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ANGELHY

Innovative solutions for design and strengthening of telecommunications and transmission lattice towers using large angles from high strength steel and hybrid techniques of angles with FRP strips

WORK PACKAGE 5 – DELIVERABLE 5.1

Proposals for Code amendments

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1 Introduction

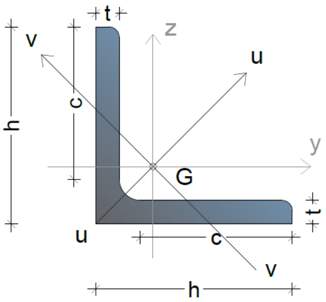
The code amendments for single angle and built-up members are presented in this deliverable through tables, and referred to prEN1993-1-1 [1], EN1993-1-5[2] and EN1993-3-1[3]. In the tables, there is a summary of the existing codes on the relevant topic as well as the proposal which came out from the investigations of ANGELHY project; the differences in the proposed formulas are distinguished with red colour from the existing ones.

More details of all the proposed formulas are available in Deliverable 4.4 [4] and Deliverable 3.4 [5], including examples of application.

2 Code amendments for single angle members

The code amendments for single angle members are summarizes in the last column of Table 2.1.

Table 2.1: Code amendments for the design of single angle members

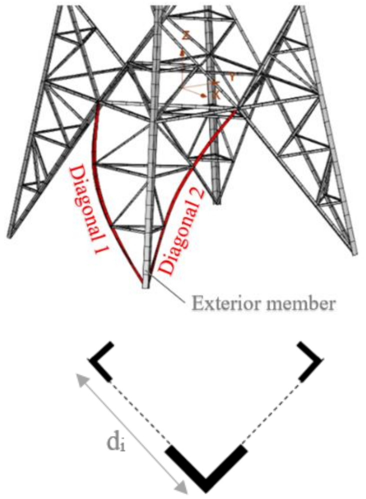
TOPIC	EXISTING RULES	ANGELHY PROPOSALS	CODE AMENDMENT
Classification system for equal leg angle cross-sections			
	G centre of gravity h,t geometrical properties (c=h-t-r) u-u major principal axis or weak axis v-v minor principal axis or strong axis y,z geometrical axes		
Part in compression Axial force N	Class 3 limit 1. limit prEN1993-1-1, Table 7.3, sheet 3: $\frac{h}{t} \leq 15\varepsilon \quad and \quad \frac{h}{t} \leq 11{,}5\varepsilon$ 2. limit prEN1993-1-1, Table 7.3, sheet 2: $\frac{c}{t} \leq 14\varepsilon$ 3. EN1993-1-5: $\frac{h}{t} \leq 13{,}9\varepsilon$ 4. EN1993-3-1: $\frac{h}{t} \leq 15{,}9\varepsilon \quad or \quad \frac{h-2t}{t} \approx \frac{c}{t} \leq 13{,}9\varepsilon$	Class 3 limit: $\frac{c}{t} \leq 13{,}9\varepsilon$ where c=h-t-r	prEN1993-1-1 (2019) §7.5 Classification of cross-sections Table 7.3 (sheet 3 of 3) should be modified properly, so as to cover the classifications of angle sections

Part in bending Strong axis bending M_u	Class 2 limit: $\frac{c}{t} \leq 10\varepsilon$ (from prEN1993-1-1- Table 7.3, sheet 2) Class 3 limit: $\frac{c}{t} \leq 14\varepsilon$ (from prEN1993-1-1- Table 7.3, sheet 2)	Class 2 limit: $\frac{c}{t} \leq 16\varepsilon$ Class 3 limit: $\frac{c}{t} \leq 26{,}3\varepsilon$ where c=h-t-r	prEN1993-1-1 (2019) §7.5 Classification of cross-sections Table 7.3 (sheet 3 of 3) should be modified properly, so as to cover the classifications of angle sections
Part in bending Weak axis bending M_v - tip in compression	Class 2 limit: $\frac{c}{t} \leq 16{,}6\varepsilon$ (from prEN1993-1-1- Table 7.3, sheet 2, with a_c=0,6) Class 3 limit: $\frac{c}{t} \leq 16\varepsilon$ (from prEN1993-1-1- Table 7.3, sheet 2, with K_σ=0,57)	Class 2 limit: $\frac{c}{t} \leq 14\varepsilon$ Class 3 limit: $\frac{c}{t} \leq 26{,}9\varepsilon$ where c=h-t-r	prEN1993-1-1 (2019) §7.5 Classification of cross-sections Table 7.3 (sheet 3 of 3) should be modified properly, so as to cover the classifications of angle sections
Part in bending Weak axis bending M_v -tip in tension	Class 2 limit: $\frac{c}{t} \leq 40\varepsilon$ (from prEN1993-1-1- Table 7.3, sheet 2, with a_c=0,4)	Class 2 limit: $\frac{c}{t} \leq 30\varepsilon$ where c=h-t-r	prEN1993-1-1 (2019) §7.5 Classification of cross-sections Table 7.3 (sheet 3 of 3) should be modified properly, so as to cover the classifications of angle sections
Cross-section characteristic resistance for equal leg angles			
Compression axial force N EN1993-1-1 & EN1993-3-1 combined with EN1993-1-5	Design resistance - class 1,2,3: $N_{Rk} = \frac{A f_y}{\gamma_{M0}}$ Design resistance - class 4: $N_{Rk} = \frac{A_{eff} f_y}{\gamma_{M0}}$ where: $A_{eff} = A - 2ct(1-\rho)$ $\bar{\lambda}_p = \frac{\bar{b}/t}{18{,}6\varepsilon}$ EN 1993-1-5 defines $\bar{b}$ = h EN 1993-3-1 defines $\bar{b}$ = h-2t - $\rho = 1$, for $\bar{\lambda}_p \leq 0{,}748$ - $\rho = \frac{\bar{\lambda}_p - 0{,}188}{\bar{\lambda}_p^2}$, for $\bar{\lambda}_p > 0{,}748$	Design resistance - class 1,2,3: $N_{c,Rk} = \frac{A f_y}{\gamma_{M0}}$ Design resistance - class 4: $N_{c,Rk} = \frac{A_{eff} f_y}{\gamma_{M0}}$ where: $A_{eff} = A - 2ct(1-\rho)$ $\bar{\lambda}_p = \frac{c/t}{18{,}6\varepsilon}$ where c=h-t-r - $\rho = 1$, for $\bar{\lambda}_p \leq 0{,}748$ - $\rho = \frac{\bar{\lambda}_p - 0{,}188}{\bar{\lambda}_p^2}$, for $\bar{\lambda}_p > 0{,}748$	EN1993-1-5 In §4.4 (2), $\bar{b}$ = h should be replaced by $\bar{b}$ = c for equal leg angle profiles

Strong axis bending M_u prEN1993-1-1	Design resistance: $M_{u,Rk} = W_u \frac{f_y}{\gamma_{M0}}$ where, $W_u = W_{pl,u}$ for class 1 or 2 $W_u = W_{el,u}$ for class 3 $W_u = W_{eff,u}$ for class 4	Design resistance: $M_{u,Rk} = W_u \frac{f_y}{\gamma_{M0}}$ Where $W_u = \alpha_{i,u} W_{el,u}$, i = 2, 3, 4 $\alpha_{2,u} = 1,5$ for class 1 or 2 $\alpha_{3,u} = \left[1 + \left(\frac{26,3\varepsilon - c/t}{26,3\varepsilon - 16\varepsilon}\right) \cdot (1,5 - 1)\right]$ for class 3 $\alpha_{4,u} = W_{eff,u} / W_{el,u} = \rho_u^2$ for class 4 $\bar{\lambda}_p = \frac{c/t}{35,58\varepsilon}$ - $\rho_u = 1$, for $\bar{\lambda}_p \leq 0,748$ - $\rho_u = \frac{\bar{\lambda}_p - 0,188}{\bar{\lambda}_p^2}$, for $\bar{\lambda}_p > 0,748$	prEN1993-1-1 (2019) §8.2.2.6 Section properties for the characteristic resistances Table 8.1 should be modified properly, so as to include the properties for angle sections ---- EN1993-1-5 In §4.4, Table 4.2 Kσ factors for fix-free boundary conditions should be added
Weak axis bending M_v tip in compression prEN1993-1-1	Design resistance: $M_{v,Rk} = W_v \frac{f_y}{\gamma_{M0}}$ where, $W_v = W_{pl,v}$ for class 1 or 2 $W_v = W_{el,v}$ for class 3 $W_v = W_{eff,v}$ for class 4	Design resistance: $M_{v,Rk} = W_v \frac{f_y}{\gamma_{M0}}$ Where $W_v = \alpha_{i,v} W_{el,v}$, i = 2, 3, 4 $\alpha_{2,v} = W_{pl,v} / W_{el,v}$ for class 1 or 2 $\alpha_{3,v} = \left[1 + \left(\frac{26,9\varepsilon - c/t}{26,9\varepsilon - 14\varepsilon}\right) \cdot \left(\frac{W_{pl,v}}{W_{el,v}} - 1\right)\right]$ for class 3 $\alpha_{4,v} = W_{eff,v} / W_{el,v} = 0,94 \cdot \rho_v^2$ for class 4 $\bar{\lambda}_p = \frac{c/t}{36,48\varepsilon}$ - $\rho_v = 1$, for $\bar{\lambda}_p \leq 0,748$ - $\rho_v = \frac{\bar{\lambda}_p - 0,188}{\bar{\lambda}_p^2}$, for $\bar{\lambda}_p > 0,748$	prEN1993-1-1 (2019) §8.2.2.6 Section properties for the characteristic resistances Table 8.1 should be modified properly, so as to include the properties for angle sections ---- EN1993-1-5 In §4.4, Table 4.2 Kσ factors for fix-free boundary conditions should be added
Weak axis bending M_v tip in tension prEN1993-1-1	Design resistance: $M_{v,Rk} = W_v \frac{f_y}{\gamma_{M0}}$ where, $W_v = W_{pl,v}$ for class 1 or 2 $W_v = W_{el,v}$ for class 3 $W_v = W_{eff,v}$ for class 4	Design resistance: $M_{v,Rk} = W_{pl,v} \frac{f_y}{\gamma_{M0}}$	prEN1993-1-1 (2019) §8.2.2.6 Section properties for the characteristic resistances Table 8.1 should be modified properly, so as to include the properties for angle sections

Member resistance - Stability for equal leg angles			
Axial force N prEN1993-1-1	prEN1993-1-1 (2019): §8.3.1 Uniform members in compression Curve b or a are used, based on steel grade according to prEN1993-1-1 (2019) Using of relevant buckling mode for the evaluation of the non-dimensional slenderness	Design resistance - class 1,2,3: $N_{b,Rd} = \frac{\chi_{min} A f_y}{\gamma_{M1}}$ where: $\chi_{min} = \min\{\chi_u, \chi_v\}$ $\bar{\lambda}_u = \sqrt{\frac{Af_y}{N_{cr,u}}}$, $\bar{\lambda}_v = \sqrt{\frac{Af_y}{N_{cr,v}}}$ χ_u, χ_v derived from buckling curves **a** and **b** (prEN1993-1-1:2019) Design resistance - class 4: $N_{Rd} = \frac{\chi_{min} A_{eff} f_y}{\gamma_{M1}}$ where: $\chi_{min} = \min\{\chi_u, \chi_v\}$ χ_u, χ_v derived from buckling curves **a** and **b** (prEN1993-1-1:2019) as for class 1 to 3 cross-sections $A_{eff} = A - 2ct(1-\rho)$ $\bar{\lambda}_p = \sqrt{\chi_{min}}\frac{c/t}{18,6\varepsilon}$ where c=h-t-r - $\rho = 1$, for $\bar{\lambda}_p \leq 0,748$ - $\rho = \frac{\bar{\lambda}_p - 0,188}{\bar{\lambda}_p^2}$, for $\bar{\lambda}_p > 0,748$	prEN1993-1-1 (2019) §8.3.1.2 Slenderness of compression members A sub-paragraph should be added for angle cross-sections to use $\bar{\lambda}_b = \{\bar{\lambda}_u; \bar{\lambda}_v\}$
Strong axis bending M_u prEN1993-1-1	prEN1993-1-1 (2019): §8.3.2 Uniform members in bending Curve d is used	Design resistance: $M_{u,Rd} = \chi_{LT} W_u \frac{f_y}{\gamma_{M1}}$ where: $\bar{\lambda}_{LT} = \sqrt{\frac{W_u \cdot f_y}{M_{cr}}}$ χ_{LT} as function of the LTB slenderness derived from buckling curve **a. Buckling curve is given from the equations** $\chi_{LT} = \frac{1}{\Phi_{LT} + \sqrt{\Phi_{LT}^2 - \bar{\lambda}_{LT}^2}}$ but $\begin{cases} \chi_{LT} \leq 1,0 \\ \chi_{LT} \leq 1/\bar{\lambda}_{LT}^2 \end{cases}$ $\Phi_{LT} = 0,5\left[1 + a_{LT}\left(\bar{\lambda}_{LT} - 0,4\right) + \bar{\lambda}_{LT}^2\right]$ LTB may be ignored and χ_{LT} =1,0 when one of the following conditions apply: • $\bar{\lambda}_{LT} \leq \bar{\lambda}_{LT,0}$ with $\bar{\lambda}_{LT,0} = 0,4$ • $\frac{M_{Ed}}{M_{cr}} \leq \bar{\lambda}_{LT,0}{}^2$	prEN1993-1-1 (2019) §8.3.2.3 Buckling reduction factors χ_{LT} for lateral torsional buckling In Table 8.4, the proposed buckling curve d for angles should be changed to a. A sub-paragraph should be added for the definition of the buckling curves (with doubling the plateau)

		- $\frac{N_{Ed}}{N_{bu,Rd}} > 0{,}5$ - $\frac{N_{Ed}}{N_{bv,Rd}} > 0{,}5$ Critical LTB moment: $M_{cr} = C_b \frac{0{,}46 \cdot E \cdot h^2 \cdot t^2}{l}$ $C_b = \frac{12.5M_{max}}{2.5M_{max} + 3M_A + 4M_B + 3M_C} \leq 1.5$ For linear moment distribution with -1 $\leq \psi = \frac{M_2}{M_1} \leq 1$, $C_b = \frac{12{,}5}{7{,}5+5\psi}$ $W_u = \alpha_{i,u} W_{el,u}$, i = 2, 3, 4 $\alpha_{2,u} = 1{,}5$ for class 1 or 2 $\alpha_{3,u} = \left[1 + \left(\frac{26{,}3\varepsilon - c/t}{26{,}3\varepsilon - 16\varepsilon}\right) \cdot (1{,}5 - 1)\right]$ for class 3 $\alpha_{4,u} = W_{eff,u} / W_{el,u} = \rho_u^2$ for class 4 $\bar{\lambda}_p = \sqrt{\chi_{LT}} \frac{c/t}{35{,}58\varepsilon}$ - $\rho_u = 1$, for $\bar{\lambda}_p \leq 0{,}748$ - $\rho_u = \frac{\bar{\lambda}_p - 0{,}188}{\bar{\lambda}_p^2}$, for $\bar{\lambda}_p > 0{,}748$	
Weak axis bending M_v prEN1993-1-1	Same with the cross-section resistance, independent of the member length	Same with the cross-section resistance, independent of the member length	Same as above
$N+M_u+M_v$ prEN1993-1-1	prEN1993-1-1 (2019): §8.3.3 Uniform members in bending and axial compression $\frac{N_{Ed}}{\frac{\chi_y N_{Rk}}{\gamma_{M1}}} + k_{yy} \frac{M_{y,Ed} + \Delta M_{y,Ed}}{\chi_{LT} \frac{M_{y,Rk}}{\gamma_{M1}}} + k_{yz}$ $\frac{N_{Ed}}{\frac{\chi_z N_{Rk}}{\gamma_{M1}}} + k_{zy} \frac{M_{y,Ed} + \Delta M_{y,Ed}}{\chi_{LT} \frac{M_{y,Rk}}{\gamma_{M1}}} + k_{zz}$	$\left(\frac{N_{Ed}}{N_{Rd}} + k_{uu} \frac{M_{u,Ed}}{M_{u,Rd}}\right)^{\xi} + k_{uv} \frac{M_{v,Ed}}{M_{v,Rd}} \leq 1$ $\left(\frac{N_{Ed}}{N_{Rd}} + k_{vu} \frac{M_{u,Ed}}{M_{u,Rd}}\right)^{\xi} + k_{vv} \frac{M_{v,Ed}}{M_{v,Rd}} \leq 1$ $k_{uu} = \frac{C_u}{1 - \frac{N_{Ed}}{N_{cr,u}}}$; $k_{uv} = C_v$; $k_{vu} = C_u$; $k_{vv} = \frac{C_v}{1 - \frac{N_{Ed}}{N_{cr,v}}}$ $C_u = 0{,}6 + 0{,}4\psi_u$; $-1 \leq \psi_u = \frac{M_{2u}}{M_{1u}} \leq 1$ $C_v = 0{,}6 + 0{,}4\psi_v$; $-1 \leq \psi_v = \frac{M_{2v}}{M_{1v}} \leq 1$ Interaction factor ξ: $c/t \leq 16\varepsilon$: $\xi = 2$ $16\varepsilon < c/t < 26{,}3\varepsilon$: $\xi = \left[1 + \left(\frac{26{,}3\varepsilon - c/t}{26{,}3\varepsilon - 16\varepsilon}\right) \cdot (2 - 1)\right]$ $c/t > 26{,}3\varepsilon$: $\xi = 1$	prEN1993-1-1 (2019) §8.3.3 Uniform members in bending and axial compression A sub-paragraph should be added for equal leg angle profiles

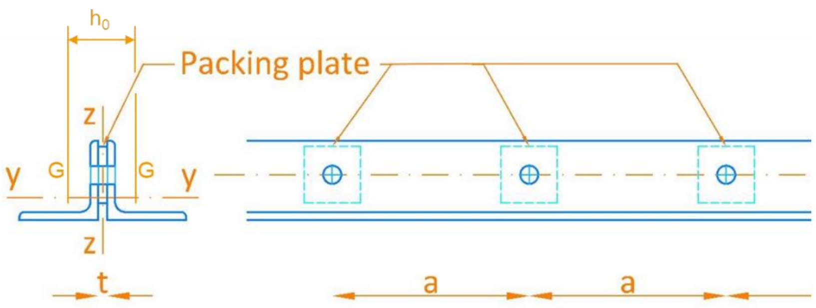
General method prEN1993-1-1	prEN1993-1-1 (2019): §8.3.4 General method for lateral and lateral torsional buckling of structural components $\chi_{op} \cdot \alpha_{ult,k} \geq 1{,}0$ $\chi_{op} = \min\{\chi_b; \chi_{LT}\}$ $\alpha_{ult,k} = \frac{\sigma_{max}}{f_y} = \frac{\sigma_N}{f_y} + \frac{\sigma_{e_0}}{f_y} +$ $\overline{\lambda_{op}} = \sqrt{\frac{\alpha_{ult,k}}{\alpha_{cr,op}}}$	$\chi_{op} \cdot \alpha_{ult,k} \geq 1{,}0$ $\chi_{op} = \min\{\chi_u; \chi_v\}$ $\alpha_{ult,k} = \frac{\sigma_{max}}{f_y} = \frac{\sigma_N}{f_y} + \frac{\sigma_{e_0}}{f_y} + \frac{\sigma_M}{f_y}$ $\overline{\lambda_{op}} = \sqrt{\frac{\alpha_{ult,k}}{\alpha_{cr,op}}}$ Where $\alpha_{cr,op}$ is the minimum load amplifier for the design loads to reach the elastic critical load of the structural component associated to **weak axis buckling.**	prEN1993-1-1 (2019) §8.3.4 General method for lateral and lateral torsional buckling of structural components A sub-paragraph should be added with clarifications of the use of general method for equal leg angle profiles
Segment instability of latice towers			
Segment instability of pylons	This mode of instability is not covered by the current codes	Two models are proposed: Simplified model: $a_{cr} = \frac{2\pi^2 EI_y}{L^2.(P_1+P_2)}$ Final model: $a_{cr} = \frac{N_{cr}}{P_1+P_2}$ $N_{cr} = \frac{\pi^2 EI_{y,tot}}{L^2} + \frac{3}{16}K_T L$ $K_T = \frac{4}{m^2}(2R_{mean}).$ $R_{mean} = \frac{3C}{2L_{ext}} \cdot \frac{1}{n}\sum_{i=1}^{n}\frac{1}{d_i^2}$ The ultimate resistance in both cases is $\frac{1}{a_u} = \frac{1}{a_{cr}} + \frac{0{,}96}{a_{pl}}$	EN1993-3-1 §6.3.1 Resistance of members-compression members A sub-paragraph should be added, indicated to check the possible appearance of a segment instability. An Annex should be added, covering the calculations of the segment instability
		α_{cr} is the critical load multiplier; α_{pl} is the plastic load multiplier equals $\alpha_{pl} = \frac{2 \cdot N_{pl}}{P_1+P_2}$; N_{pl} is the plastic resistance of the diagonal's cross-section ($N_{pl}=Af_y$) α_u is the ultimate load multiplier; I_y is the moment of inertia about y-y geometrical axis of the diagonal's cross-section; L is the buckling length of the diagonal; E is the modulus of elasticity; P_1,P_2 are the axial forces in the two diagonals; $I_{y,tot}$ is the total moment of inertia about y-y geometrical axis of both diagonals (i.e $I_{y,tot}=2I_y$); m is the number of zones of length of the leg $l_i = L/m$ separated by rigid horizontal triangles in the leg; the accuracy of the formulae for K_T is sufficient for a value of m≤6 (i.e for maximum 5 horizontal rigid triangles in the leg). C is the torsional rigidity of the cross-section; L_{ext} is the length of the exterior (main) member of the leg;	

	d_i	is the horizontal distance of the longitudinal axis of the diagonal from the longitudinal axis of the main leg, at the i horizontal level.

3 Code amendments for built-up members

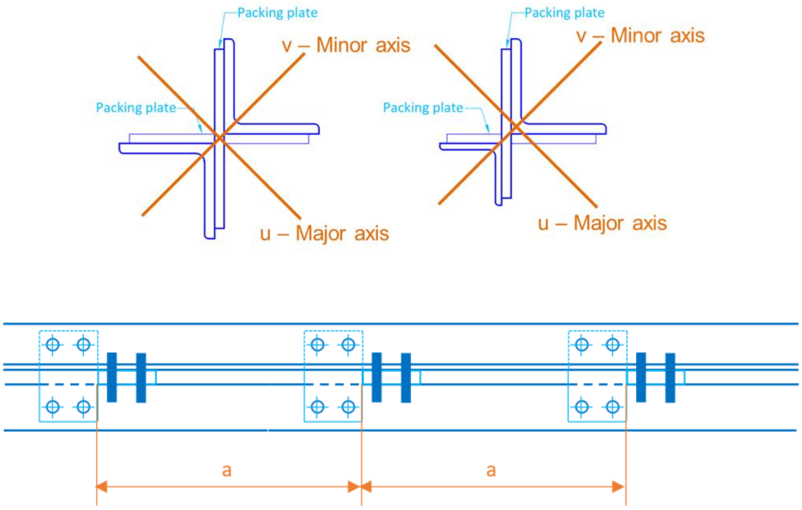
Table 3.1 summarizes the ANGELHY proposals for the design of built-up members. These modifications might be introduced into section 8.4.5 of prEN 1993-1-1 in order to propose a design model.

Table 3.1: Code amendments for the design of closely spaced built-up sections

TOPIC	EXISTING RULES	ANGELHY PROPOSALS	CODE AMENDMENT
Buckling resistance of back to back connected angle section members			
		z-z : Major axis y-y : Minor axis h_0: Distance between the centroids a: Distance between the packing plates i_v: Radius of gyration about the angle section's minor axis (see Table 2.1) L: Member length i_z: Radius of gyration of the built-up section member considered as integral about z-z	
Major axis buckling	<u>prEN1993-1-1 (2019):</u> If a ≤ $15i_v$: Member may be treated as integral without considering the influence of the connections. Buckling resistance is determined based on: - Reduction curve b – steel grades up to S420 - Reduction curve a – for higher steel grades up to S700 <u>If a > $15i_v$:</u> The influence of connections and the resulting shear stiffness should be accounted for. No design proposal is provided. <u>EN 50341-1 (2015)</u> Independently from the packing plate distance, the buckling	<u>Buckling resistance:</u> $\frac{N_{Ed}}{\chi \frac{A f_y}{\gamma_{M1}}} \leq 1,0$ χ: is the buckling reduction factor determined based on the slenderness $\bar{\lambda}_{Sv}$ and buckling curve *b* $\bar{\lambda}_{Sv} = \sqrt{\frac{A f_y}{N_{cr,SV}}}$ The critical axial force $N_{cr,SV}$ considering the influence of the shear stiffness is calculated as follows: $N_{cr,SV} = \frac{1}{\frac{1}{N_{cr}} + \frac{1}{S_v}}$	prEN1993-1-1 (2019) §8.4.5 Closely spaced-built up members

	resistance is based the effective geometric slenderness λ_{zi}: $\boldsymbol{\lambda_{zi} = \sqrt{\lambda_z^2 + \lambda_1^2 \frac{m}{2}}}$ λ_z: geometric slenderness of the built-up member considered as uniform - $\lambda_z = L/i_z$ λ_1: geometric slenderness of an individual angle section between packing plates - $\lambda_1 = a/i_v$ m: number of angle sections	N_{cr}: is the critical axial force of the built-up member considered as integral neglecting the influence of the shear stiffness S_v: is the shear stiffness of the built-up member determined depending on the connection type as follows: For members connected through fit bolts: $S_v = S_{v1} = \frac{1}{\frac{a^2}{24EI_{v,ch}}}$ $I_{v,ch}$: is the 2nd moment of area of one angle section about its minor axis For members connected preloaded bolts: $S_v = S_{v2} = \frac{1}{\frac{a^2}{24EI_{v,ch}} + \frac{ah_0}{12EI_{pp}}}$ I_{pp}: is the 2nd moment of area of the effective part of the packing plate $I_{pp} = \frac{\pi\left(B + 2t + t_p\right)^4 - \pi d^4}{64}$ t: is the thickness of the angle section t_p: is the thickness of the packing plate B: is the inside diameter of the bolt head (noted s in EN 14399) d: is the diameter of the hole S_{v2} may also be applied if the design slip resistance $F_{s,Rd}$ for non fully preloaded bolt connections is higher than the shear force to be transmitted. Connection resistance: The resistance of the connection should be verified according to EN 1993-1-8 based on the shear force V_{Ed} calculated as follows: $V_{Ed} = \frac{\pi}{L}\frac{a}{h_0}M_{Ed}$ $M_{Ed} = \frac{N_{Ed}\frac{L}{200}}{1 - \frac{N_{Ed}}{N_{cr,SV}}}$	

Resistance of star battened back to back connected angle section members



v-v : Major axis
u-u : Minor axis
h_0: Distance between the centroids of the angle sections
a: Distance between the packing plates
i_v: Radius of gyration about the angle section's minor axis (see Table 2.1)
L: Member length
i_z: Radius of gyration of the built-up section member considered as integral about z-z

Flexural buckling	prEN1993-1-1 (2019): If a ≤ 70i_v: Member may be treated as integral without considering the influence of the connections. Buckling resistance is determined based on: - Reduction curve b – steel grades up to S420 - Reduction curve a – for higher steel grades up to S700 If a > 70i_v: The influence of connections and the resulting shear stiffness should be accounted for. No design proposal is provided. EN 50341-1 (2015) Independently from the packing plate distance, the buckling resistance is based the effective geometric slenderness λ_{zi}: $\boldsymbol{\lambda_{zi} = \sqrt{\lambda_z^2 + \lambda_1^2 \frac{m}{2}}}$ λ_z: geometric slenderness of the built-up member considered as uniform - $\lambda_z = L/i_z$	Buckling resistance: The buckling resistance should be checked about both principle axis. For simplicity the index indicating the relevant axis is omitted in the following. $\frac{N_{Ed}}{\chi \frac{A f_y}{\gamma_{M1}}} \leq 1{,}0$ χ: is the buckling reduction factor determined based on the slenderness $\bar{\lambda}_{Sv}$ and buckling curve *b* $\bar{\lambda}_{Sv} = \sqrt{\frac{A f_y}{N_{cr,SV}}}$ The critical axial force $N_{cr,SV}$ considering the influence of the shear stiffness is calculated as follows: $N_{cr,SV} = \frac{1}{\frac{1}{N_{cr}} + \frac{1}{S_v}}$ N_{cr}: is the critical axial force of the built-up member considered as integral neglecting the influence of the shear stiffness S_v: is the shear stiffness of the built-up member determined depending on the connection type as follows:	prEN1993-1-1 (2019) §8.4.5 Closely spaced-built up members

	λ_1: geometric slenderness of an individual angle section between packing plates - $\lambda_1 = a/i_v$ m: number of angle sections	<u>For members connected through fit bolts:</u> $S_v = S_{v1} = \frac{1}{\frac{a^2}{24EI_{v,ch}}}$ $I_{v,ch}$: is the 2nd moment of area of one angle section about its minor axis <u>For members connected preloaded bolts:</u> $S_v = S_{v2} = \frac{1}{\frac{a^2}{24EI_{v,ch}} + \frac{ah_0}{12EI_{pp}}}$ I_{pp}: is the 2nd moment of area of the effective part of the packing plate $I_{\mathrm{pp}} = \frac{\pi\left(B + 2t + t_{\mathrm{p}}\right)^4 - \pi d^4}{32}$ t: is the thickness of the angle section t_p: is the thickness of the packing plate B: is the inside diameter of the bolt head (noted s in EN 14399) d: is the diameter of the hole S_{v2} may also be applied if the design slip resistance $F_{s,Rd}$ for non fully preloaded bolt connections is higher than the shear force to be transmitted. <u>Connection resistance:</u> The resistance of the connection should be verified according to EN 1993-1-8 based on the shear force V_{Ed} calculated as follows: $V_{Ed} = \frac{1}{2}\frac{\pi}{L}\frac{a}{h_0}M_{Ed}$ $M_{Ed} = \frac{N_{Ed}\frac{L}{200}}{1 - \frac{N_{Ed}}{N_{cr,SV}}}$	

Interaction between axial force and bending	<u>prEN1993-1-1 (2019):</u> No suitable design method is provided Elastic 2nd order analysis is the only option but the imperfection amplitude is not well defined	<u>Interaction equations:</u> The following interaction equations may be applied if at least two intermediate pairs of batten plates are used along the built-up member. $\left(\frac{N_{Ed}}{\chi_u \frac{N_{Rk}}{\gamma_{M1}}} + k_{uu} \frac{M_{u,Ed}}{\chi_{LT} \frac{M_{u,Rk}}{\gamma_{M1}}}\right)^{\xi} + k_{uv} \frac{M_{v,Ed}}{\frac{M_{v,Rk}}{\gamma_{M1}}} \leq 1$ $\left(\frac{N_{Ed}}{\chi_v \frac{N_{Rk}}{\gamma_{M1}}} + k_{vu} \frac{M_{u,Ed}}{\chi_{LT} \frac{M_{u,Rk}}{\gamma_{M1}}}\right)^{\xi} + k_{vv} \frac{M_{v,Ed}}{\frac{M_{v,Rk}}{\gamma_{M1}}} \leq 1$ $k_{uu} = \frac{C_u}{1 - \frac{N_{Ed}}{N_{cr,Sv,u}}}$ $k_{uv} = C_v$ $k_{vu} = C_u$ $k_{vv} = \frac{C_v}{1 - \frac{N_{Ed}}{N_{cr,v}}}$ $\xi = 1{,}5$ for SBE members $\xi = 1{,}1$ for SBU members $N_{cr,Sv,u}$: is the critical axial force for buckling about the major-axis considering the shear stiffness as determined before $N_{cr,Sv,u}$: is the critical axial force for buckling about the minor-axis N_{Rk}: is the characteristic value of the axial force resistance of the built-up section: Af_y $M_{u,Rk}$: is the characteristic value of the major axis bending resistance of the built-up section: $0{,}9W_uf_y$ $M_{v,Rk}$: is the characteristic value of the minor axis bending resistance of the built-up section: $0{,}9W_vf_y$ C_u, C_v: are the equivalent uniform moment factors determined as follows: $C_u = 0{,}6+0{,}4\psi_u \geq 0{,}4$; $-1 \leq \psi_u = \frac{M_{2u}}{M_{1u}} \leq 1$ $C_v = 0{,}6+0{,}4\psi_v \geq 0{,}4$; $-1 \leq \psi_v = \frac{M_{2v}}{M_{1v}} \leq 1$ χ_u, χ_v: are the reduction factors for buckling about the major/minor axis χ_{LT}: is the reduction factor for lateral torsional buckling determined based on the critical moment $M_{cr,SV}$ and reduction curve *a* as follows	prEN1993-1-1 (2019) §8.4.5 Closely spaced-built up members

		$\bar{\lambda}_{LT} = \sqrt{\frac{0{,}9 W_u f_y}{M_{cr}}}$ $M_{cr} = C_b \pi \frac{\sqrt{E I_v G I_t}}{L}$ I_v: is the second moment of area of the built-up member considered as integral (considering $S_v = \infty$) about its minor axis	

4 References

[1] prEN1993-1-1: Design of steel structures - Part 1-1: General rules and rules for buildings, Brussels, Comité Européen de Normalisation (CEN), 2019.

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[3] EN 1993-3-1: Design of steel structures - Part 3-1: Towers, musts and chimneys. Tower and masts, Brussels, Comité Européen de Normalisation (CEN), 2005.

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