STABILITY OF COLD-FORMED ELEMENTS
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 idealisation
Cross-section

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

Actual cross-section  \[ \rightarrow \]  Idealized cross-section

Approximate allowance for rounded corners
5 Buckling in compression
Buckling strength

- Local buckling
- Distortional buckling
  - Section distortion
- Global buckling
- Shear buckling

Sectional modes

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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)

\[
\lambda_p = \sqrt{\frac{\sigma_{com}}{\sigma_{cr}}} = 1.052 \frac{b}{t} \sqrt{\frac{\sigma_{com}}{k_\sigma E}} \quad \sigma_{com} \leq f_y
\]

- 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)

\[ K \left[ \frac{N}{\text{m} \cdot \text{mm}} \right] \]
Buckling of edge stiffener
Spring stiffness of stiffener

a) Actual system

b) Equivalent system

c) Calculation of $\delta$ for C and Z sections

**Determination of spring stiffness**

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Stress distribution - idealisation

- distortional buckling
Calculation procedure

1. Stiffener provides rigid support to the plate ⇒ effective widths
2. $K, A_s, l_s$
3. Critical stress $\sigma_{cr}$
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. $A_s, l_s$
9. $t_{red} = \chi_d t$
Final effective cross-section

\[ b_{e,i2} \geq b_{e,i1} \]
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 $0.45 \leq t \leq 15 \text{ mm}$
  - sheeting $0.45 \leq t \leq 4 \text{ mm}$
Compression

- Interaction of local and global buckling

\[ N_{b,Rd} = \chi A_{\text{eff}} \frac{f_y}{\gamma_{M1}} \]

\[ \overline{\lambda} = \sqrt{\frac{N_R}{N_{cr}}} = \sqrt{\frac{A_{\text{eff}} f_y}{A_g \sigma_{cr}}} = \frac{\lambda}{\lambda_1} \sqrt{\frac{A_{\text{eff}}}{A_g}} \Rightarrow \chi \]
Buckling modes for a lipped channel in compression

**Single modes:**
- (a) local (L);
- (b) distortional (D);
- (c) flexural (F);
- (d) torsional (T);
- (e) flexural-torsional (FT).

**Coupled (interactive) modes:**
- (f) L + D;
- (g) F + L;
- (h) F + D;
- (i) FT + L;
- (j) FT + D;
- (k) F + FT.
Flexural-torsional buckling

- uniaxial symmetrical profiles

\[
\begin{cases}
\end{cases}
\]

- torsional buckling:

\[
\sigma_{cr,T} = \frac{1}{A_g i_o^2} \left[ G I_t + \frac{\pi^2 E I_w}{\ell_T^2} \right]
\]

- flexural-torsional buckling: \( \sigma_{cr,TF} \) combination of \( \sigma_{cr,T}, \sigma_{cr,y} \)

\[
\sigma_{cr,y} = \frac{\pi^2 E}{(\ell_y / i_y)^2}
\]

- buckling curve b
Members subjected to bending
\[ M_{\text{eff.Rd}} = (\chi_{LT}) W_{\text{eff}} f_{yd} \]

- Lateral-torsional buckling

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

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Cross-section distortion

- Simplified model

\[ K_{CD} + q_y = + q_z \]
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)
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

\[ \Delta M_{z,Ed} = N_{Ed} e_{N,y} \]
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, $b_0$:

\[
\text{Effective width:} \quad b_{\text{eff}} = \frac{\int_0^b \sigma(y) \, dy}{\sigma_{\text{max}}}
\]

$\int_0^b \sigma(y) \, dy$
Shear lag

- **Effective width**: \( b_{\text{eff}} = \beta \cdot b_0 \)

- **Effective width factor**

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<tr>
<th>( \kappa )</th>
<th>Verification</th>
<th>( \beta )-value</th>
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<td>( \kappa \leq 0,02 )</td>
<td>( \beta = 1,0 )</td>
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<td>( 0,02 &lt; \kappa \leq 0,70 )</td>
<td>sagging bending</td>
<td>( \beta = \beta_1 = \frac{1}{1 + 6,4 \kappa^2} )</td>
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<td>hogging bending</td>
<td>( \beta = \beta_2 = \frac{1}{1 + 6,0 \left( \kappa - \frac{1}{2500 \kappa} \right) + 1,6 \kappa^2} )</td>
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<td>( &gt; 0,70 )</td>
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<td>( \beta = \beta_1 = \frac{1}{5,9 \kappa} )</td>
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<td>( \beta = \beta_2 = \frac{1}{8,6 \kappa} )</td>
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<td>all ( \kappa )</td>
<td>end support</td>
<td>( \beta_0 = (0,55 + 0,025 / \kappa) \beta_1 ), but ( \beta_0 &lt; \beta_1 )</td>
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<tr>
<td>all ( \kappa )</td>
<td>Cantilever</td>
<td>( \beta = \beta_2 ) at support and at the end</td>
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\( \kappa = \frac{a_0 \cdot b_0}{L_e} \) with \( a_0 = \sqrt{1 + \frac{A_{\text{st}}}{b_0 t}} \)

in which \( A_{\text{st}} \) 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.
Connections
Connections

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

![Weld Types Diagram](image)
Connections

- **Mechanical fasteners**
  - **blind rivets**
  - **screws** \( 3 \leq d \leq 8 \text{ mm} \)
    - self-drilling (self-tapping)
    - thread-cutting
  - **cartridge fired pins**
  - **bolts**
Blind rivets

- Self-plugging
- Pull-through
- Open end
- Closed end

Crimped Mandrel

- Open end
- Closed end

(a) (b) (c)
Different failure modes compared with classic bolts
New types of connections

- “Rossete” system

- Adhesive bonding (problem of lifespan reliability)
Design aids
## Tables

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Design aids

Software

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