**DESIGN EXAMPLE 12 – DESIGN OF A LIPPED CHANNEL IN AN EXPOSED FLOOR**

Design a simply supported beam with a lipped channel in an exposed floor. The material is stainless steel grade 1.4401 CP500, i.e. cold worked to a yield strength of 500 N/mm². The beam is simply supported with a span, \( l \) of 4 m. The distance between adjacent beams is 1 m.

As the load is not applied through the shear centre of the channel, it is necessary to check the interaction between the torsional resistance of the cross-section and the lateral torsional buckling resistance of the member. However, this example only checks the lateral torsional buckling resistance of the member.

**Factors**

Partial factor \( \gamma_{M0} = 1,1 \) and \( \gamma_{M1} = 1,1 \)

Load factor \( \gamma_G = 1,35 \) (permanent loads) and \( \gamma_Q = 1,5 \) (variable loads)

**Actions**

Permanent actions (\( G \)): 2 kN/m²

Variable actions (\( Q \)): 3 kN/m²

Load case to be considered in the ultimate limit state:

\[
q^* = \sum \gamma_{G,j} G_{k,j} + \gamma_{Q,j} Q_{k,j} = 7,2 \text{ kN/m}
\]

**Structural Analysis**

Reactions at support points (Design shear force)

\[
V_{Ed} = \frac{q^* \times 4}{2} = 14,4 \text{ kN}
\]

Design bending moment

\[
M_{Ed} = \frac{q^* \times 4^2}{8} = 14,4 \text{ kNm}
\]

**Material Properties**

Yield strength \( f_y = 500 \text{ N/mm}^2 \)

Modulus of elasticity \( E = 200 \text{ 000 N/mm}^2 \)

Shear modulus \( G = 76900 \text{ N/mm}^2 \)

**Cross-section Properties**

The influence of rounded corners on cross-section resistance may be neglected if the internal radius \( r \leq 5t \) and \( r \leq 0,10b_p \) and the cross section may be assumed to consist of plane elements with sharp corners. For cross-section stiffness properties the influence of rounded corners should always be taken into account.
h = 160 mm
b = 125 mm
c = 30 mm
t = 5 mm
r = 5 mm

\[ b_p = b - t - 2g_r = 115.6 \text{ mm} \]
\[ g_r = r_m \left[ \tan(\phi/2) - \sin(\phi/2) \right] = 2.2 \text{ mm} \]
\[ r_m = r + t/2 = 7.5 \text{ mm} \]
\[ r = 5 \text{ mm} \leq 5t = 25 \text{ mm} \]
\[ r = 5 \text{ mm} \leq 0.10b_p = 11.56 \text{ mm} \]

The influence of rounded corners on section properties may be taken into account with sufficient accuracy by reducing the properties calculated for an otherwise similar cross-section with sharp corners, using the following approximations:

Notional flat width of the flange, \( b_{p,f} = b - t - 2g_r = 115.6 \text{ mm} \)

Notional flat width of the web, \( b_{p,w} = h - t - 2g_r = 150.6 \text{ mm} \)

Notional flat width of the lip, \( b_{p,l} = c - t/2 - g_r = 25.30 \text{ mm} \)

\[ A_{g,sh} = 2162 \text{ mm}^2 \]
\[ I_{g,sh} = 9.069 \times 10^6 \text{ mm}^4 \]
\[ \delta = 0.43 \sum_{j=1}^{m} \phi_j / 90^\circ \sum_{i=1}^{m} b_{p,i} = 0.02 \]

\[ A_g = A_{g,sh} (1 - \delta) = 2119 \text{ mm}^2 \]
\[ I_g = I_{g,sh} (1 - 2\delta) = 8.708 \times 10^6 \text{ mm}^4 \]

**Classification of the cross-section**

\[ \varepsilon = \left[ \frac{235}{f_{y}} \frac{E}{210000} \right]^{0.5} = 0.669 \]

**Flange:** Internal compression parts. Part subjected to compression.

\[ c = b_p = b - t - 2g_r = 115.6 \text{ mm} \]

\( c/t = 23.12 > 30.7 \varepsilon \), therefore the flanges are Class 4

**Web:** Internal compression parts. Part subjected to bending.
**CALCULATION SHEET**

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\[
c = h - t - 2g_r = 150.6 \text{ mm}
\]

\[
c/t = 30.12 \leq 56 \varepsilon, \text{ therefore the web is Class 1}
\]

**Lip:** Outstand flanges. Part subjected to compression, tip in compression,

\[
c = t - t/2 - g_r = 25.30 \text{ mm}
\]

\[
c/t = 5.06 \leq 10 \varepsilon, \text{ therefore the lip is Class 1}
\]

**Calculation of the effective section properties**

**Flange effective width:** Internal compression elements. Part subjected to compression.

\[
\bar{b} = b_p = b - t - 2g_r = 115.6 \text{ mm}
\]

Assuming uniform stress distribution in the compression flange:

\[
\psi = \frac{\sigma_2}{\sigma_1} = 1 \quad \text{and the buckling factor } k_\sigma = 4
\]

\[
\bar{x}_p = \frac{\bar{b}/t}{28.4e}\sqrt{k_\sigma} = 0.608
\]

Cold formed internal elements:

\[
\rho = \frac{0.772}{\bar{x}_p} - \frac{0.125}{\bar{x}_p^2} = 0.9311 < 1
\]

\[
b_{eff} = \rho \bar{b} = 107.64 \text{ mm}, \quad b_{e1} = 0.5b_{eff} = 53.82 \text{ mm}, \quad b_{e2} = 0.5b_{eff} = 53.82 \text{ mm}
\]

**Effects of shear lag**

Shear lag in flanges may be neglected if \( b_0 < L_e/50 \), where \( b_0 \) is taken as the flange outstand or half the width of an internal element and \( L_e \) is the length between points of zero bending moment.

For internal elements: \( b_0 = (b-t)/2 = 60 \text{ mm} \)

The length between points of zero bending moment: \( L_e = 4000 \text{ mm}, \quad L_e/50 = 80 \text{ mm} \)

Therefore shear lag can be neglected

**Flange curling**

\[
u = 2 \frac{\sigma_a^2 b_s^4}{E^2 t^2 z} = 2.55 \text{ mm}
\]

\( b_s = 141 \text{ mm is the distance between webs} \)

\( t = 5 \text{ mm} \)

\( z = 77.5 \text{ mm is the distance of the flange under consideration from neutral axis} \)

\( \sigma_a \) is mean stress in the flanges calculated with gross area (\( f_y = 500 \text{ N/mm}^2 \) is assumed)

Flange curling can be neglected if it is less than 5% of the depth of the profile cross-section:

\[
u = 2.55 \text{ mm} < 0.05h = 8 \text{ mm, therefore flange curling can be neglected.}
\]
Stiffened elements. Edge stiffeners
Distortional buckling. Plane elements with edge stiffeners

**Step 1:** Initial effective cross-section for the stiffener

For flanges (as calculated before)

- b = 125 mm
- b_p = 115,61 mm
- b_eff = 107,65 mm
- b_e1 = 0,5b_eff = 53,82 mm
- b_e2 = 0,5b_eff = 53,82 mm

For the lip, the effective width c_eff should be calculated using the corresponding buckling factor k_σ, \( \lambda_p \), and \( \rho \) expressions as follows:

- \( b_{p,c} = c-t/2 - b_p = 25,30 \) mm
- \( b_p = 115,6 \) mm
- \( b_{p,c}/b_p = 0,22 < 0,35 \) then \( k_\sigma = 0,5 \)

\[
\bar{\lambda}_p = \frac{\overline{b}/t}{28,4\sqrt{\kappa \sigma}} = 0,45 \quad (\bar{b} = 30 \text{ mm})
\]

Cold formed outstand elements: \( \rho = \frac{1}{\lambda_p} - \frac{0,231}{\lambda_p^2} = 1,08 > 1 \) then \( \rho = 1 \)

- \( c_{eff} = \rho b_{p,c} = 25,30 \) mm

**Step 2:** Reduction factor for distortional buckling

Calculation of geometric properties of effective edge stiffener section

- \( b_{e2} = 53,82 \) mm
- \( c_{eff} = 25,30 \) mm
- \( A_s = (b_{e2} + c_{eff})t = 395,64 \text{ mm}^2 \)
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![Diagram](image)

\( y_s = 4.01 \text{ mm} \)
\( y_b = 18.27 \text{ mm} \)

\( I_s = 21211.8 \text{ mm}^4 \)

Calculation of linear spring stiffness

\[
K_1 = \frac{E t^3}{4(1 - \nu^2) b^2 h_y + b^2 t + 0.5 b^2 h_y k_f} = 2487 \text{ N/mm}^2
\]

\( b_1 = b - y_b - t/2 = 104.23 \text{ mm} \) (the distance from the web-to-flange junction to the gravity center of the effective area of the edge stiffener, including the efficient part of the flange \( b_{o2} \))

\( k_f = 0 \) (flange 2 is in tension)

\( h_w = 150 \text{ mm} \) is the web depth

Elastic critical buckling stress for the effective stiffener section

\[
\sigma_{cr, s} = \frac{2\sqrt{K E I_s}}{A_s} = 519.195 \text{ N/mm}^2
\]

Reduction factor \( \chi_d \) for distortional buckling

\[
\lambda_d = \sqrt{\frac{f_{yb}}{\sigma_{cr, s}}} = 0.98
\]

\( 0.65 < \lambda_d < 1.38 \) then \( \chi_d = 1.47 - 0.723 \lambda_d = 0.76 \)

Reduced area and thickness of effective stiffener section

\[
A_{s, red} = \chi_d A_s \frac{f_{yb}}{\gamma_{M0}} = 300.88 \text{ mm}^2
\]

\( t_{red} = t A_{s, red}/A_s = 3.8 \text{ mm} \)

Calculation of effective section properties with distortional buckling effect

\[
A_{eff, sh} = 2028 \text{ mm}^2
\]

\[
\delta = 0.43 \sum_{j=1}^{m} \delta_j / 90^\circ \sum_{i=1}^{n} b_{p,i} = 0.02
\]

\[
A_{eff} = A_{eff, sh} (1 - \delta) = 1987 \text{ mm}^2
\]

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prEN 1993-1-3, Fig. 5.9

prEN 1993-1-3, Eq. 5.10b

prEN 1993-1-3, Eq. 5.15

prEN 1993-1-3, Eq. 5.12d

prEN 1993-1-3, Eq. 5.17

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Eq 4.21

Eq 4.18
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Design Example 12 – Design of a lipped channel in an exposed floor

z\text{G} = 68.98 \text{ mm} \quad \text{(distance from the bottom fibre to the neutral axis)}

\begin{align*}
I_{y,\text{eff,sh}} &= 8.274 \times 10^6 \text{ mm}^4 \\
I_{y,\text{eff}} &= I_{y,\text{eff,sh}} (1 - 2\delta) = 7.943 \times 10^6 \text{ mm}^4 \\
W_{y,\text{eff, sup}} &= 92.34 \times 10^3 \text{ mm}^3 \\
W_{y,\text{eff, inf}} &= 115.2 \times 10^3 \text{ mm}^3
\end{align*}

Resistance of cross-section

Cross-section subject to bending moment

\begin{align*}
M_{c,Rd} &= W_{y,\text{eff}} \frac{f_y}{\gamma_M 0} = 41.97 \text{ kNm} \quad \text{for Class 4 cross-section}
\end{align*}

Design bending moment \( M_{Ed} = 14.4 \text{ kNm} \)

Cross-section moment resistance is Ok

Cross-section subject to shear

\begin{align*}
V_{pl,Rd} &= A_v \frac{f_y}{\sqrt{3}} \frac{1}{\gamma_M 0} = 209.95 \text{ kN}
\end{align*}

\( A_v = 800 \text{ mm}^2 \) is the shear area

Design shear force \( V_{Ed} = 14.4 \text{ kN} \)

Cross-section shear resistance is Ok

Cross-section subjected to combination of loads

\begin{align*}
V_{Ed} = 14.4 \text{ kN} > 0.5V_{pl,Rd} = 104.97 \text{ kN}
\end{align*}

There is no interaction between bending moment and shear force

Flexural members

Lateral-torsional buckling

\begin{align*}
M_{b,Rd} &= \chi_{LT} W_{y,\text{eff, sup}} f_y \frac{1}{\gamma_M 1} \quad \text{for Class 4 cross-section}
\end{align*}

\begin{align*}
\chi_{LT} &= \frac{1}{\varphi_{LT} + \left( \frac{\varphi_{LT}^2 - \chi_{LT}^2}{2} \right)^{0.5}} \leq 1 \\
\varphi_{LT} &= 0.5 \left( 1 + \alpha_{LT} \left( \chi_{LT} - 0.4 \right) + \chi_{LT}^2 \right) \\
\chi_{LT} &= \sqrt{W_{y,\text{eff}} f_y \frac{1}{M_{cr}}}
\end{align*}

\( \alpha_{LT} = 0.34 \) for cold formed sections

Determination of the elastic critical moment for lateral-torsional buckling

\begin{align*}
M_{cr} &= C_1 \frac{\pi^2 E I_z}{(k_z L)^2} \left( \frac{k_z}{k_w} \right)^2 I_w + \left( \frac{k_z L}{\pi^2 E I_z} \right)^2 G I_x + \left( C_2 z_g - C_3 z_j \right)^2 \right) ^{1/2} - \left( C_2 z_g - C_3 z_j \right)^2
\end{align*}

Appendix B, Section B.1
For simply supported beams with uniform distributed load: $C_1=1,12$, $C_2=0,45$ and $C_3=0,525$.

Assuming normal conditions of restraint at each end: $k_z=k_w=1$

$z_0=0$ for equal flanged section

$z_b = z_c = h/2 = 80$ mm

$z_a$ is the co-ordinate of point load application

$z_g$ is the co-ordinate of the shear centre

$y_G=45,34$ mm (distance from the central axis of the web to the gravity centre)

$I_{z,sh}=4,274 \times 10^6$ mm$^4$

$I_{x,sh}=18,02 \times 10^3$ mm$^4$

$I_{w,sh}=23,19 \times 10^9$ mm$^6$

$I_z=I_{z,sh}(1-2\delta) = 4,103 \times 10^6$ mm$^4$

$I_t=I_{t,sh}(1-2\delta) = 17,30 \times 10^3$ mm$^4$

$I_w=I_{w,sh}(1-4\delta) = 21,33 \times 10^9$ mm$^6$

Note: The expression used to determine the warping torsion is obtained from Wei-Wen You, “Cold-Formed Steel Design”, Appendix B-Torsion

Then, $M_{cr}=C_1 \pi^2 E I_z \left[ \left( k_z \right) \left( k_w \right) \right]^2 + \left( k_z L \right)^2 G I_t + (C_2 z_g)^2 \right]^{1/2} - \left( C_2 z_g \right) \right] = 33,74$ kNm

$\lambda_{LT} = \sqrt{\frac{W_{y,eff, sup} f_y}{M_{cr}}} = 1,17$ (\(W_{y,eff, sup}=92,39 \times 10^3$ mm$^3$, compression flange)

$\phi_{LT} = 0,5 \left( 1 + \alpha_{LT} \left( \frac{\bar{z}}{\lambda_{LT}} - 0,4 \right) + \frac{\bar{z}}{\lambda_{LT}} \right) = 1,315$

$\chi_{LT} = \frac{1}{\phi_{LT} + \left[ \phi_{LT}^2 - \lambda_{LT}^2 \right]^{0.5}} = 0,522$

$M_{b, Rd} = \chi_{LT} \frac{W_{y,eff, sup} f_y}{\gamma_{M1}} = 21,91$ kNm

Design moment $M_{Ed} = 14,4$ kNm, therefore lateral torsional buckling resistance Ok

Note: As the load is not applied through the shear centre of the channel, it is also necessary to check the interaction between the torsional resistance of the cross-section and the lateral torsional buckling resistance of the member.

**Shear buckling resistance**

The shear buckling resistance only requires checking when $h_w/t \geq 52 \epsilon / \eta$ for an unstiffened web.

The recommended value for $\eta = 1,20$

$h_w/t = 28$, $52 \epsilon / \eta = 28,99$, therefore no further check required.