STABILITY OF COLD-FORMED ELEMENTS

21/11/2010

Czech Technical University in Prague

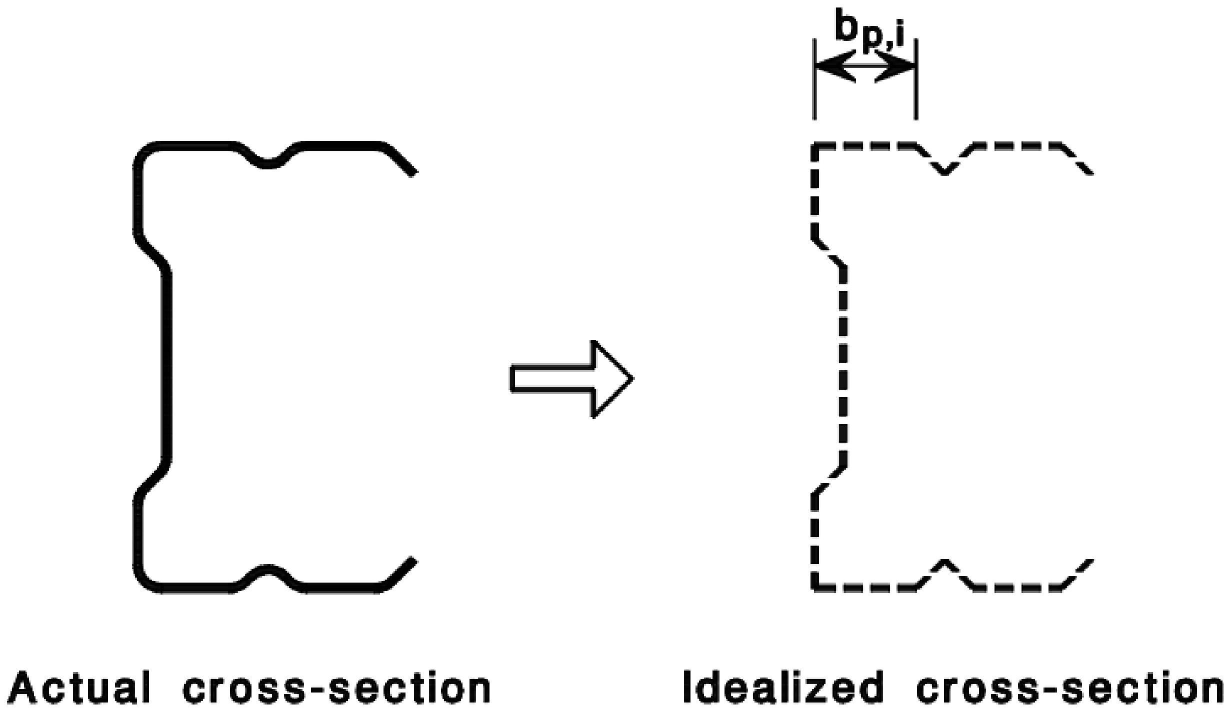
Contents

- Behavior features:
  - local buckling of compression elements
    - plane elements
    - elements with stiffeners
  - shear lag
  - web crippling
- Cross-section check
- Beams restrained by sheeting
- Connections

Cross-section idealiseation

Cross-section

- Idealised section with radiuses r=0 when r<5t



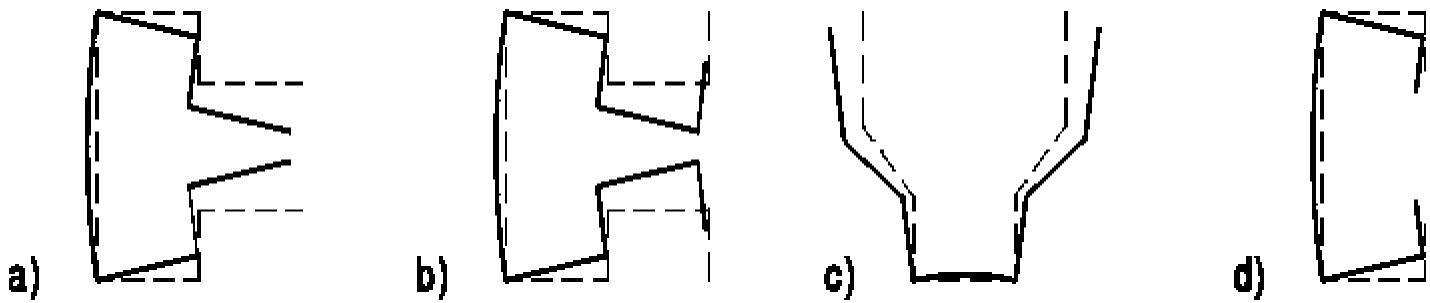
Approximate allowance for rounded corners

Buckling in compression

Buckling strength

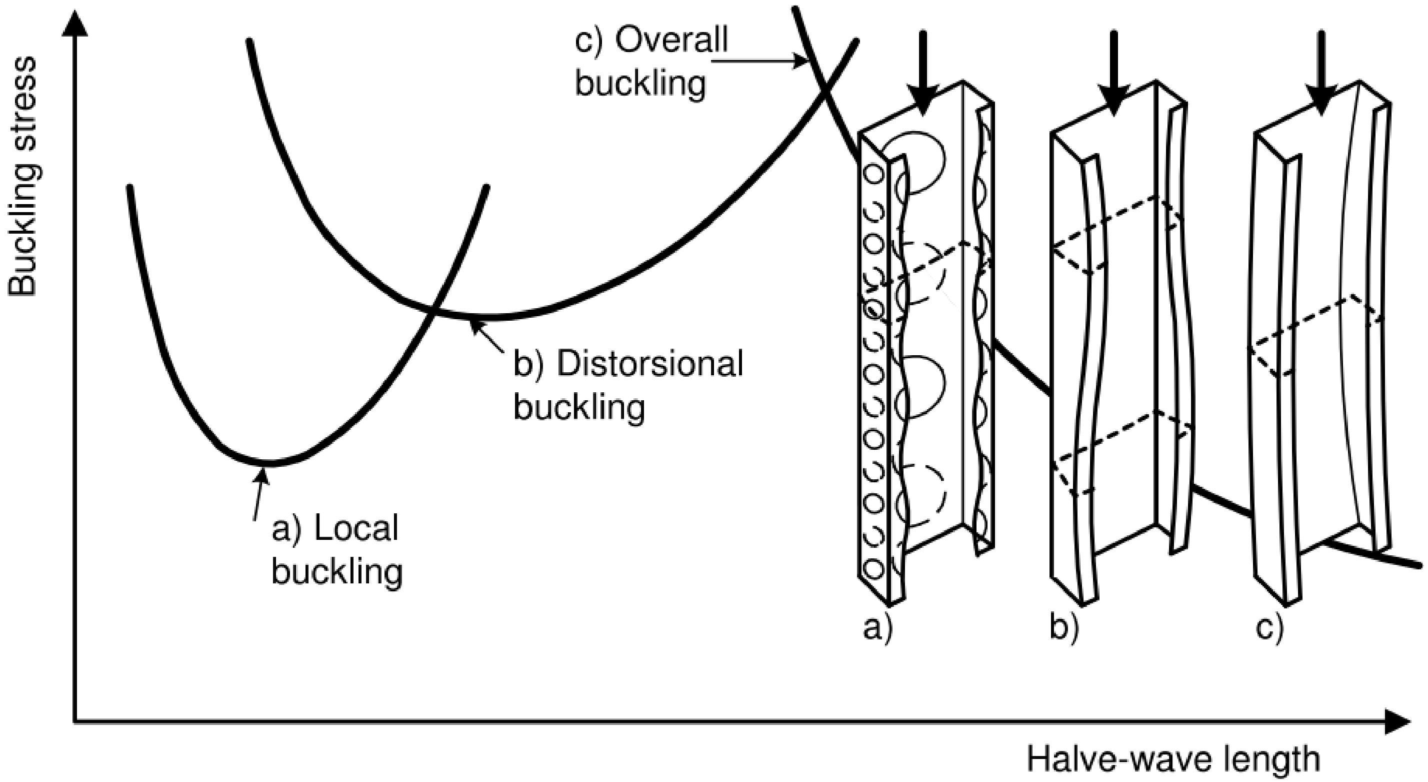
- Local buckling
- Distortional buckling
  - Section distortion

Sectional modes



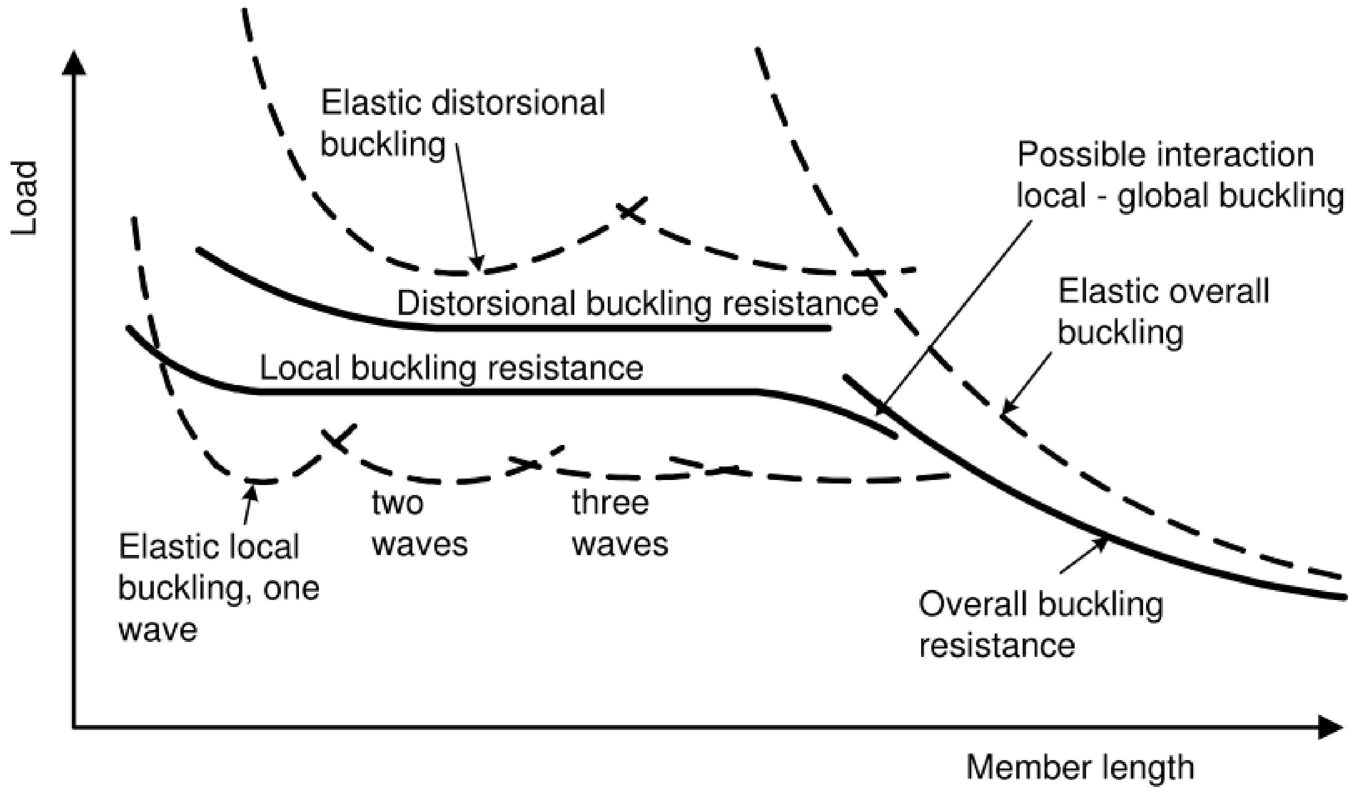
- Global buckling
- Shear buckling

Buckling strength



Examples of elastic critical stress for various buckling modes as function of *halve-wave length* and examples of buckling modes.

Buckling strength



Examples of elastic buckling load and buckling resistance as a function of member length

Local buckling

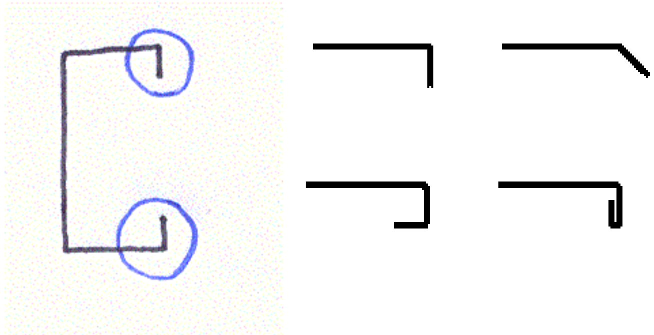
- Theory + calculation procedures (see local buckling of plates)

$$\bar{\lambda}_p = \sqrt{\frac{\sigma_{com}}{\sigma_{cr}}} = 1{,}052\,\frac{b}{t}\sqrt{\frac{\sigma_{com}}{k_\sigma\,E}} \qquad \sigma_{com} \le f_y$$

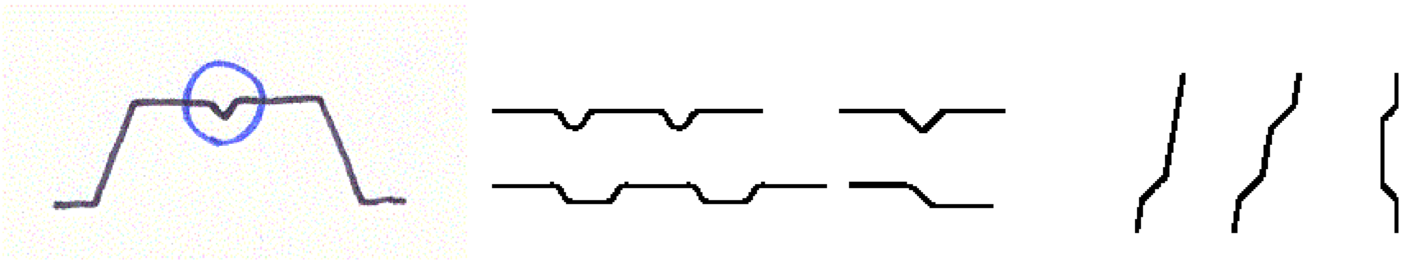
  - Elements:
    - doubly supported
    - outstands
    - stiffened
    - plain

Stiffeners

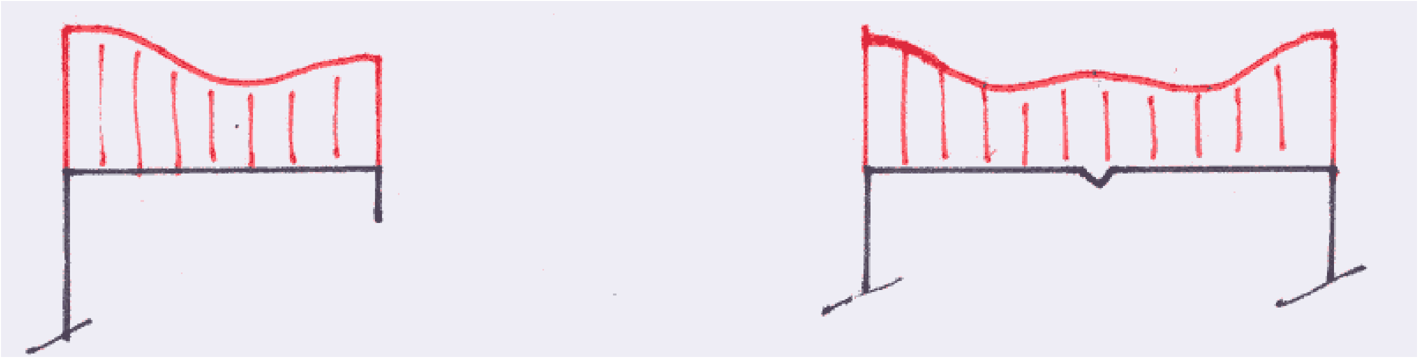
- Edge stiffeners



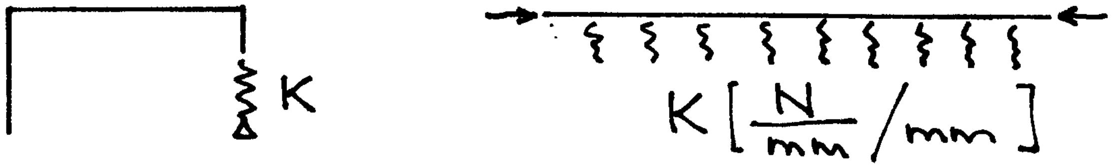
- Intermediate stiffeners



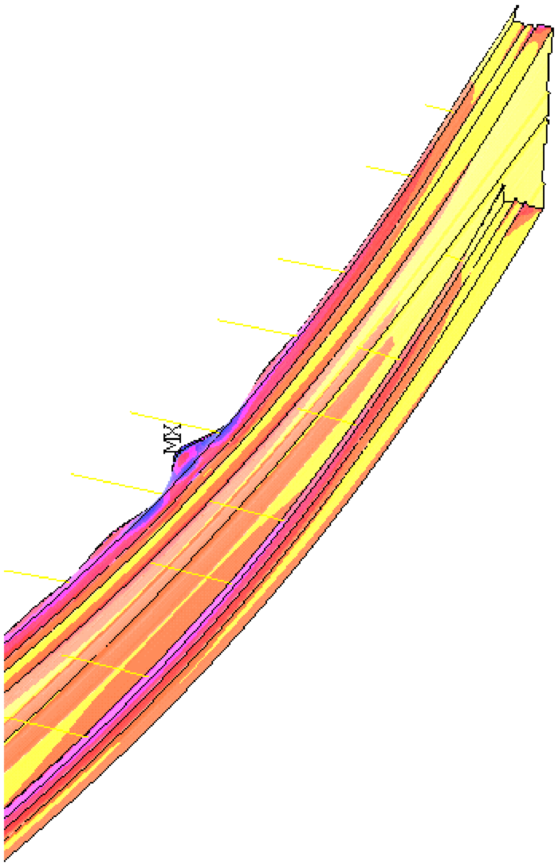
Stress distribution on stiffened plate



- Calculation model
  - stiffener supports plane element
  - stiffener itself can buckle (as compression member on elastic foundation)

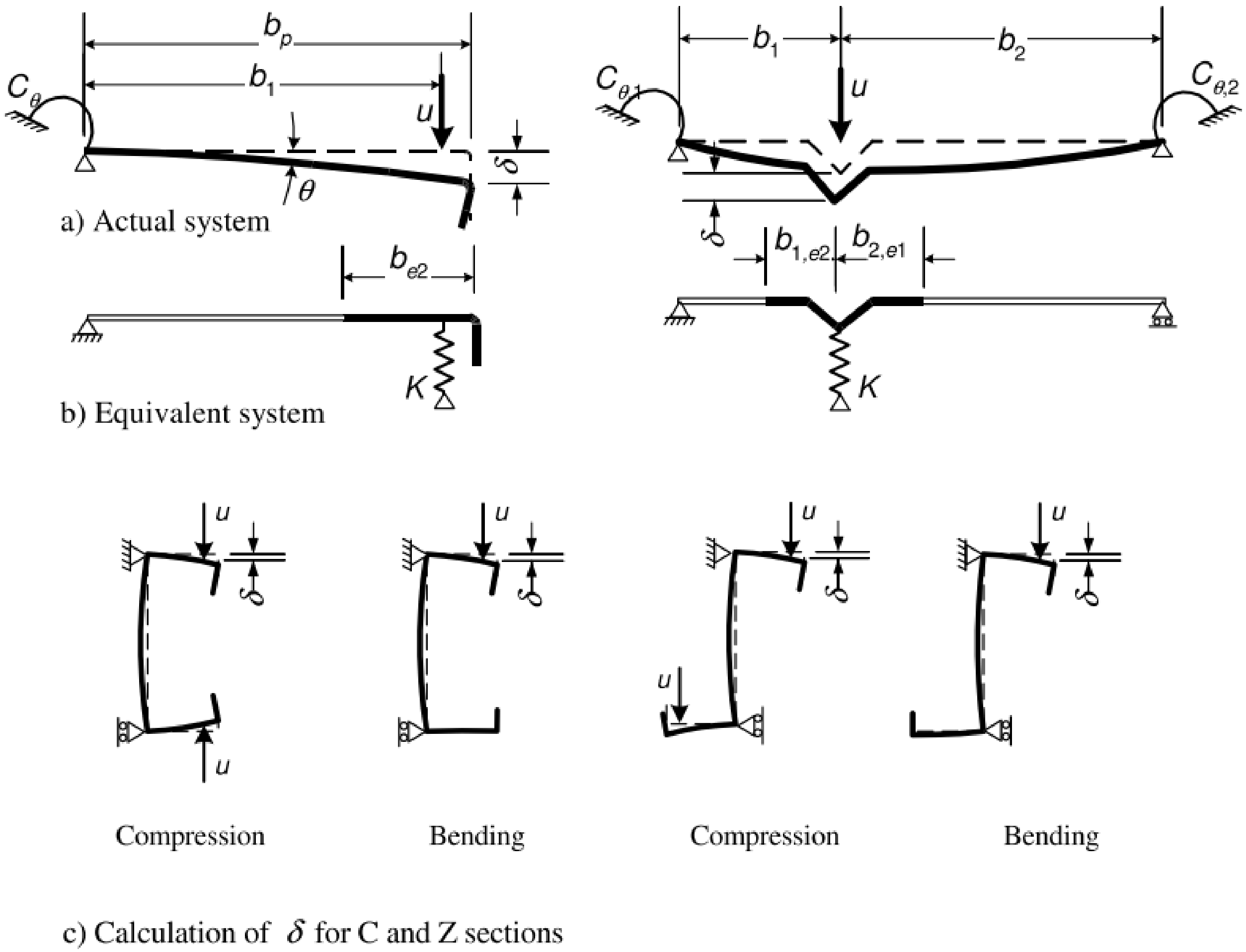


Buckling of edge stiffener



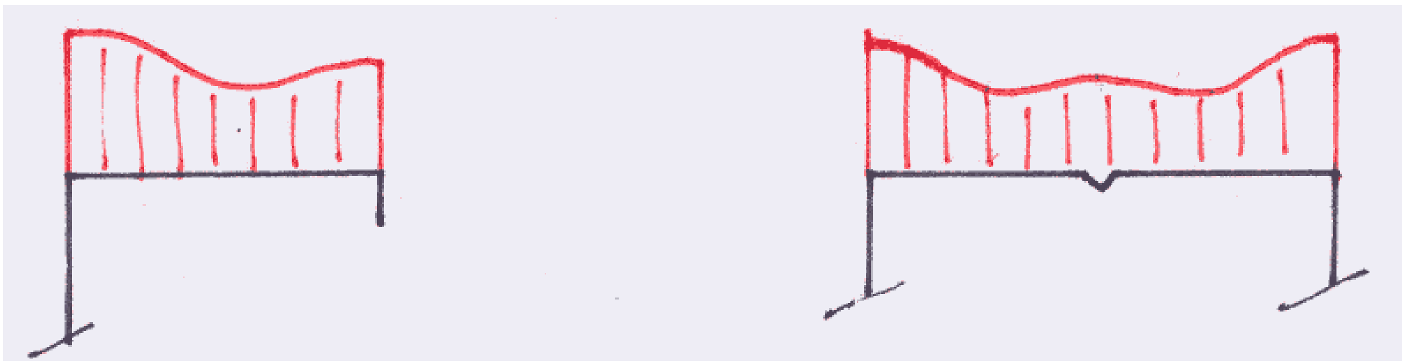
Vrany

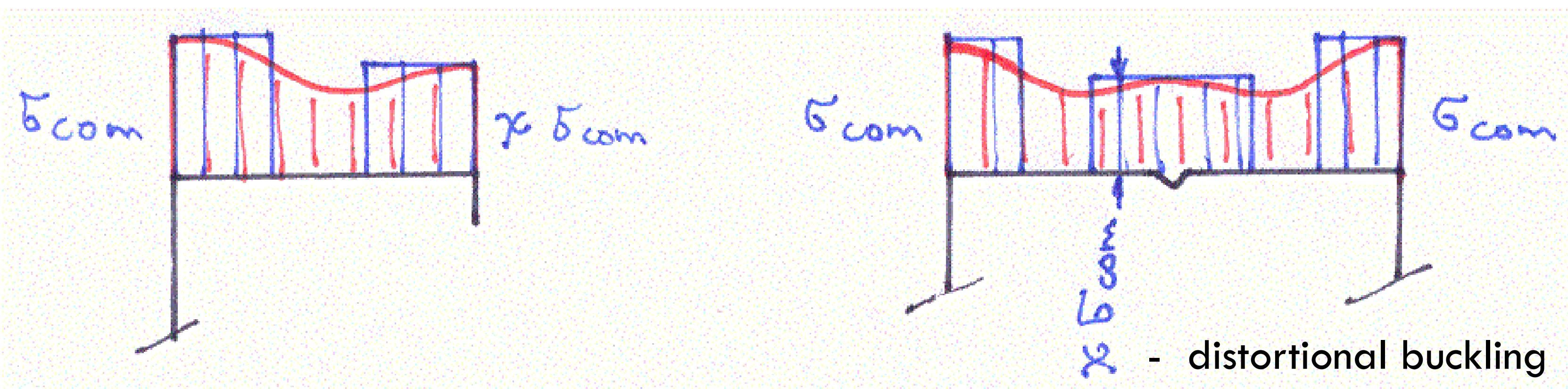
Spring stiffness of stiffener



Determination of spring stiffness

Stress distribution - idealisation

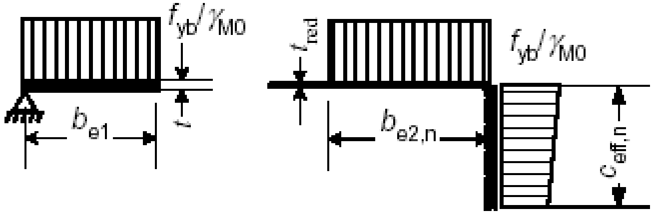


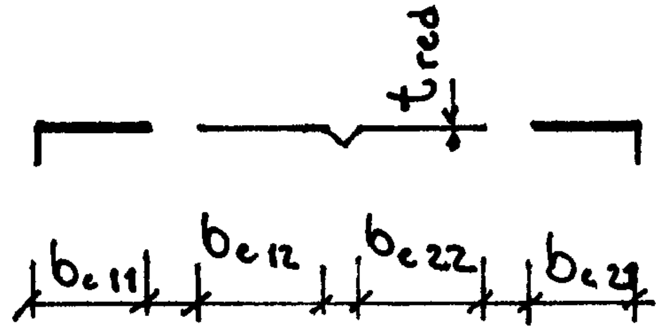


Calculation procedure

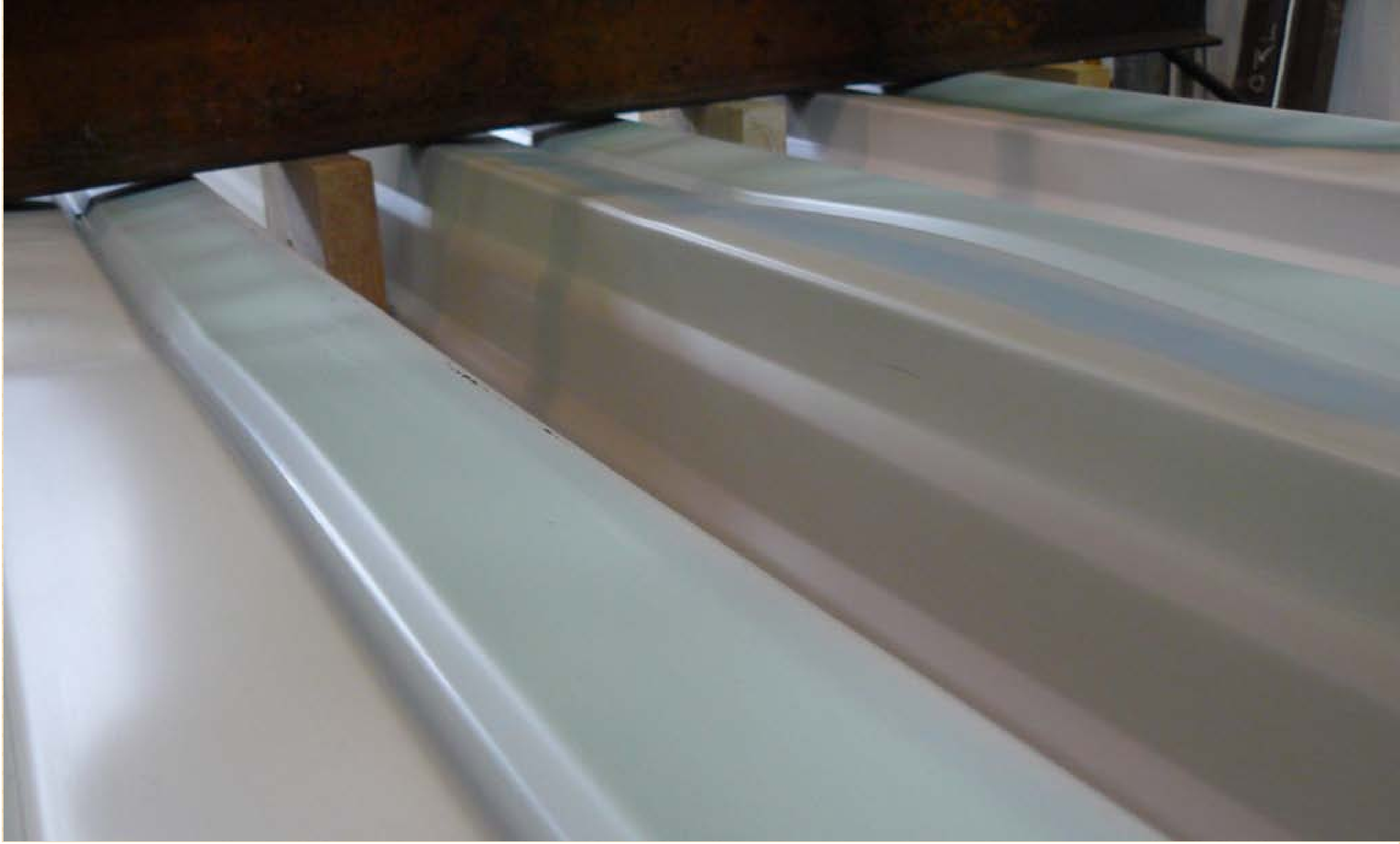
1. Stiffener provides rigid support to the plate $\Rightarrow$ effective widths
2. K, A_s, I_s
3. Critical stress σ_{cr}
4. for $\sigma_{com} = f_y \Rightarrow \chi_d$ (distortional buckling)
5. $\sigma_{com} = \chi_d f_y$
6. Effective widths of parts adjacent to the stiffener
7. A_s, I_s
8. iteration 3. – 7.
9. $t_{red} = \chi_d t$

Final effective cross-section





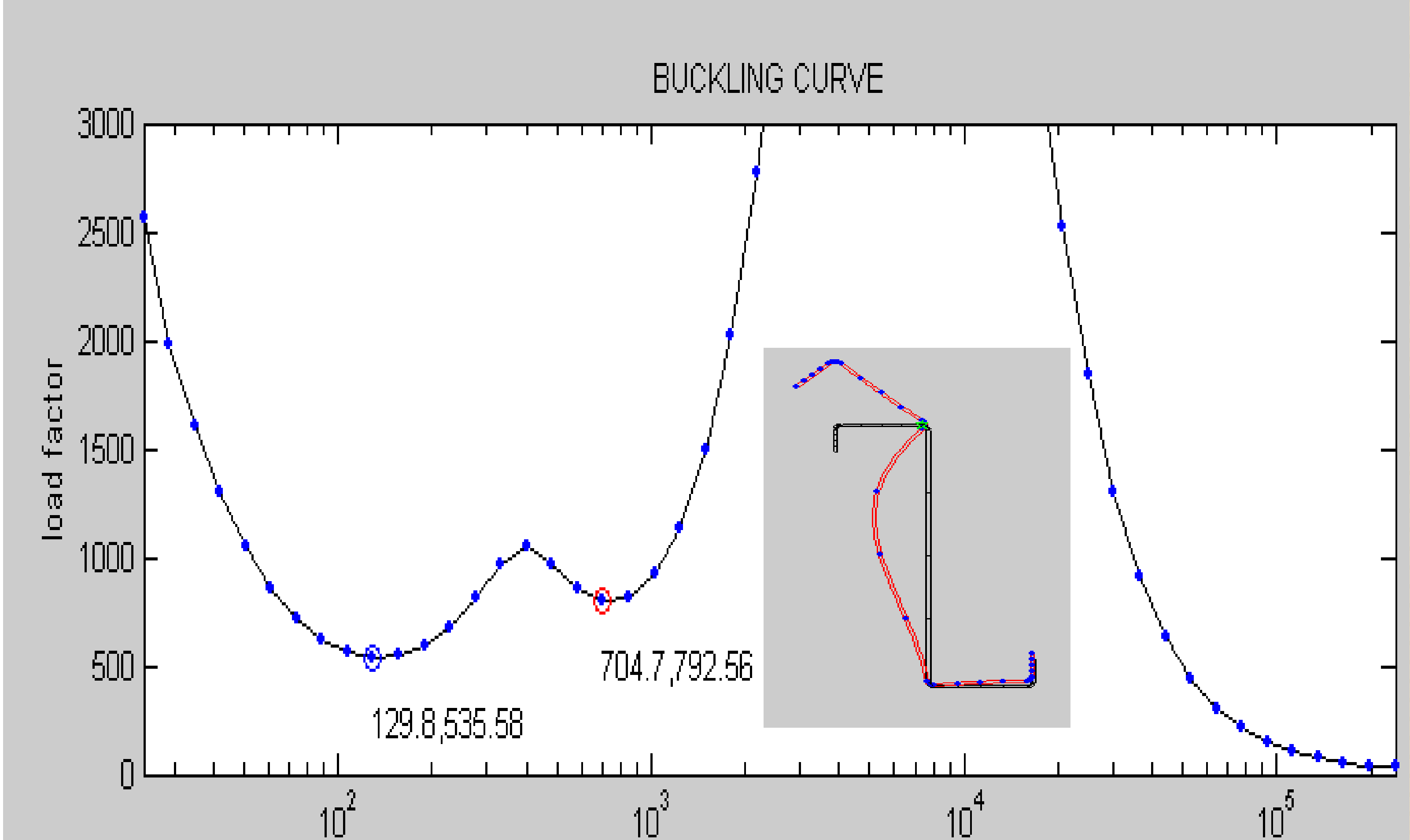
$$b_{e,i2} \geq b_{e,i1}$$



17

Interaction of local and distortional buckling

(Vrany)



Buckling modes

http://www.ce.jhu.edu/bschafer/cufsm

Check – cross-sections, members

- EN 1993-1-3
- Limits:
  - members $0{,}45 \leq t \leq 15$ mm
  - sheeting $0{,}45 \leq t \leq 4$ mm

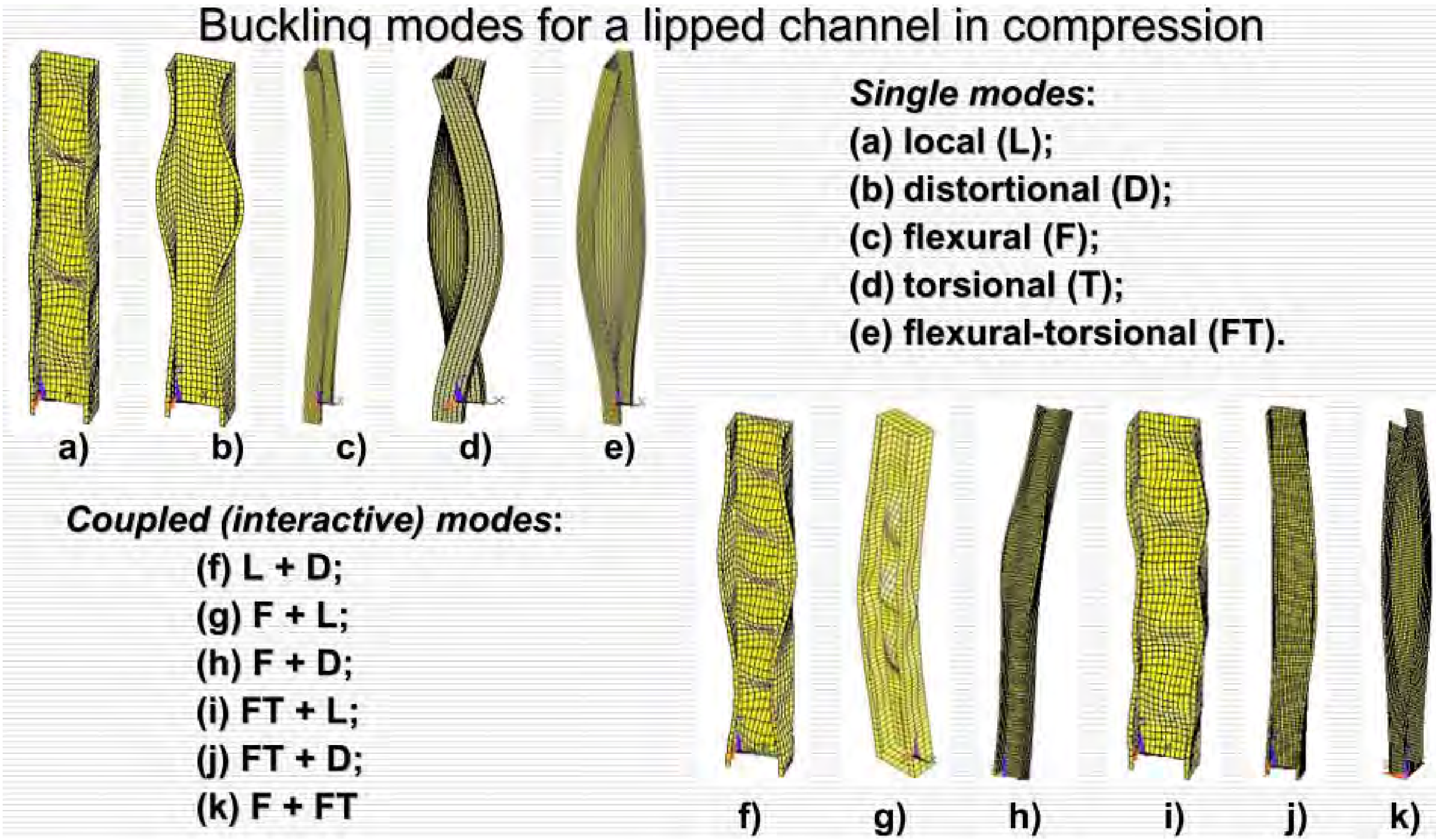
Compression

- interaction of local and global buckling

$$N_{b.Rd} = \chi\, A_{eff}\, f_y / \gamma_{M1}$$

$$\bar{\lambda} = \sqrt{\frac{N_R}{N_{cr}}} = \sqrt{\frac{A_{eff}\, f_y}{A_g\, \sigma_{cr}}} = \frac{\lambda}{\lambda_1}\sqrt{\frac{A_{eff}}{A_g}} \quad => \chi$$

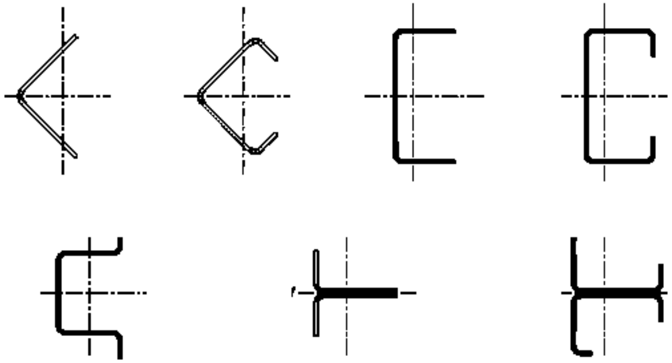
Buckling modes



(Dubina)

Flexural-torsional buckling

- uniaxial symmetrical profiles



- torsional buckling: $$\sigma_{cr,T} = \frac{1}{A_g i_o^2}\left[GI_t + \frac{\pi^2 EI_w}{\ell_T^2} \right]$$
- flexural-torsional buckling: $\sigma_{cr,TF}$ …combination $\sigma_{cr,T}, \sigma_{cr,y}$

$$\sigma_{cr,y} = \pi^2 E \Big/ \left(\ell_y / i_y \right)^2$$

- buckling curve b

Members subjected to bending

Bending

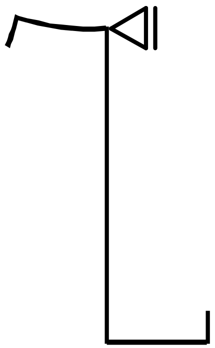
$$M_{eff.Rd} = \left(\chi_{LT}\right) W_{eff}\ f_{yd}$$

- Lateral-torsional buckling

- Specific design of cold-formed members in bending subjected to lateral-torsional buckling

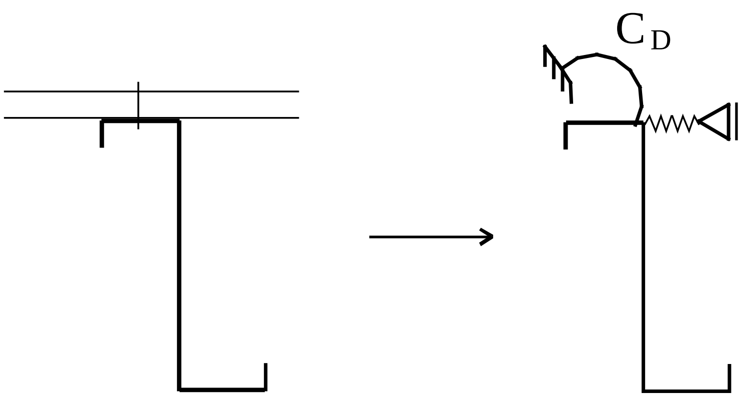
Behaviour - Z section in bending

- Slender section → local buckling
- Edge stiffener – distortional buckling



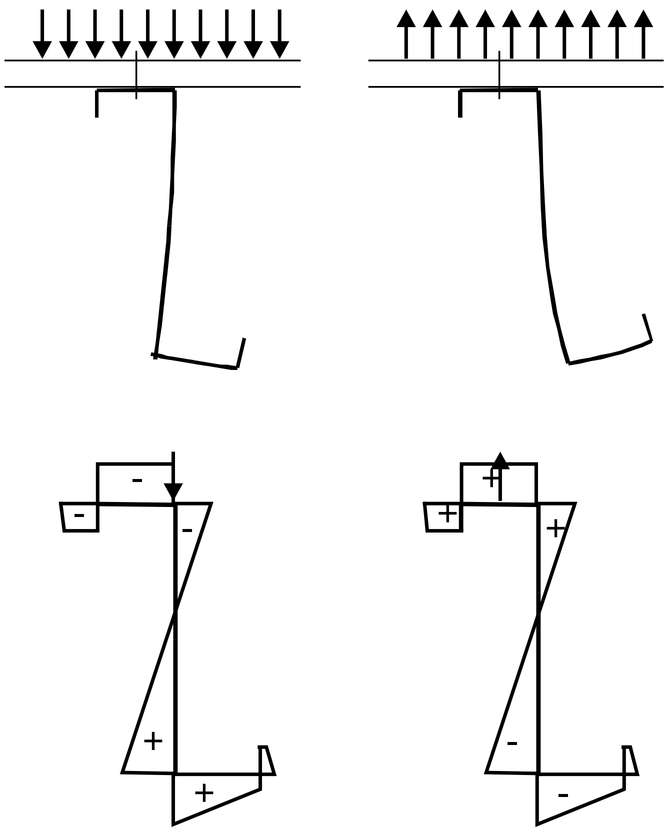
- Non-symmetry → distortion of cross-section
  Out-of-plane buckling of free flange in hogging moment areas

Cross-section distortion



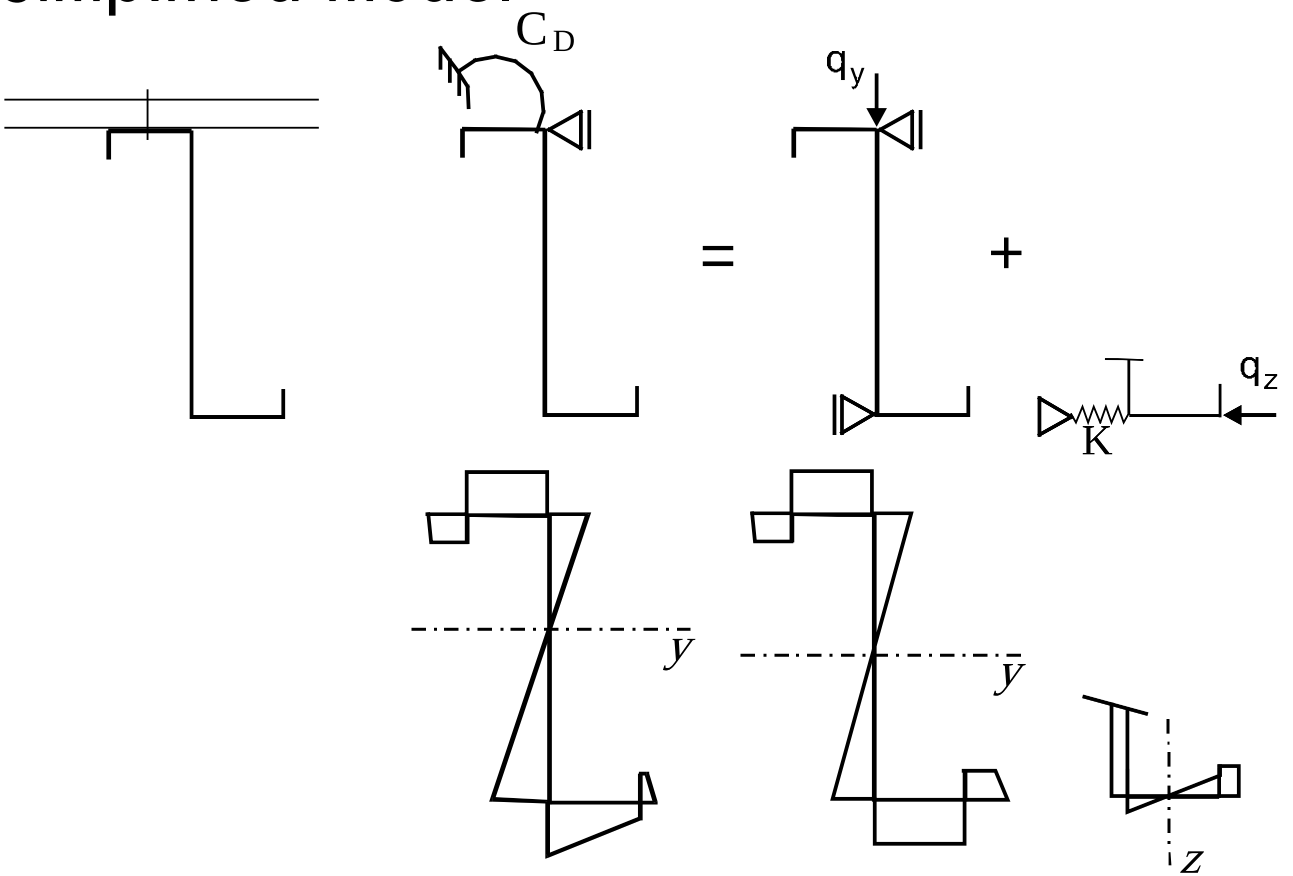
Reality

Idealized model



Cross-section distortion

- Simplified model



Calculation procedure EN1993-1-3

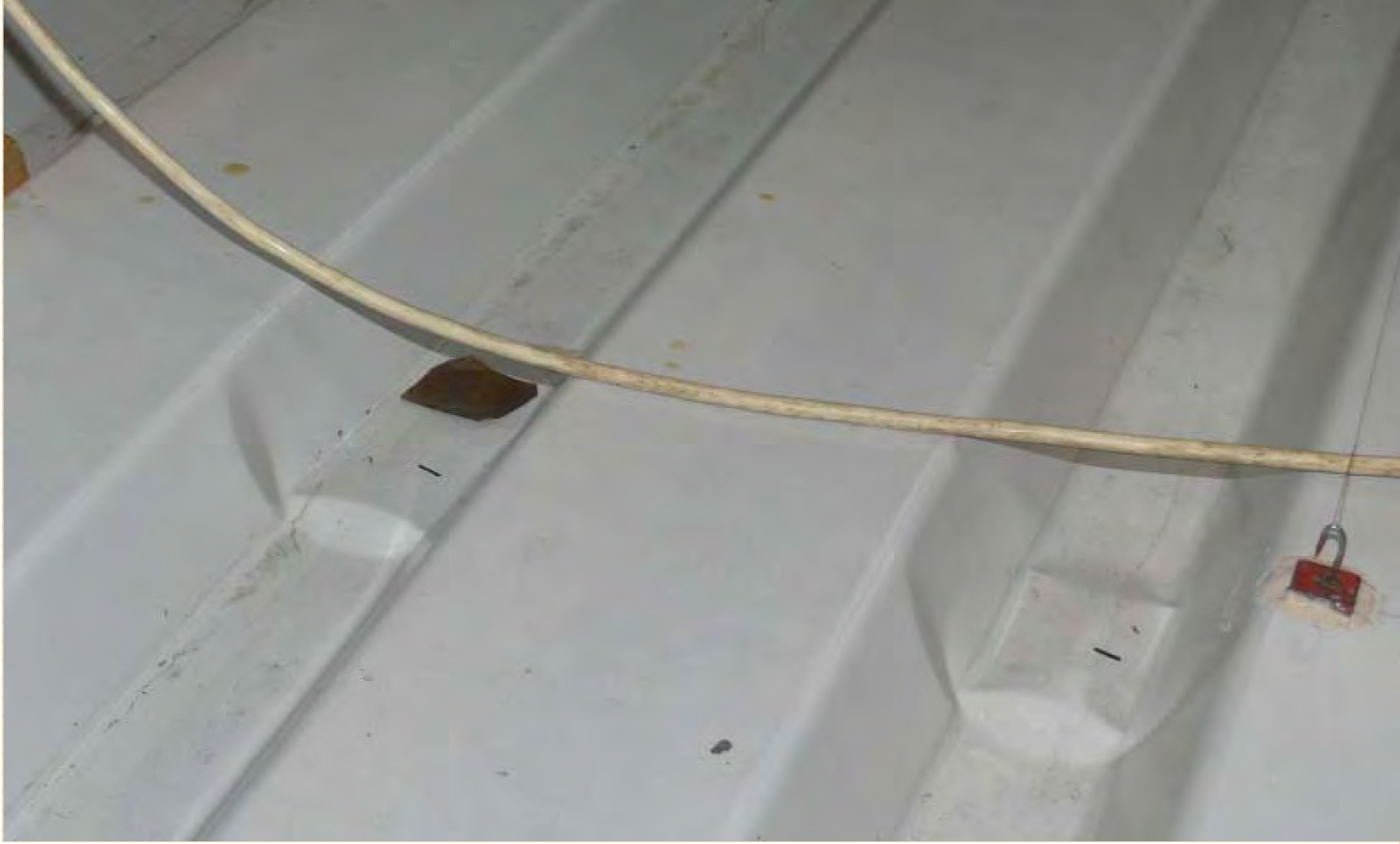
- Sagging moments:

$$\sigma_{Ed} = \frac{M_{y,Ed}}{W_{eff,y}} \leq f_{yd} = f_y / \gamma_{M1}$$

- Hogging moments:

$$\sigma_{Ed} = \frac{M_{y,Ed}}{\chi\, W_{eff,y}} + \frac{M_{fz}}{W_{fz}} \leq f_{yd} = f_y / \gamma_{M1}$$

Web crippling



Web crippling

(Vrany)

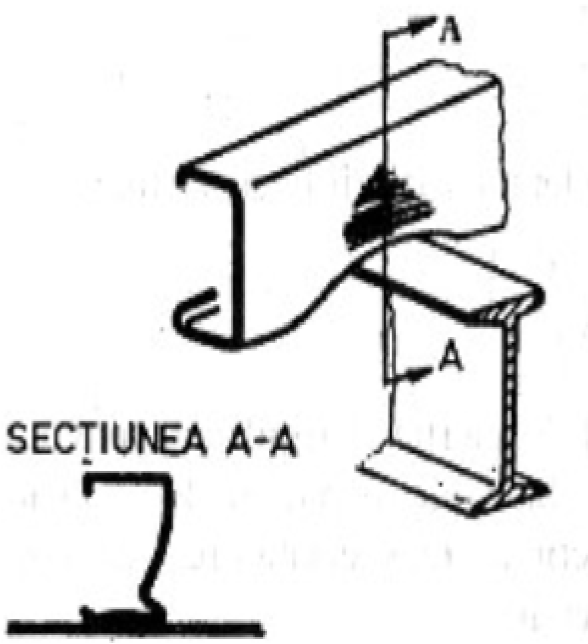
31

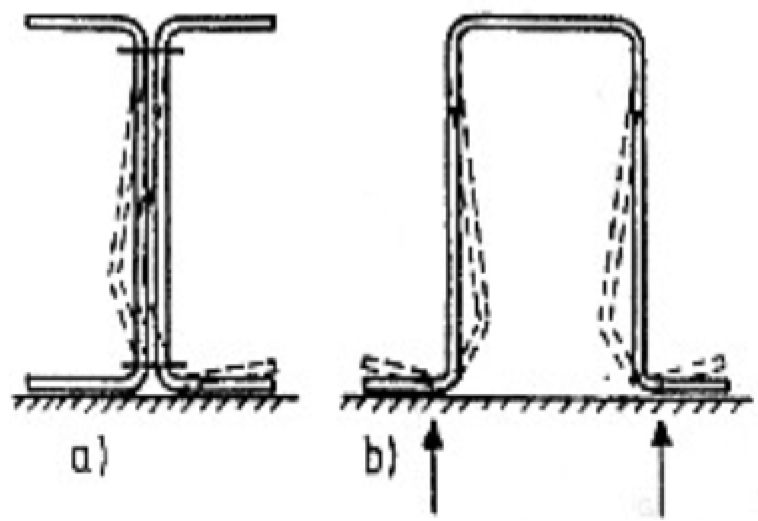
Web crippling

(Vrany)

Web crippling

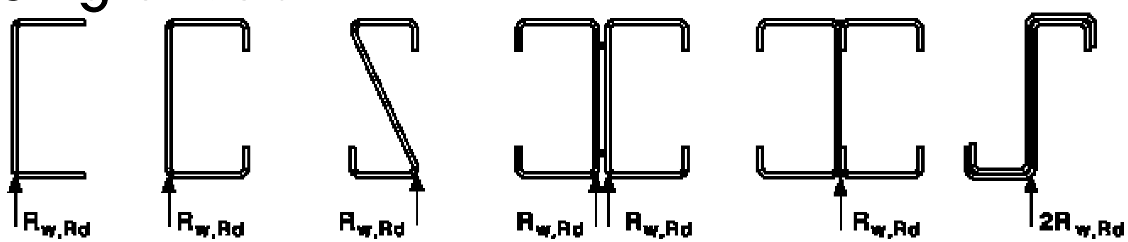
- Eccentric compression to web
- $R_{w,Rd}$ …equations derived experimentally



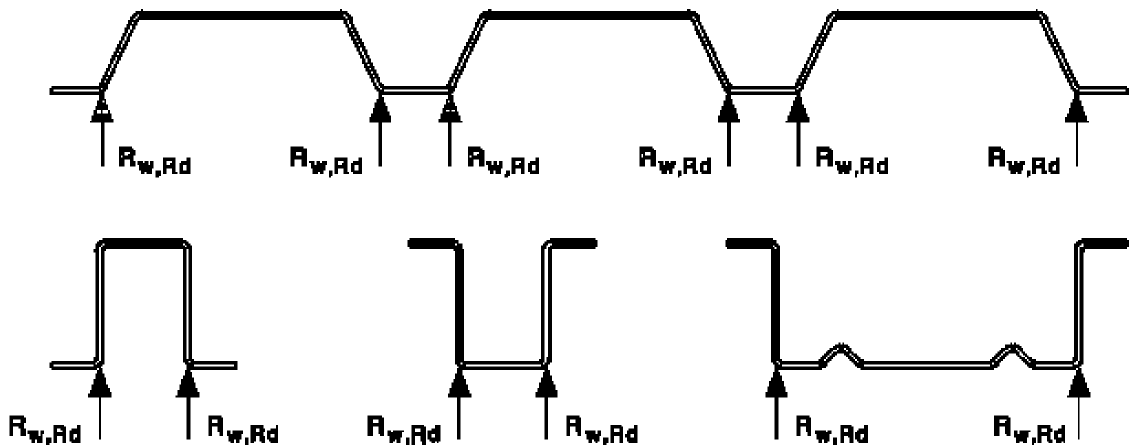


Web crippling

- Cases:
  - Single web



  - Two or more webs



Web crippling

- Loading – cases:
  - a) close to free end
  - b) far from free end

  - a) from one side
  - b) from both opposite sides

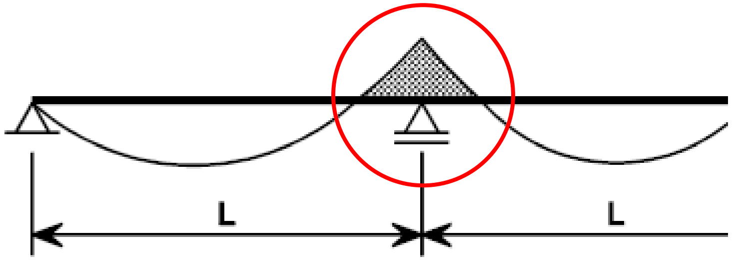
- $R_{w,Rd} = f(t^2, r/t, f, s_s \ldots)$
- product of individual factors

Interaction

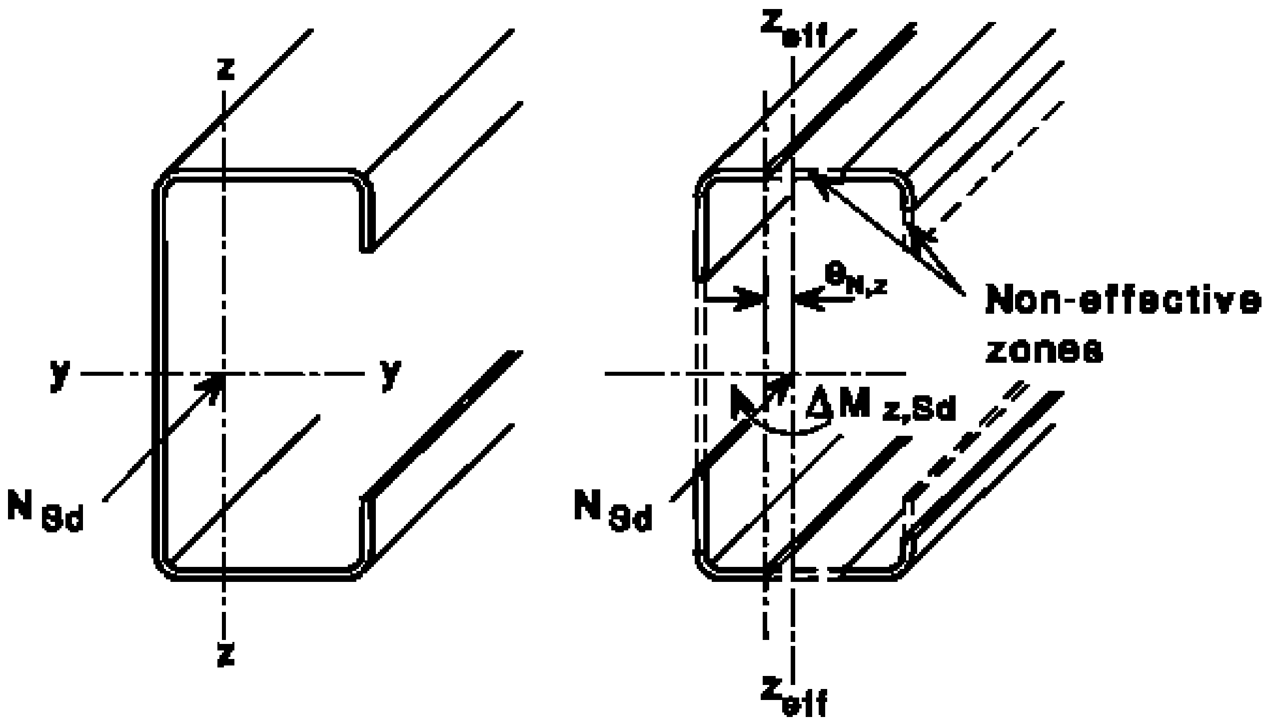
Combination M+R

$$\frac{M_{Ed}}{M_{c,Rd}} + \frac{F_{Ed}}{R_{w,Rd}} \leq 1{,}25$$

- Governing condition e.g. for corrugated sheeting, continuous beams



Combination compression + bending

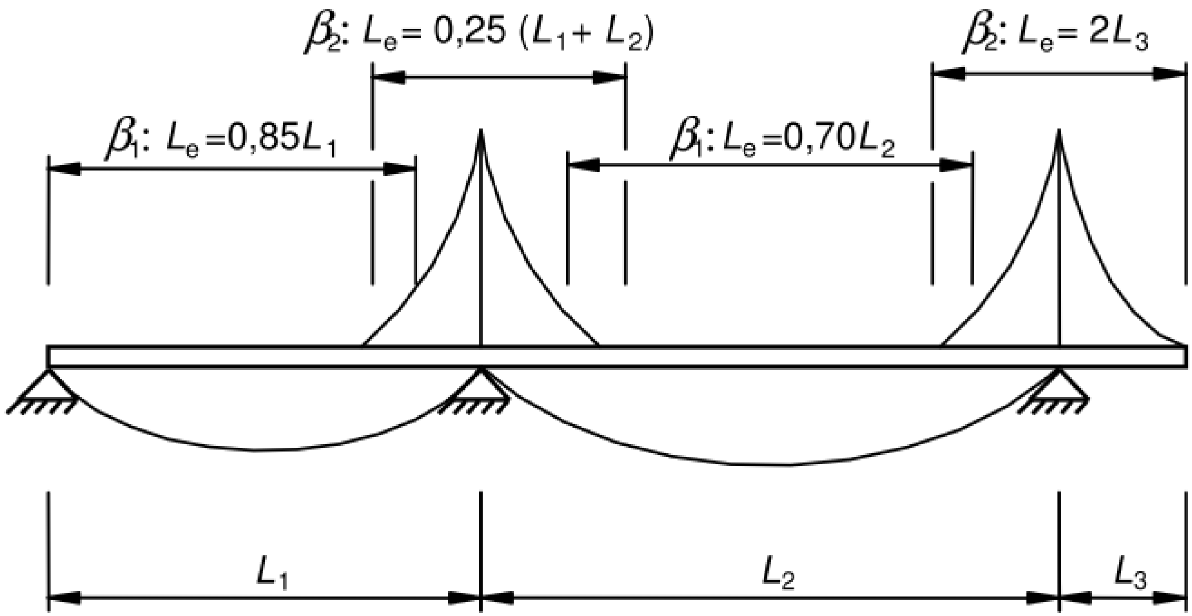


$$\Delta M_{z,\mathrm{Ed}} = N_{\mathrm{Ed}}\, e_{N,y}$$

Shear lag

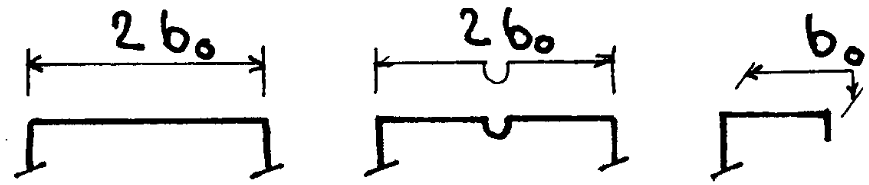
Shear lag

- by elastic analysis (I. order) ⇒ both tension and compression
- factor of ratio L_e/b_0 … to solve when $L_e/b_0 < 50$



Shear lag

- for thin-walled sections, b_0:



- Effective width:

$$b_{eff} = \frac{\int_0^b \sigma(y)\, dy}{\sigma_{max}}$$

Shear lag

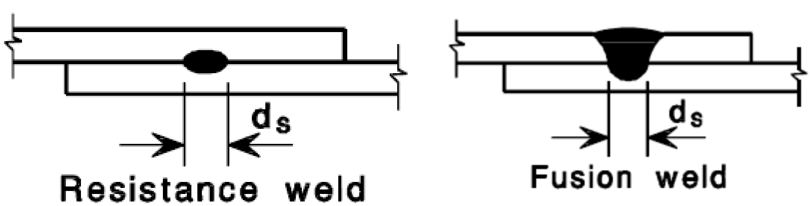
- Effective width: $b_{eff} = \beta \cdot b_0$
- Effective width factor

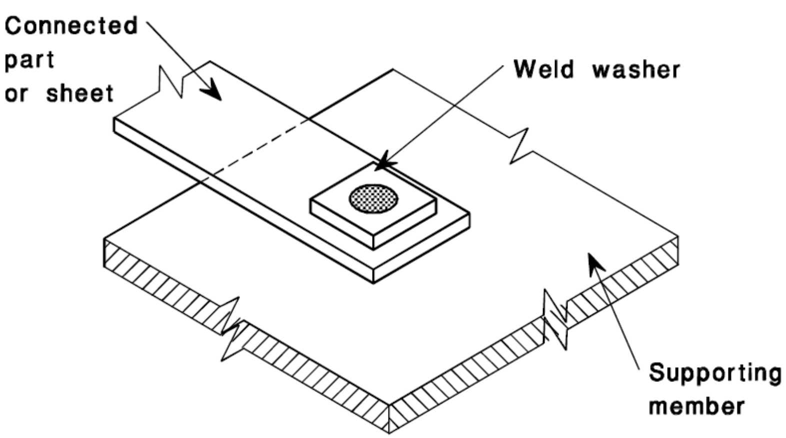
<table>
<tr><th>κ</th><th>Verification</th><th>β – value</th></tr>
<tr><td>$\kappa \leq 0{,}02$</td><td></td><td>$\beta = 1{,}0$</td></tr>
<tr><td rowspan="2">$0{,}02 < \kappa \leq 0{,}70$</td><td>sagging bending</td><td>$\beta = \beta_1 = \dfrac{1}{1 + 6{,}4\,\kappa^2}$</td></tr>
<tr><td>hogging bending</td><td>$\beta = \beta_2 = \dfrac{1}{1 + 6{,}0\left(\kappa - \dfrac{1}{2500\,\kappa}\right) + 1{,}6\,\kappa^2}$</td></tr>
<tr><td rowspan="2">$> 0{,}70$</td><td>sagging bending</td><td>$\beta = \beta_1 = \dfrac{1}{5{,}9\,\kappa}$</td></tr>
<tr><td>hogging bending</td><td>$\beta = \beta_2 = \dfrac{1}{8{,}6\,\kappa}$</td></tr>
<tr><td>all κ</td><td>end support</td><td>$\beta_0 = (0{,}55 + 0{,}025 / \kappa)\,\beta_1$, but $\beta_0 < \beta_1$</td></tr>
<tr><td>all κ</td><td>Cantilever</td><td>$\beta = \beta_2$ at support and at the end</td></tr>
<tr><td colspan="3">$\kappa = \alpha_0\, b_0 / L_e$ with $\alpha_0 = \sqrt{1 + \dfrac{A_{s\ell}}{b_0 t}}$
in which $A_{s\ell}$ is the area of all longitudinal stiffeners within the width b_0 and other symbols are as defined in Figure 3.1 and Figure 3.2.</td></tr>
</table>

Connections

Connections

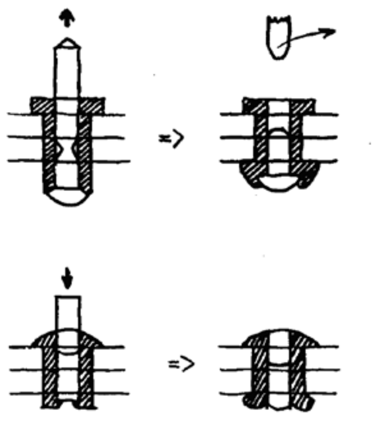
- Welds
  - fillet
    - $t \geq 3$ mm (automatic … $t \geq 2$ mm)
    - MAG is best
    - lap connections
  - spot

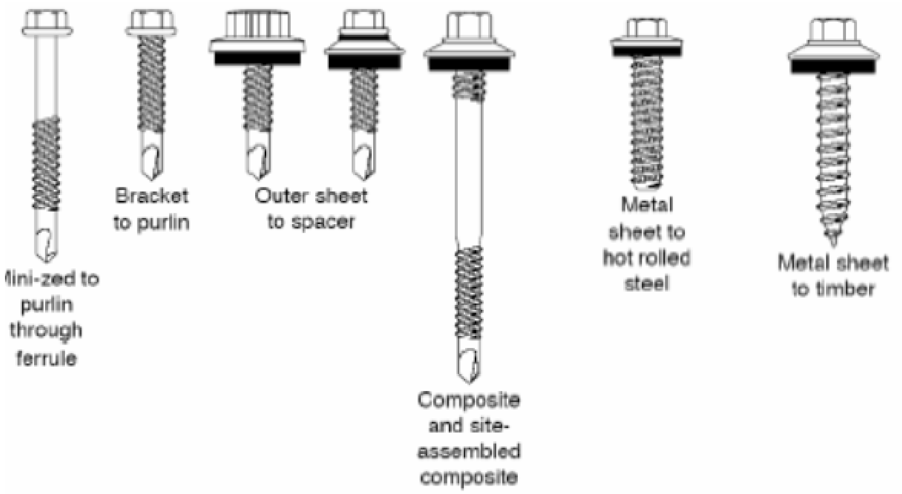




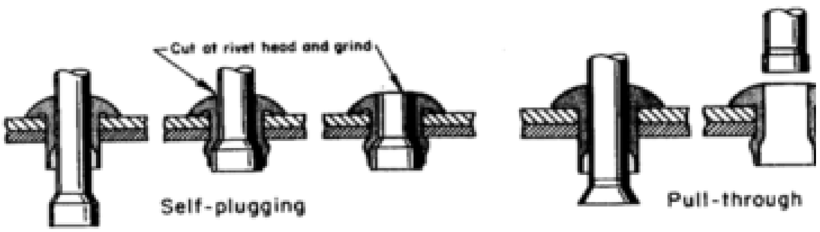
Connections

- Mechanical fasteners
  - blind rivets
  - screws $3 \leq d \leq 8$ mm
    - self-drilling (self-tapping)
    - thread-cutting
  - cartridge fired pins
  - bolts

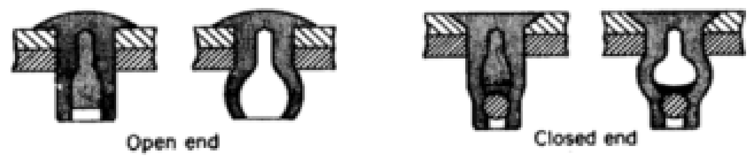




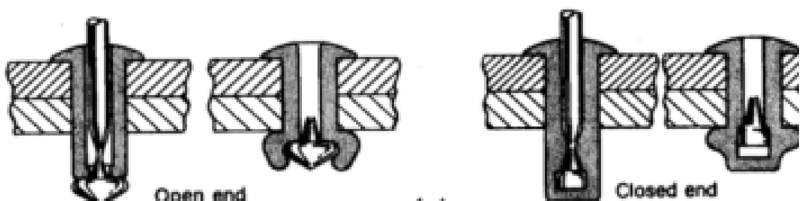
Blind rivets



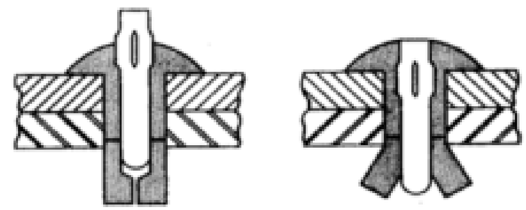
Crimped Mandrel



(b)



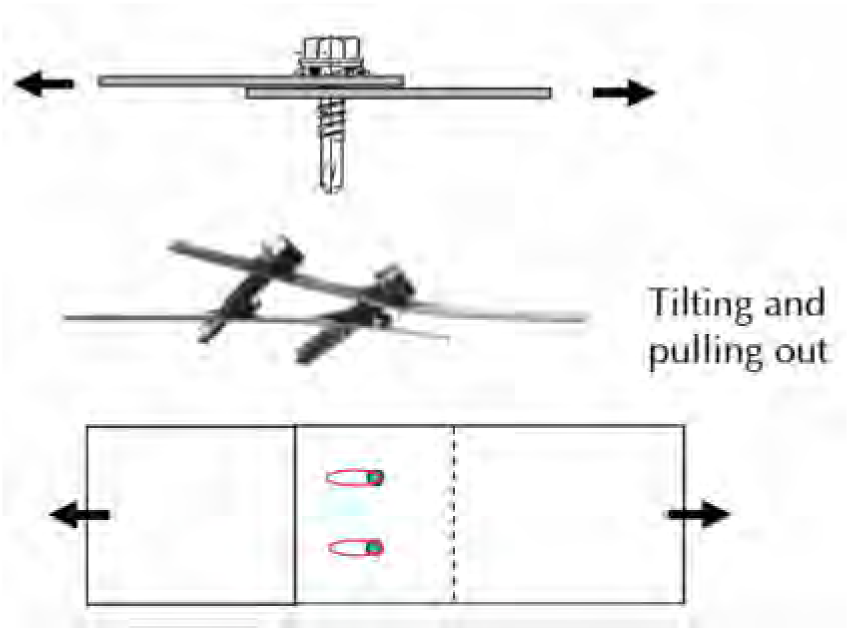
(a)



(c)

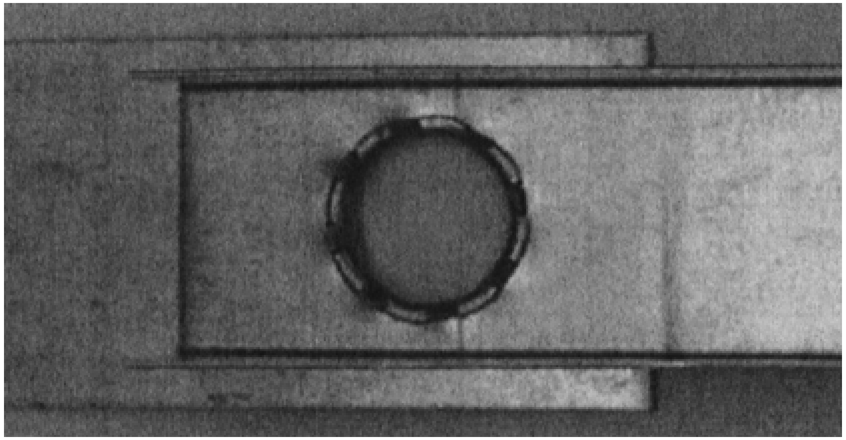
Screws

- Different failure modes compared with classic bolts



New types of connections

- "Rossete" system

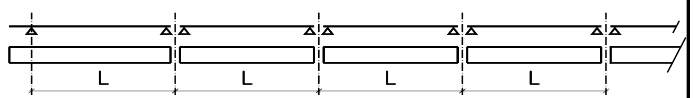
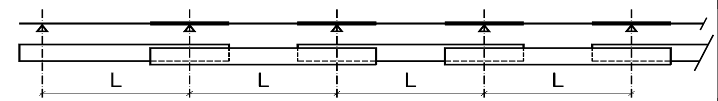


- Adhesive bonding (problem of lifespan reliability)

Design aids

Design aids

- Tables

PROFIL váha profilu	řádek číslo	PROSTÝ NOSNÍK 						SPOJITÝ NOSNÍK S PŘESAHY 					
		rozpětí pole L [m]						rozpětí pole L [m]					
		5,0	**6,0**	**7,0**	**8,0**	**9,0**	**10,0**	**5,0**	**6,0**	**7,0**	**8,0**	**9,0**	**10,0**
Z 250/2,0 7,80 kg/m	1	3,41	2,34	1,70	1,29	1,00		4,91	3,03	2,09	1,54	1,19	
	2	3,41	2,34	1,70	1,15			4,91	3,03	2,09	1,54	1,19	
	3	3,28	1,86	1,15				4,91	3,03	2,09	1,48	1,02	
	4	2,49	1,63	1,12				3,95	2,48	1,70	1,25		
	5	-2,44	-1,65	-1,19	-0,89	-0,69		-3,95	-2,64	-1,90	-1,43	-1,11	
	6	-1,92	-1,29	-0,91	-0,68	-0,52		-3,16	-2,08	-1,48	-1,10	-0,85	
Z 250/2,5 9,70 kg/m	1	4,61	3,17	2,31	1,74	1,36	1,08	6,59	4,10	2,84	2,11	1,64	1,30
	2	4,61	3,17	2,28	1,50	1,02		6,59	4,10	2,84	2,11	1,64	1,30
	3	4,25	2,42	1,49	0,97			6,59	4,10	2,84	1,92	1,32	
	4	3,66	2,43	1,68	1,20			5,75	3,57	2,47	1,83	1,41	1,03
	5	-3,31	-2,26	-1,63	-1,22	-0,95	-0,75	-5,29	-3,58	-2,59	-1,95	-1,52	-1,21
	6	-2,81	-1,91	-1,37	-1,02	-0,78	-0,62	-4,53	-3,04	-2,19	-1,64	-1,27	-1,01

Design aids

- Software