ANGELHY project

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

Supported by

European Commission

Research Fund for Coal & Steel

Prof. Ioannis Vayas NTUA

Overview of Works

WP 1 Market analysis – case studies – Code review

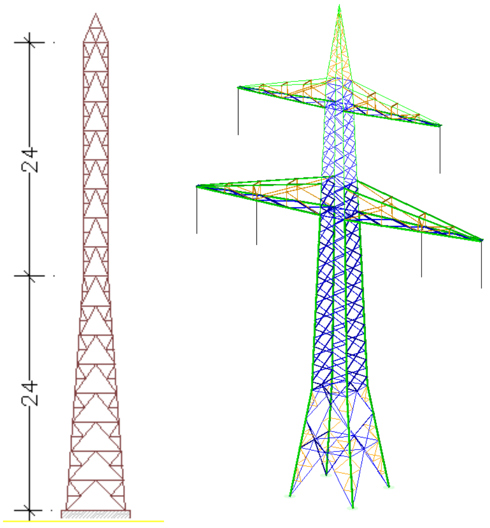
WP 2 Steel and hybrid members from angle sections from HSS

WP 3 Closely spaced built-up members

WP 4 Validation and design guide

WP 5 Validation and Dissemination

WP 6 Management



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Partners and Time Schedule

1. Partners

- National Technical University of Athens (NTUA, coordinator)
- ArcelorMittal Belval & Differdange SA (AMBD)
- Universite De Liege (ULG)
- Cosmote Kinites Tilepikoinonies AE (COSMOTE)
- Centre Technique Industriel de la Construction Metallique (CTICM)
- Sika France SAS (SIKA)

2. Time schedule

- Start date 01/07/2017
- End date 31/12/2020
- Duration 42 months

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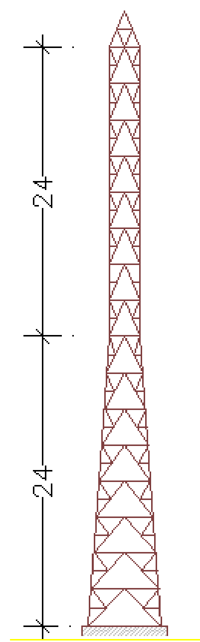
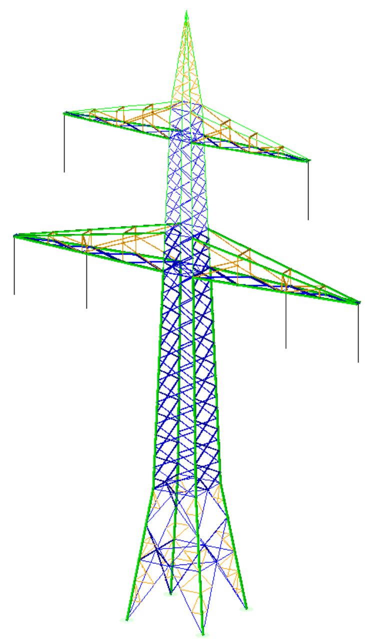
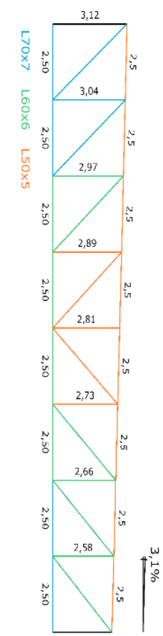
WP 1 Market analysis – Case studies – Code review

- Task 1.1 Market analysis and identification of structural typologies for telecommunication towers and transmission towers
- Task 1.2 Design of six case studies
- Task 1.3 Critical assessment of EN rules for lattice towers and design assisted by testing







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Task 1.1 Market analysis – transmission towers

<u>Installation of new lines:</u>

- Extension of existing 110-kV/220-kV lines
- Installation of new 380-kV lines
- Installation of new high-voltage direct current lines (HVDC)

HVDC lines: Less losses, more economical for long distances (> 750 km), more slender (2 conductors per circuit, taller (higher voltage 400-600 kV).

Demand for larger angle profiles (> L 150) and HSS

Transmission tower for a HVDC line

<u>Reinforcement of existing lines:</u>

- Upgrading existing lines from 110-kV/220-kV to 380-kV
- Combining direct current lines with alternative current lines (e.g. ultranet)
- Increasing the section of the conductors
- Use of high-temperature conductors (HTLS)

Upgrading existing lines: conductors with bigger diameters, more bundles (4 against 1 or 2), longer insulators (5 against 1 or 2 m), longer protection strip

Additional segments, higher loads, larger angles, HSS

Upgrade of a 220-kV line to a 380-kV line

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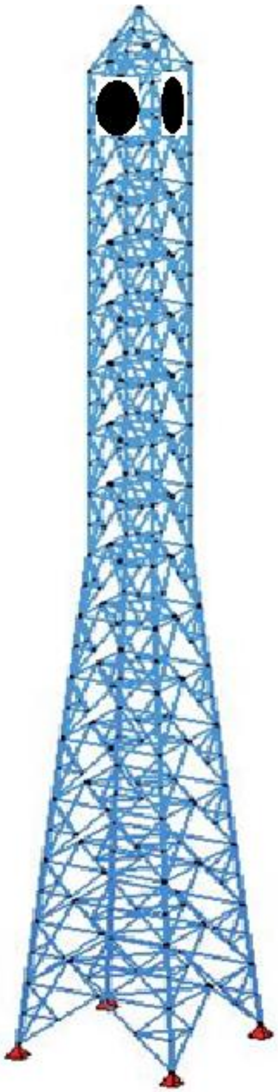
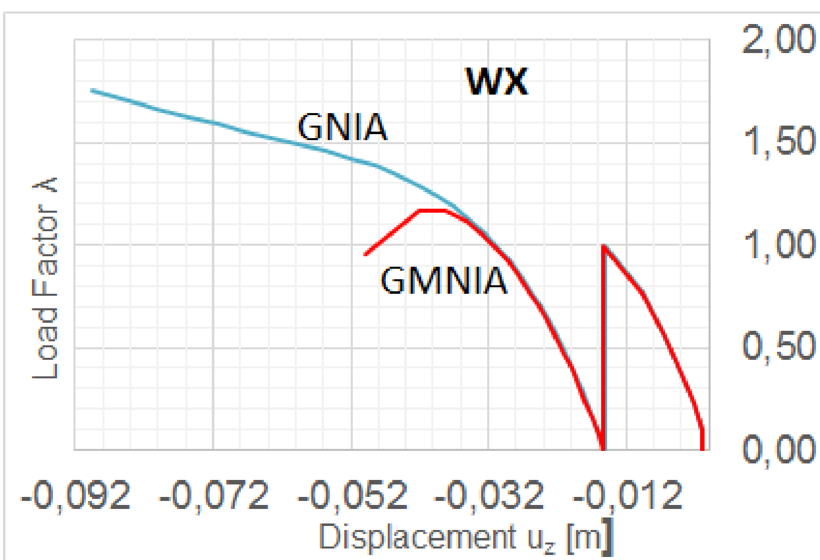
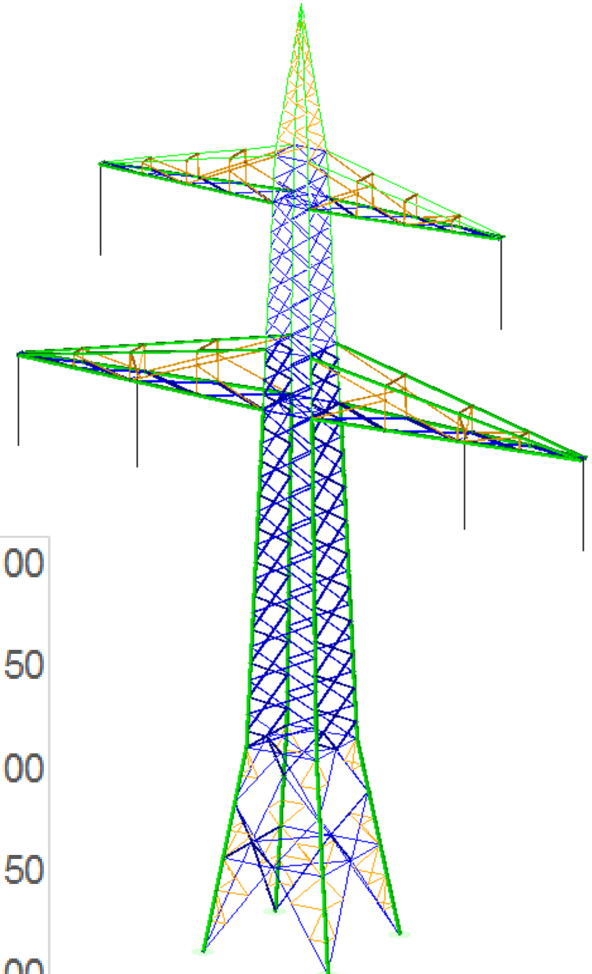
Task 1.2 Design of 6 case studies



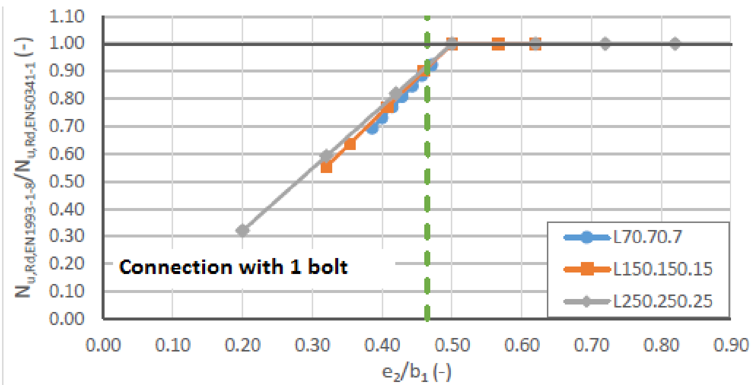
- Typical Danube tower
- Located in Saxony, Germar
- 380 kV transmission line
- 350 m wind span
- 525 m weight span

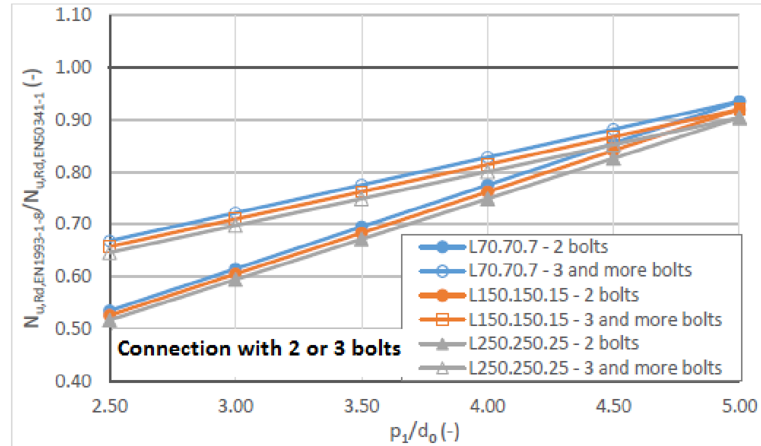




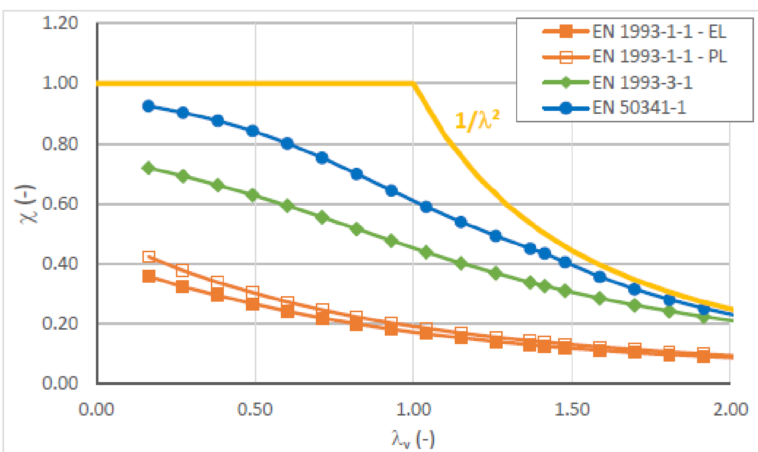
Task 1.3 Comparison between EN 1993 and EN 50341-1

Tension resistance of angles

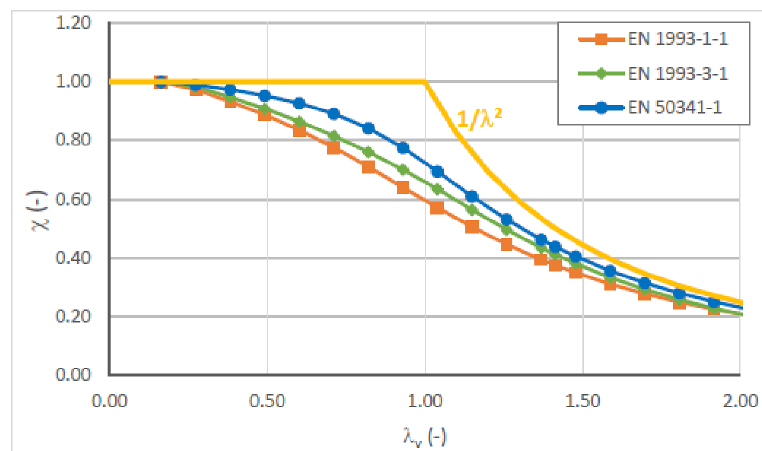




Buckling resistance of angles



diagonal member L70.7: connection with one bolt



leg member L70.7

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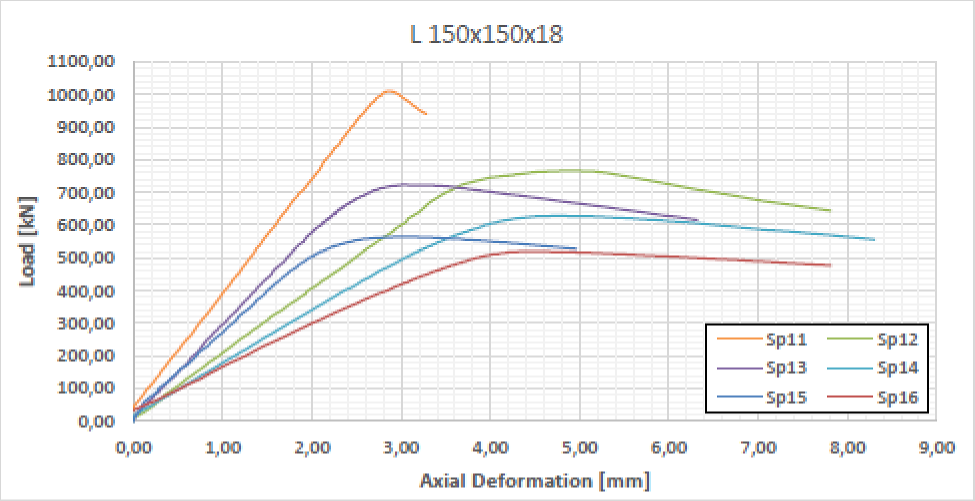
WP 2 Steel and hybrid members from angle section

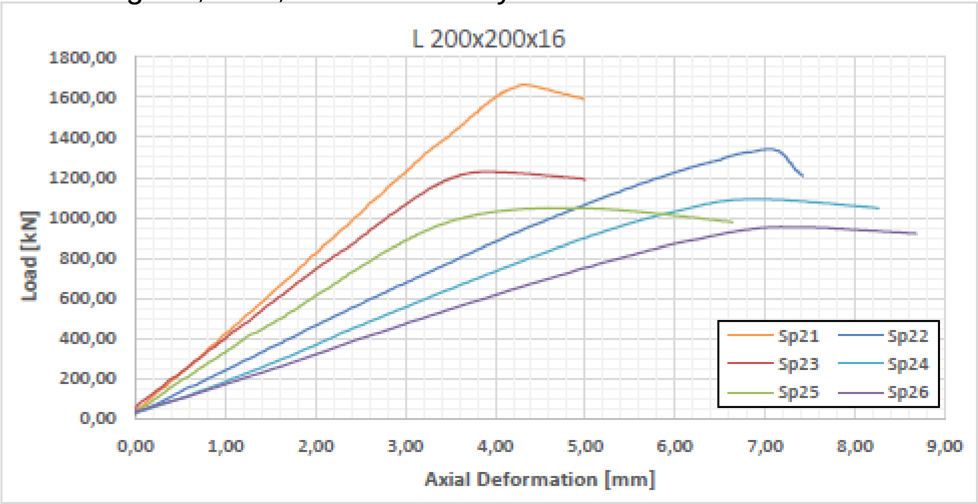
- Task 2.1 Compression tests on large angle columns from HSS
- Task 2.2 Numerical investigations and design rules for single angle members
- Task 2.3 Bending and buckling tests on hybrid angle members strengthened with FRPs
- Task 2.4 Numerical investigations and design rules for hybrid angle members with FRPs
- Task 2.5 Full scale tests on cell network lattice towers
- Task 2.6 Numerical models for lattice towers

Task 2.1 Tests on large angle HSS columns

Length 2,5 – 3,5 m Eccentricity 0 – 49 mm Material S460



Length 3,0 – 4,0 m Eccentricity 0 – 49 mm Material S460



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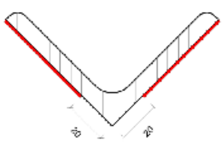
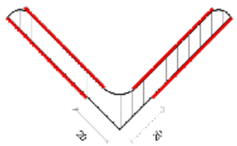
Task 2.2 Design rules for single angle members

- **Cross section classification**
- **Cross section design**
- **Member design**
- **Experimental validation**

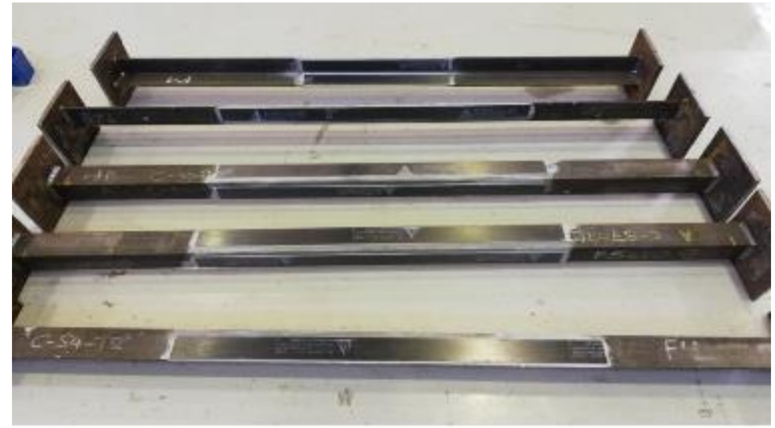
Task 2.3 Tests on hybrid members

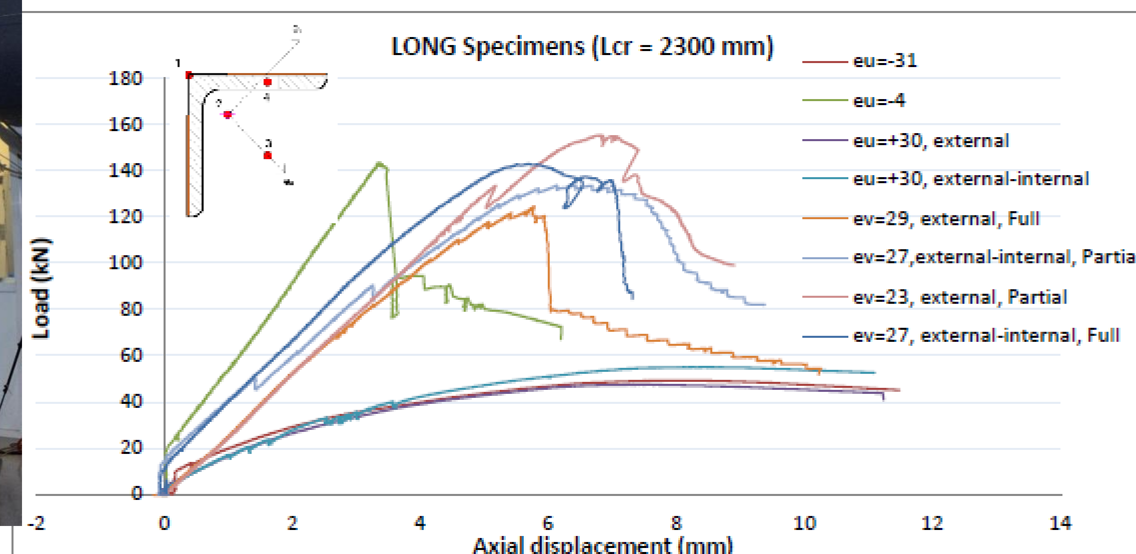




- 5 thee-point bending tests
- 16 Buckling tests

Cross section L70x70x7



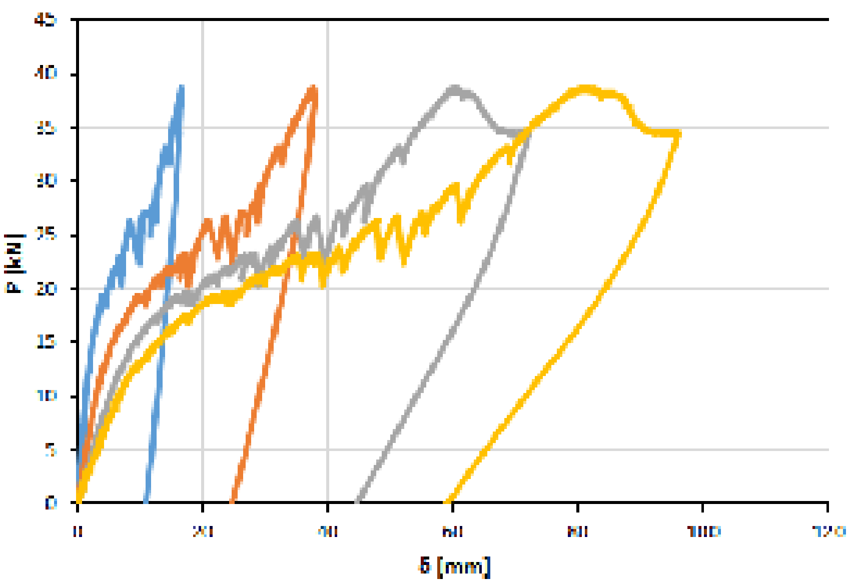


Task 2.4 Design rules for hybrid angle members

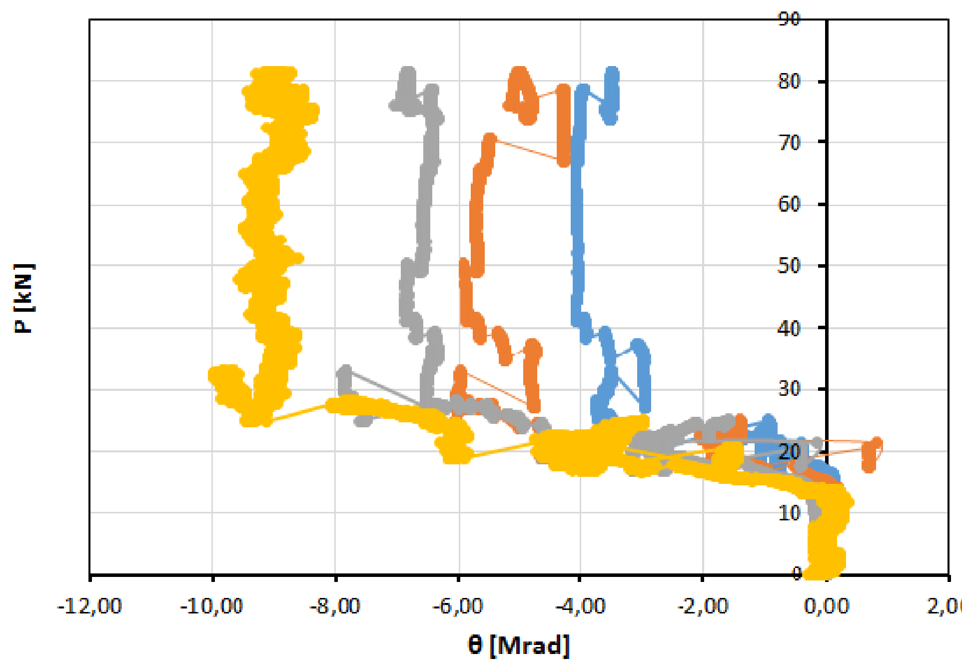
- **Mechanical properties of hybrid sections**
- **Safety factors**
- **Cross section design**
- **Member design**
- **Experimental validation**

Task 2.5 Full scale tests on complete towers

Orthogonal loading



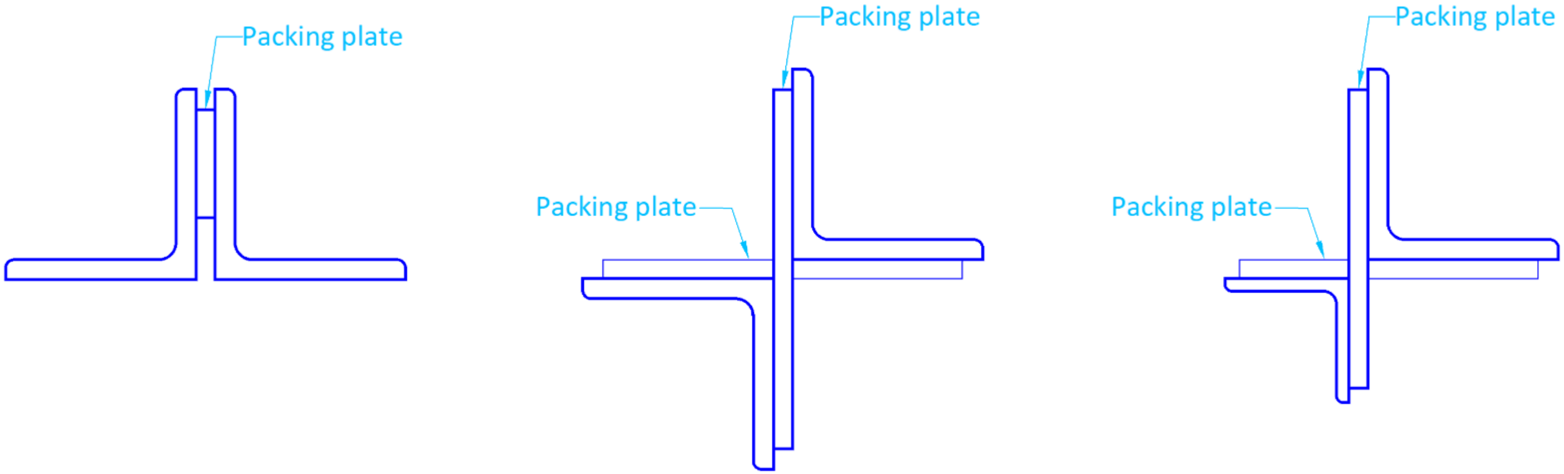
Diagonal loading



Task 2.6
Guidance on analysis models for complete towers

WP 3 Closely spaced built-up members

- Task 3.1 Technical specifications for laboratory tests
- Task 3.2 Laboratory tests
- Task 3.3 Parametric studies
- Task 3.4 Development of design rules



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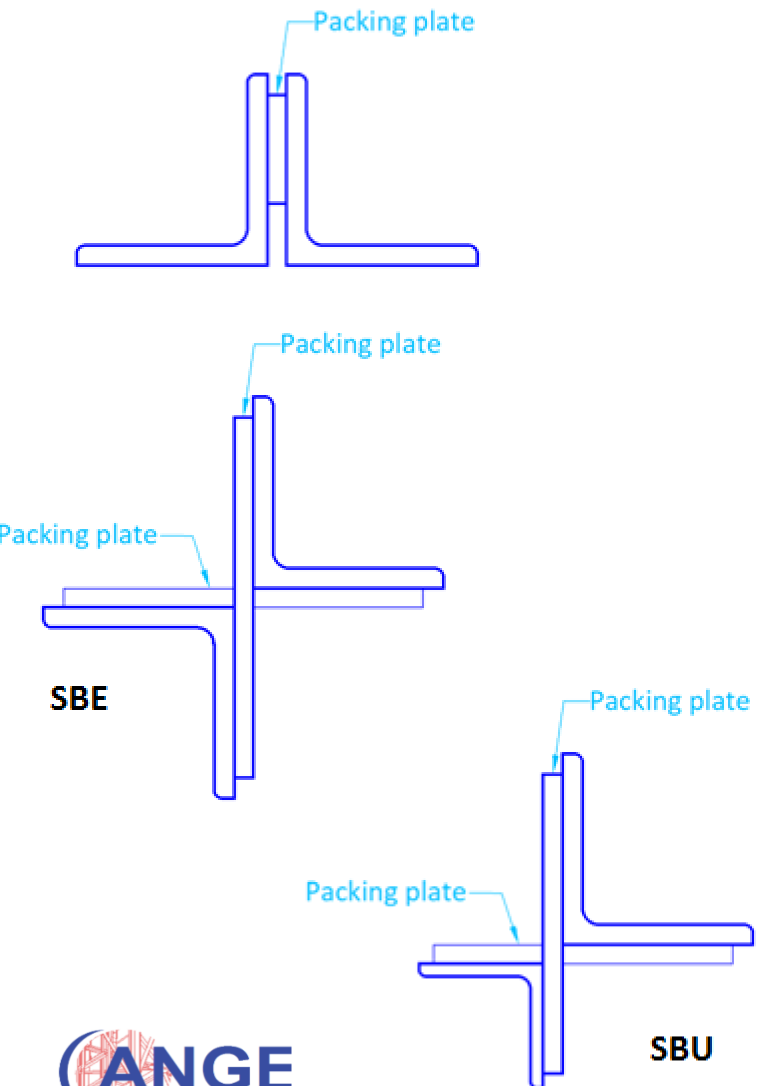
Task 3.1 Test specifications



Notation	Cross-section	Member length L (mm)*	Total number of packing plates**
BBE1	2 L 70 x 70 x 7	1200	7
BBE2	2 L 70 x 70 x 7	3600	19
BBE3	2 L 70 x 70 x 7	2000	4
BBE4	2 L 70 x 70 x 7	3600	6
BBE5	2 L 70 x 70 x 7	3600	19
BBE6	2 L 70 x 70 x 7	3600	6
SBE1	2 L 60 x 60 x 6	2200	2 x 4
SBE2	2 L 60 x 60 x 6	3000	2 x 5
SBE3	2 L 60 x 60 x 6	3000	2 x 4
SBE4	2 L 60 x 60 x 6	4000	2 x 5
SBE5	2 L 60 x 60 x 6	3000	2 x 5
SBE6	2 L 60 x 60 x 6	4000	2 x 5
SBU1	L 80 x 80 x 8 + L 60 x 60 x 6	2200	2 x 4
SBU2	L 80 x 80 x 8 + L 60 x 60 x 6	3000	2 x 5
SBU3	L 80 x 80 x 8 + L 60 x 60 x 6	3000	2 x 4
SBU4	L 80 x 80 x 8 + L 60 x 60 x 6	4000	2 x 5

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Task 3.2 Laboratory tests – revised test matrix

B2. Specimen BBE2

ID of specimen: BBE2	
Date of testing	27/02/2020
Type of specimen	Back to back connected angles
Mean actual dimensions	
Cross-section	2 L70x70x7
ha_2 [mm]	69,93
ea_1 [mm]	6,86
hb_2 [mm]	70
eb_1 [mm]	6,83
a_1 / a_2 [mm]	86,3 / 75,3
b_1 / b_2 [mm]	77,2 / 66,2
a_3 / a_4 [mm]	86,4 / 75,4
b_3 / b_4 [mm]	77,3 / 66,3
L [mm]	3600
$L_{crit, major-axis}$ [mm]	3660
$L_{crit, minor-axis}$ [mm]	1830
Tightening torque [Nm]	253
Total number of packing plates	19
Total number of bolts for packing plate connection	19 M16 10.9
Level of bolt pretension [%]	100
Material	S 355
Actual f_y [Mpa]	414,6
Actual f_u [Mpa]	544,4
Response	
Ultimate resistance [kN]	485,36
Comments	Bifurcation around weak axis and no flexural buckling around strong axis as expected !

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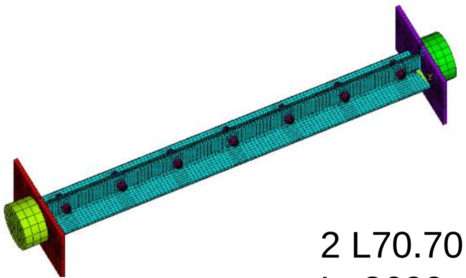
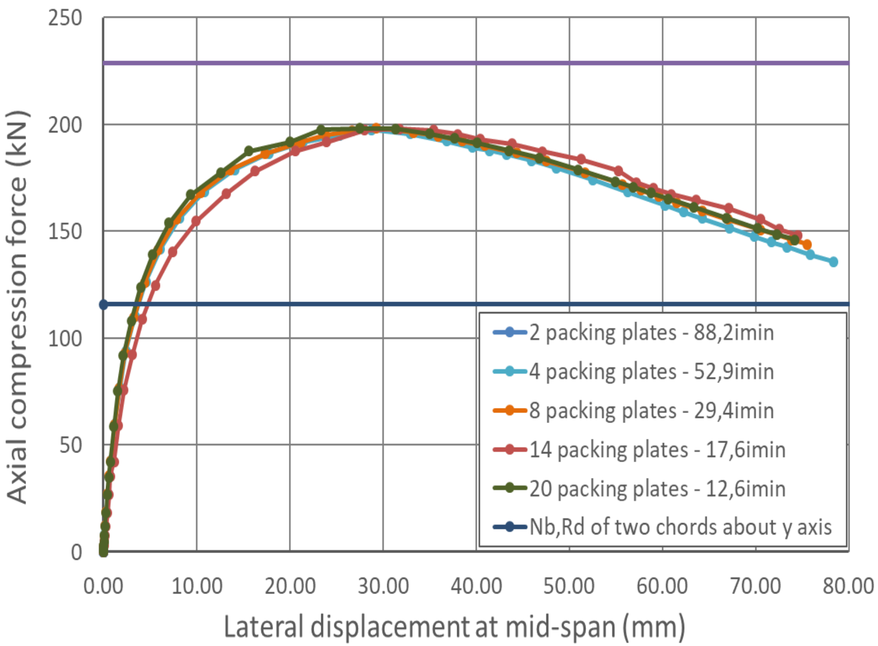
Task 3.3 Parametric studies



2 L70.70.7
L=3600mm clearance 2 mm



Parameters considered

- Connection type: bolted – welded
- Clearance: 0,2 – 0,5 – 1.0 mm
- Level of preloading: 0,2 – 0,6 – full
- Friction: μ = 0,05 – 0,30 – 0,50

Conclusions

Even a very small clearance (0,2mm) highly degrades the resistance

For a clearance higher than 0,5mm, a lower bound resistance is attained

Even small bolt preloading increases the resistance

Low level of preloading may be sufficient to attain the “full connection”

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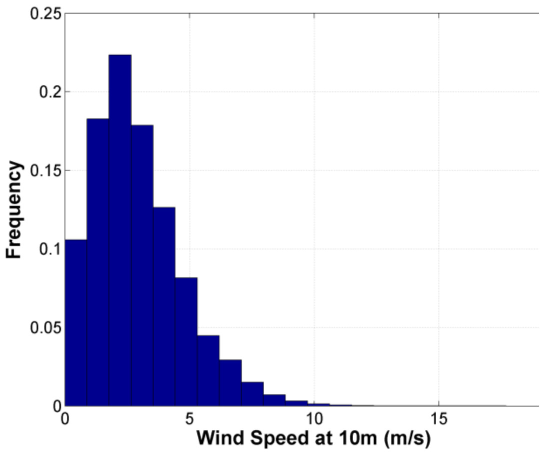
Task 3.4 Design rules

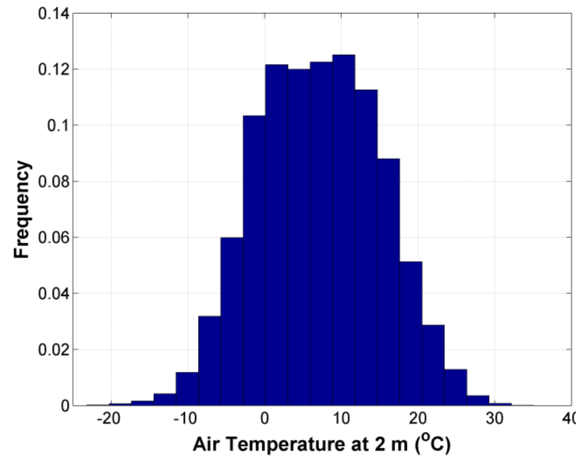
TOPIC	EXISTING RULES	ANGELHY PROPOSALS	CODE AMENDMENT
Buckling resistance of back to back connected angle section members			
Major axis buckling	prEN1993-1-1 (2019): If a ≤ 15i_v: Member may be treated as integral without considering the influence of the connections. If a > 15i_v: The influence of connections 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}:	Buckling resistance: $\frac{N_{Ed}}{\chi \frac{A f_y}{\gamma_{M1}}} \leq 1{,}0$ $\bar{\lambda}_{Sv} = \sqrt{\frac{A f_y}{N_{cr,SV}}}$ $N_{cr,SV} = \frac{1}{\frac{1}{N_{cr}} + \frac{1}{S_v}}$	prEN1993-1-1 (201 §8.4.5 Closely space built up members

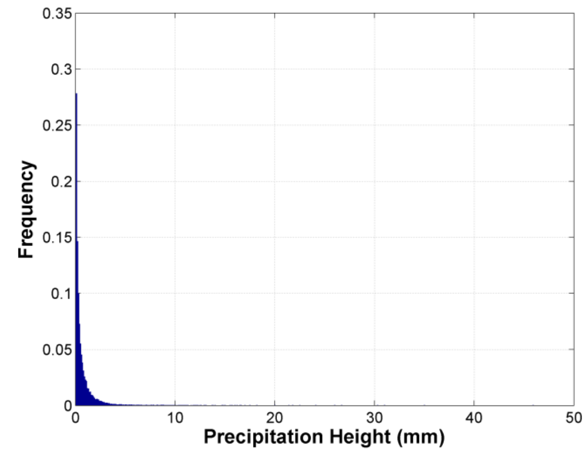
WP 4 Validation and design guide

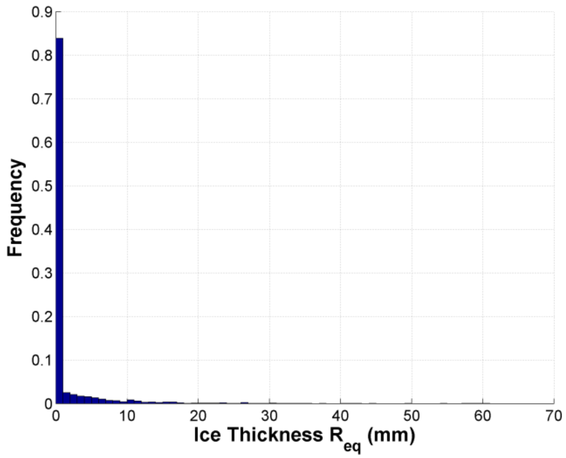
- Task 4.1 Probabilistic modelling of structure and loads
- Task 4.2 Performance-based assessment of single towers and ensembles of towers
- Task 4.3 Verification and calibration of rules
- Task 4.4 Design guide containing design recommendations

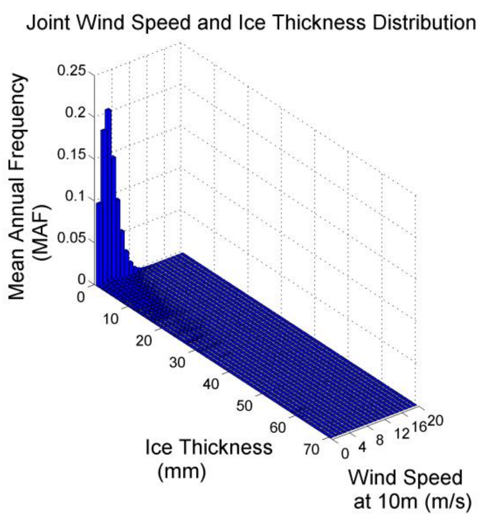
Task 4.1 Probabilistic modeling of structure and loads











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Task 4.2 Performance-based assessment

$$Risk = \int Vulnerability \cdot \mathrm{d}Hazard$$

Rehabilitation decision-making

Consider options after 50 years of service

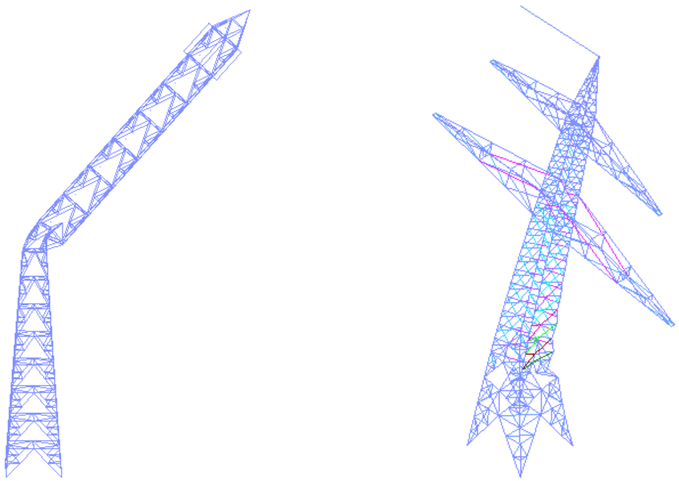
- Do nothing?
- Hybrid Strengthening?
- High-strength replacement?
- Cost versus benefit analysis

Single tower performance

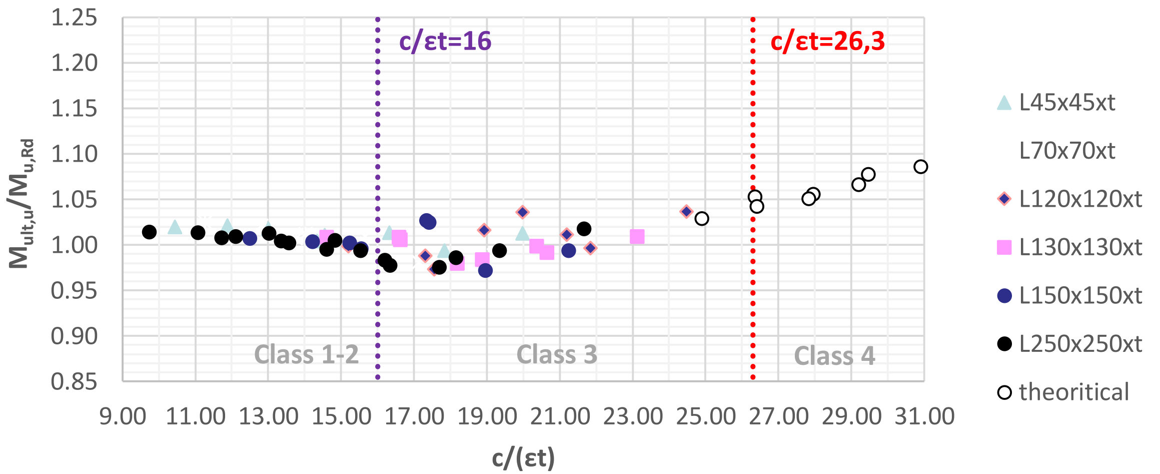
- Random loads
- Random properties
- Simplified model uncertainty
- Estimate Risk

Transmission line performance

- 2 linear groups meeting at an angle
- Angles in 180 – 130 degrees
- Cascading failures
- Assume community served by towers, assess indirect costs (no main line – branch line)



Task 4.3 Verification and calibration of rules



Comparison between numerical and analytical results for the CS-resistance subjected to strong axis bending moment M_u, related with the c/εt ratio

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Task 4.4 Design Guide

1 Scope

2 Notations, symbols and abbreviations

3 Angle profiles

4 CFRP-material

5 Angles with CFRP-strips

6 Steel lattice towers

7 Design rules for single angle members

8 Design rules for hybrid angle members

9 Design rules for closely spaced built-up angle members

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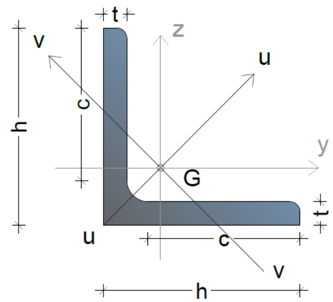
WP 5 Codification and Dissemination

- Task 5.1 Design rules and principles for single angles and built-up cross sections to be included in the next revision of EN 1993-3-1 and EN 1993-1-1
- Task 5.2 Design and construction recommendations for hybrid members
- Task 5.3 Dissemination and implementation of project results

- 5 accepted presentations in EUROSTEEL 2020
- 2 submitted papers in scientific Journals

Task 5.1 Design recommendations for angles

<table>
<tr><th>TOPIC</th><th>EXISTING RULES</th><th>ANGELHY PROPOSALS</th><th>CODE AMENDMENT</th></tr>
<tr><td colspan="4">Classification system for equal leg angle cross-sections</td></tr>
<tr><td colspan="4">


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
</td></tr>
<tr>
<td>Part in compression

Axial force N</td>
<td><u>Class 3 limit</u>

1. limit EN1993-1, Table 5.2, sheet 3:
$\frac{h}{t} \leq 15\varepsilon \quad and \quad \frac{h}{t} \leq 11{,}5\varepsilon$

2. limit EN1993-1, Table 5.2, sheet 2:
$\frac{c}{t} \leq 14\varepsilon$

3. EN1993-1-5:
$\frac{h}{t} \leq 13{,}9\varepsilon$

4. EN1993-3-1:
$\frac{h}{t} \leq 15{,}9\varepsilon \quad or \quad \frac{h-2t}{t} \approx \frac{c}{t} \leq 13{,}9\varepsilon$</td>
<td><u>Class 3 limit:</u>
$\frac{c}{t} \leq 13{,}9\varepsilon$
where c=h-t-r</td>
<td>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</td>
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Task 5.2 Construction recommendations for hybrid angles

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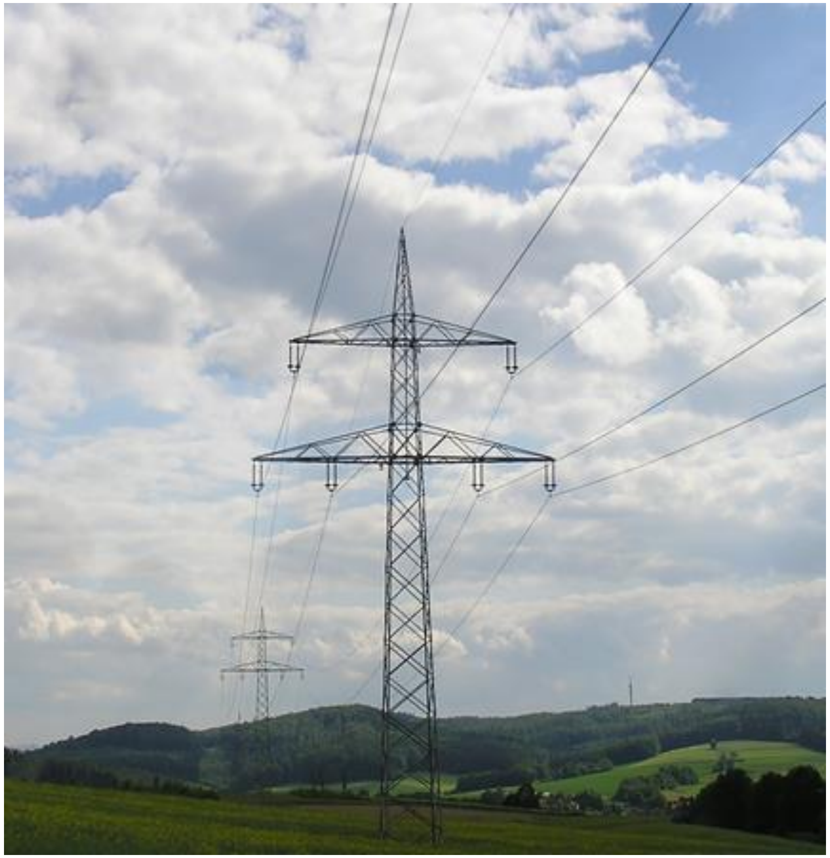
Task 5.3 Dissemination



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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

Webinar/Workshop

08 | 12 | 2020

Innovative developments in the field of steel lattice towers
News from research and practice

Free of charge registration:

xxx

5 accepted presentations in EUROSTEEL 2020

2 submitted papers in scientific Journals

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End

Thank you very much

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