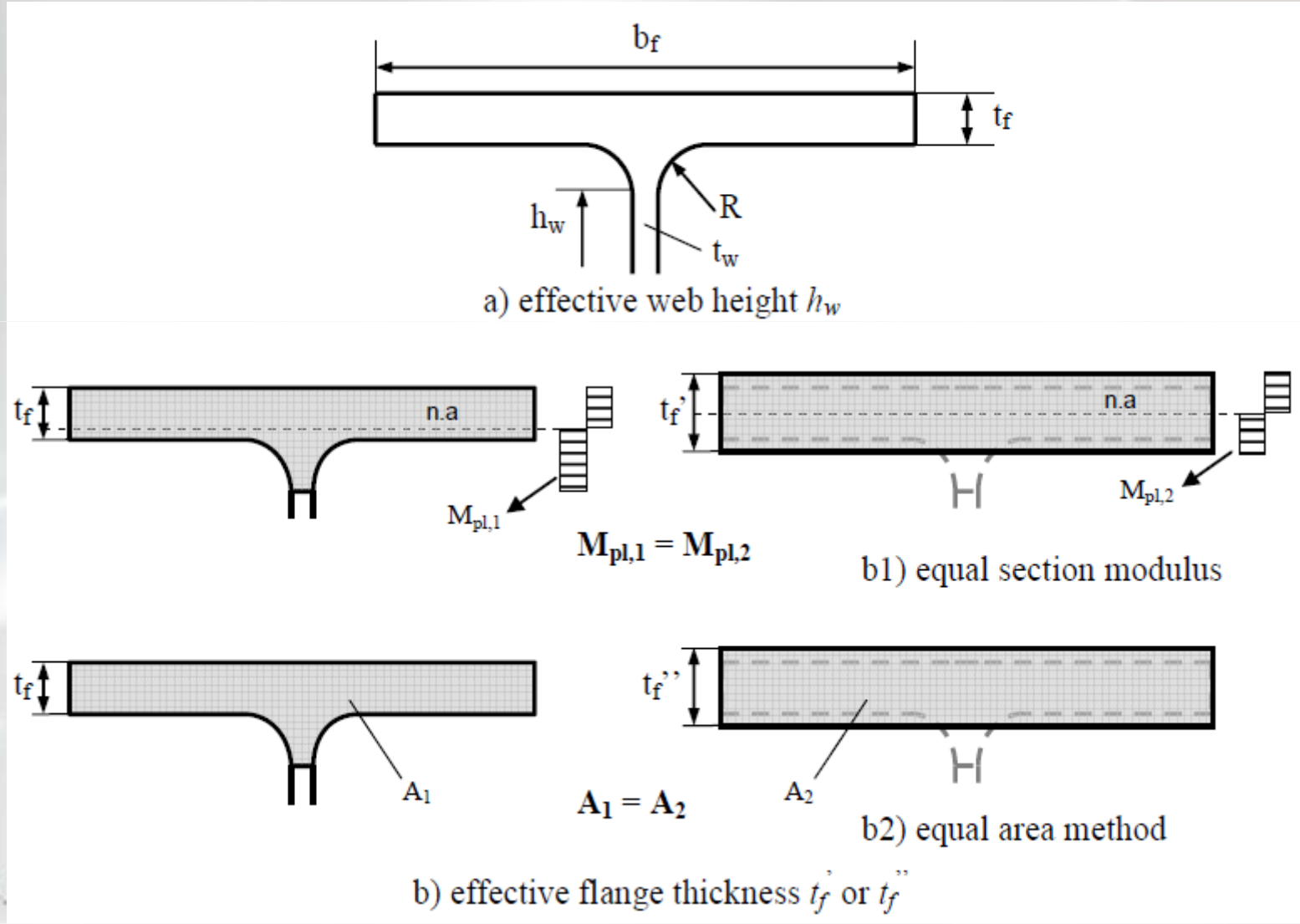
transverse load resistance: $F_{Rd} = \chi_F l_y \frac{f_{ow}}{\gamma_{M1}}$

- **interaction:**

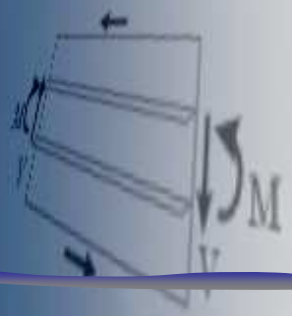
$$\frac{F_{Ed}}{F_{Rd}} + 0.8 \frac{M_{Ed}}{M_{c,Rd}} \le 1.4$$

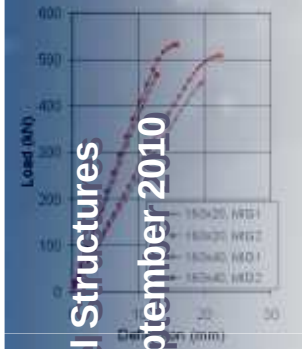
Modified procedure

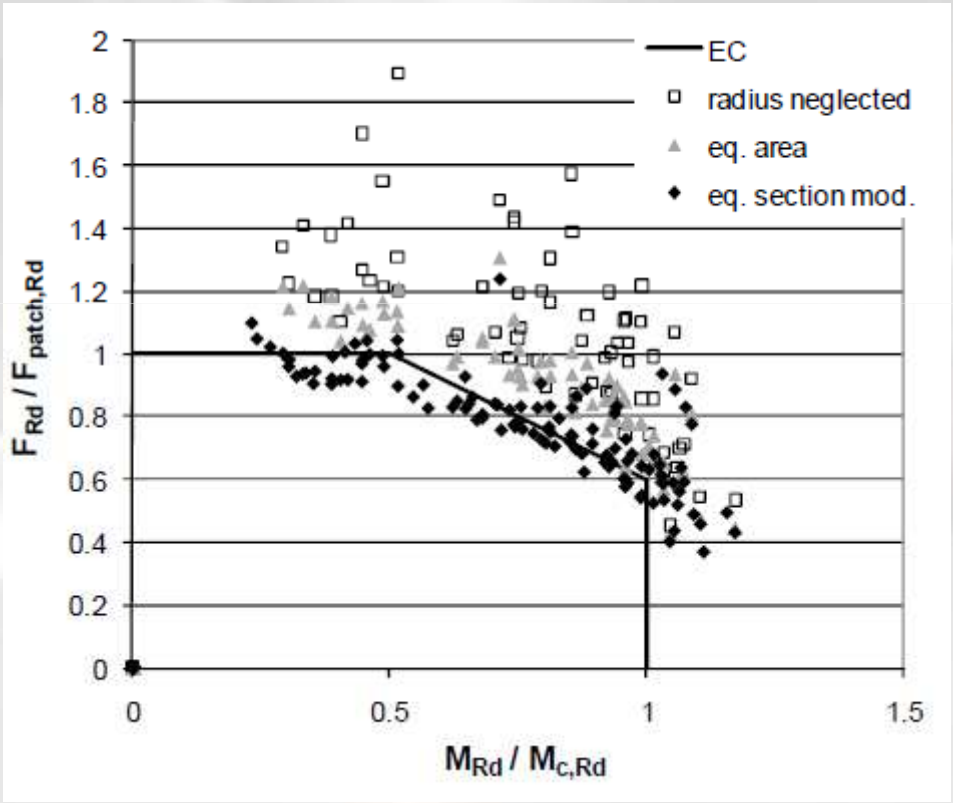


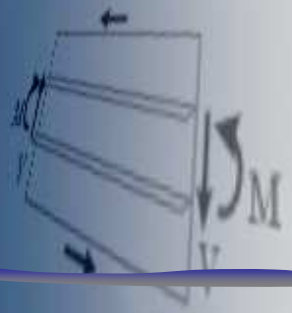


Modified procedure

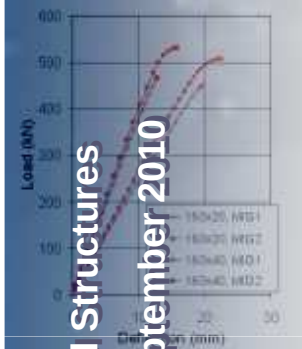






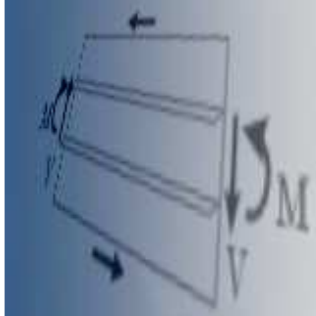


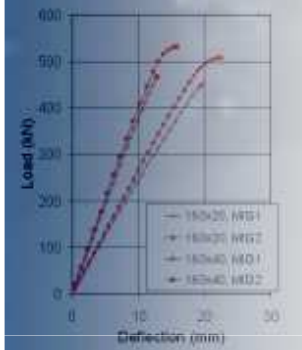
Concluding remarks

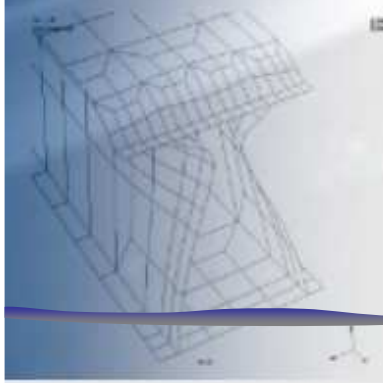


- **Parametric study:** is completed on simply supported girders made of rolled steel or extruded aluminium profiles, subjected to transverse load.
- **Influence:**
  of the curved-corner web-to-flange joint on the transverse load resistance can be significant in case of stocky webs (may reach 60-90%)
- **Proposed modification in Eurocode:**
  utilizes the clear web height and effective flange thickness; accurately representing the actual connection rigidity and plastic flange strength.
  good agreement with non-linear numerical simulation
- **Further study: Reliability**
  relation of the basic standardized procedure and the numerical simulation. Role of imperfection, knifeedge loading, material modelling
- **Further study:**
  other load application types
  F+M+V interaction
- **Further details in:**

  Vigh, L.G.: *Virtual and real test based analysis and design of non-conventional thin-walled metal structures*, PhD dissertation, Budapest University of Technology and Economics, 2006.







Acknowledgement

Thanks are due to the support of OTKA Foundation.

Thank you for your attention!