Lattice tower for wind energy and power line pylons

November 2014
Some giants

1135 ft
Yangtse crossing
500 kV

745 ft
Elbe crossing
380 kV

575 ft
Tracy Quebec
380 kV

Remember : Eiffel tower : 1065 ft
Lattice/Truss Tower

2006 - Fuhrlander Laasow
- 525 ft lattice tower (world record/ 160 m)
- rotor 295 ft diameter (90 m)
- Power 2.5 MW
Construction basics

- The technical issue when building big towers is to « strengthen » the legs. There are 3 possibilities to do this:
  - increasing number of angles: square and butterfly designs
  - taking bigger angles: 250 mm and 300 mm (L10” or L12”)
  - improving mechanical resistance:
    - EN10025-4: S420M & S460M
    - Grades 60 & 65 (ASTM A 572)

Type square

Type butterfly

L250 & L300; from 18 to 35mm (L10” or L12”)

European Standard
Norme Européenne
Europäische Norm
Large angles L250 & L300 (L10” & L12”)

ArcelorMittal
Extract of the catalogue for large angles

<table>
<thead>
<tr>
<th>Désignation Bezeichnung</th>
<th>Dimensions Abmessungen</th>
<th>Position des axes Lage der Achsen</th>
<th>Surface Oberfläche</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<tr>
<td>G kg/m²</td>
<td>h-b</td>
<td>l</td>
<td>l₁</td>
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<td>250 21 18 9</td>
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<td>114.2</td>
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<td>250 25 18 9</td>
<td>118.7</td>
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<td>100</td>
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<td>127.7</td>
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<td>260 28 18 9</td>
<td>132.1</td>
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<td>L 300 x 300 x 28</td>
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<tr>
<td>L 300 x 300 x 32</td>
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<td>L 300 x 300 x 31</td>
<td>133</td>
<td>300 31 19 12 15</td>
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<td>300 32 19 12 15</td>
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<td>L 300 x 300 x 33</td>
<td>142</td>
<td>300 33 19 12 15</td>
<td>158.1</td>
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<tr>
<td>L 300 x 300 x 34</td>
<td>146</td>
<td>300 34 19 12 15</td>
<td>163.6</td>
</tr>
<tr>
<td>L 300 x 300 x 35</td>
<td>150</td>
<td>300 35 19 12 15</td>
<td>169.1</td>
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<tr>
<td>L 300 x 300 x 36</td>
<td>154</td>
<td>300 36 19 12 15</td>
<td>174.7</td>
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</tbody>
</table>

L250 and L300
L10” & L12”
Large Angles Advantage (2-butterfly instead of square-4)

**Comparison depending on buckling length of the profile**

**L8” L200x14**

- $A_{\text{eff}} = 183.81 \text{cm}^2$
- $i_y = i_z = 8.92 \text{cm}$

**L10” L250x20**

- $A_{\text{eff}} = 181.1 \text{cm}^2$
- $i_u = 9.7 \text{cm}$ (weak axis)

**L10” L250x22**

- $A_{\text{eff}} = 420.4 \text{cm}^2$
- $i_y = i_z = 11.08 \text{cm}$

**L12” L300x35**

- $A = 393.4 \text{cm}^2$
- $i_u = 11.52 \text{cm}$ (weak axis)
Large Angles Advantage (1-large angle instead of 2-butterfly or 4-square)

Comparison depending on buckling length of the profile

- **L6”**
  - \( A_{\text{eff}} = 182.8 \text{cm}^2 
  - i_y = i_z = 6.98 \text{cm} 

- **L8”**
  - \( A_{\text{eff}} = 145.4 \text{cm}^2 
  - i_u = 7.72 \text{cm} 
  (weak axis)

- **L12”**
  - \( A = 196.7 \text{cm}^2 
  - i_v = 5.84 \text{cm} 
  (weak axis)

- **L150x16**

- **L300x35**
Large Angles Advantage (1-large angle instead of 2-butterfly)

$L_{8''}^{''}$
$L_{200x19}$

$A_{\text{eff}} = 145.4 \text{cm}^2$
$i_u = 7.72 \text{cm}$ (weak axis)

$L_{12''}$
$L_{300x35}$

Comparison $L_{300x35}$ single angle in S355 with butterfly angles $L_{20x20x19}$ in S355

$A = 196.7 \text{cm}^2$
$i_v = 5.84 \text{cm}$ (weak axis)

Ultimate load (KN) vs. buckling length in m
Construction basics

• The highest wind turbine in the world (2006) : 525 ft (160m) in Germany

At that time, only L10” in 1’ 1/4 available (L250x250x28): 3 angles were used.

=> With L12” (L300), 2 angels are sufficient (butterfly)
High-strength steel grades S420 & S460
• ArcelorMittal has the largest angle offer in terms of sizes and grades
• Additionally to the size, design can also be improved by using thermo-mechanical grades:

<table>
<thead>
<tr>
<th>Designation</th>
<th>Steel grades</th>
<th>EN 10025-2: 2004</th>
<th>EN 10025-4: 2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>L30 to L110</td>
<td>✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓</td>
<td>✓</td>
<td>✓  1)</td>
</tr>
<tr>
<td>L 120 to L200</td>
<td>✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓</td>
<td>✓ ✓ ✓</td>
<td>for t &gt; 15 mm ✓  2)</td>
</tr>
<tr>
<td>L 250 and L 300</td>
<td>✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓</td>
<td>✓ ✓ ✓</td>
<td>for t &lt; 31 mm</td>
</tr>
</tbody>
</table>

1) 2) : after mill acceptance

2) L140, L160 excluded
Comparison L200x200x26 in S355 with single angles in S460M

Ultimate load (kN)

buckling length in m

L200x200x26 in S355
L200x200x22 in S460M
L200x200x25 in S460M
Market segmentation for lattice tower wind turbine

• ArcelorMittal Long Carbon Europe considers lattice tower as the best solution for the following market segments:
  – For OECD countries: hub heights > 110 m and low wind class
  – Emerging countries: hub heights between 80 m to 120 m and medium to low wind class

• To meet the demand, ArcelorMittal LCE has developed and produces:
  – Very big angles: L250 (L10") & L300 (L12") acc. to EN 10025 & ASTM A-6
  – Thermo-mechanical grades S420M & S460M acc. to EN 10025 & ASTM A-6 for the main part of our angle sales program
Lattice tower pre-design for wind energy pylons
Efficient steel solutions for wind energy based on angles

- Demand for energy is increasing, driven by population growth and economic development.
  
  » wind energy capacity has seen steady annual growth in recent years

- Changes such as increasing offshore installations and larger turbines with new drive train configurations have an impact on steel usage for realizing that growth

- The trend for taller towers implies the use of longer blades. Longer blades sweep a larger area, and so capture more wind. However, they lead to greater loads on the rotor and per unit of tower-length.

  » AM is proposing efficient steel solutions for wind towers based on hot rolled angles
Introduction

• Lattice construction is the most common fabrication type for towers

• This document is based on a joint study between ArcelorMittal and P.E. Concept

• Objective: develop pre-design of lattice tower based on angle L300 and thermomechanical grades and compare it with different tower types

<table>
<thead>
<tr>
<th></th>
<th>100m</th>
<th>110m</th>
<th>120m</th>
<th>140m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lattice tower</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Tubular tower</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Concrete tower</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Hybrid tower</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
Relevant parameters and assumptions for the Pre-Design of windmill based on lattice towers

Construction:
- Segment 1 defined by
  - blade length
  - outer shell diameter at tower top
  - max. allowable outer diameter at blade tip passage
- Foundation designed as stiff

Boundary Conditions:
- Extreme-, operation- and fatigue loads
- Wind pressure on tower
- Nacelle mass incl. rotor blades
- Speed range during operation

The towers are pre-designed following to:
- EC3 and DIBt recommendation
- Ultimate loads (ULS)
  - Stress and stability check
- Fatigue loads (FLS)
  - Fatigue evidence according to the notch classes along the tower
- Frequency analyses of tower and wind turbine
Lattice tower comparison for wind energy pylons
Pre-Design based on a representative wind turbine from 3MW

Comparison of lattice wind towers for different hub heights

Boundary conditions:
- 3 MW Turbine, 3 rotor blades, rotor diameter 110m
- nacelle mass incl. rotor blades and blade adjustment 150to
- wind class IEC IIIA

Boundary conditions for the lattice towers:
- spread width top of lattice tower (center lines): 3m
- spread width at blade tip pass (center lines): 4,5m

<table>
<thead>
<tr>
<th>Angles</th>
<th>Position</th>
<th>100m hub height</th>
<th>110m hub height</th>
<th>120m hub height</th>
<th>140m hub height</th>
</tr>
</thead>
<tbody>
<tr>
<td>L160-L200</td>
<td>Main Diagonals</td>
<td>77 to 33%</td>
<td>82 to 31,50%</td>
<td>89 to 31%</td>
<td>106 to 31%</td>
</tr>
<tr>
<td>L300</td>
<td>Corner Beam</td>
<td>115 to 49%</td>
<td>126 to 48,50%</td>
<td>135 to 48%</td>
<td>159 to 47%</td>
</tr>
<tr>
<td>Bolts (estimated)</td>
<td></td>
<td>8900 pc</td>
<td>9400 pc</td>
<td>9800 pc</td>
<td>10000 pc</td>
</tr>
<tr>
<td>SUM</td>
<td></td>
<td>235 100%</td>
<td>260 100%</td>
<td>283 100%</td>
<td>341 100%</td>
</tr>
</tbody>
</table>
Cost comparison

Source for Cost calculation: PE Concept, Germany (www.p-e-concepts.de)

Total costs (foundation, material, assembly, logistic)_EUR/m height

1): The hybrid tower is a combination of a concrete part at the bottom and a steel part at the top.
Cost comparison

Source for Cost calculation: PE Concept, Germany (www.p-e-concepts.de)

- L300 allows any design over 2 MW
- Big angle L300 reduce
  - Steel weight in the tower fabrication
  - Assembling and safety risks through profile reduction

Above 110 m, lattice tower is cost competitive
  → up to 25% cost reduction

For the range 100-110 m, also interesting for emerging countries
  → Up to 15% cost reduction
Wind turbine – Lattice tower OEM
2000 - 2011
VESTAS (V66)

- Ewiger Fuhrmann
  - 1 x 1,75 MW
  - 385 ft hub height

- Others VESTAS V66
  - Oyten (Germany)
    - 2 x 1,75 MW
    - 385 ft hub height
  - Achim (Germany)
    - 3 x 1,75 MW
    - 385 ft hub height
  - Beedenbostel (Germany)
    - 5 x 1,75 MW
    - 385 ft hub height
  - Krichtlinteln (Germany)
    - 5 x 1,75 MW
    - 385 ft hub height
  - ...
• Others REPOWER
  – Pattensen (Germany)
    • 1 x 2,5 MW
    • 365 ft hub height
  – Kölkebeck (Germany)
    • 2 x 2,5 MW
    • 365 ft hub height
  – Schorbus (Germany)
    • 2 x 2,5 MW
    • 365 ft hub height
  – Werl (Germany)
    • 2 x 2,5 MW
    • 315 ft hub height
  – Litzendorf
    • 2 x 2,5 MW
    • 315 ft hub height
NORDEX

Fohren-Linden/Eckersweiler (Germany)
  • 5 x Nordex N90

Kloppberg (Germany)
  • 14 x Nordex N43

EIME (Germany)

Melle (Germany)
  • 6 x 1,75 MW
  • 365 ft hub height

Badbergen (Germany)
  • 12 x 1,5 MW
  • 375 ft hub height

Ostercappeln (Germany)
  • 12 x 1,5 MW
  • 365 ft hub height

Achmer (Germany)
  • 9 x 2,5 MW
  • 345 ft hub height

Alfhausen
  • 12 x 2,5 MW
  • 345 ft hub height

…
2006 - FUHRLENDE

2006 - Fuhrlander Laasow
- 525 ft lattice tower (world record)
- rotor 295 ft diameter
- Power 2.5 MW
2009 - FUHRLänder

- SPREMBERG (Germany)
- 9 x 2.5 MW
- 465 ft hub height
Contact Information

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• Website: sections.arcelormittal.com
• Email: sections.tecom@arcelormittal.com
Case study: Lattice tower pre-design for transmission pylons for 400KV
Case Study: Overview and Analysis of a lattice tower model for 400KV

Optimisation of the lattice structure with the use of higher steel grades compared to the original structure

Total height of the tower: 102.43m
Width at the bottom of the tower: 15.11m x 15.11m
Total tonnage for the whole tower: 112,116t
Case study: Overview of a lattice tower model for 400KV

- Steel grade used for the original structure:
  - main legs: S355J2
  - main diagonals: S235JR
  - bracings: S235JR

- Assumptions made for the original structure:
  - Angle tower with $\alpha = 135^\circ$
  - Average wind span length: 500m
  - Average weight span length: 600m

- The original structure is already optimised

Assumed loads according to EN 50341-3-4 for the original structure:

- Permanent loads:
  - Weight of the angle profiles, plates, etc.
  - Conductors: 2x3 x3 AFL-8-350 (357-Al1/46-St1) with Z=22,7KN at $+10^\circ$C which leads to 68,1KN per conductor
  - lightning protection: 2x1AFL-1,7 95 (85-AL1/49-St1A) with Z=13,7KN at $+10^\circ$C

- Variable loads:
  - Wind zone 1: The transverse and longitudinal wind pressure is modeled along the height of the structure based on EN 50341-3-4. The wind pressure for this zone: $q_0=320$N/m²
  - Ice zone 1 with $g=7.61$N/m
Analysis of a lattice tower model for 400KV

List of profiles: Main Legs in steel grade S355J2 and Main Diagonals in steel grade S235JR

<table>
<thead>
<tr>
<th>Section</th>
<th>Height of the tower</th>
<th>Main Legs</th>
<th>Weight Main Legs [to]</th>
<th>% of weight Main Legs per Section</th>
<th>Main Diagonals</th>
<th>Weight Main Diagonals [to]</th>
<th>% of weight Main Diagonals per Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>0 - 5m</td>
<td>L300x35</td>
<td>3,097</td>
<td>33</td>
<td>L160x15, L150x12</td>
<td>2,304</td>
<td>25</td>
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<tr>
<td>13</td>
<td>5 -12,56m</td>
<td>L300x35</td>
<td>4,687</td>
<td>42</td>
<td>L150</td>
<td>3,851</td>
<td>34</td>
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<tr>
<td>12</td>
<td>12,56 -20,13m</td>
<td>L300x35</td>
<td>4,687</td>
<td>44</td>
<td>L150</td>
<td>3,606</td>
<td>34</td>
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<td>11</td>
<td>20,13-27,688m</td>
<td>L300x35</td>
<td>4,687</td>
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<td>L150</td>
<td>3,371</td>
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<td>10</td>
<td>27,688-35,25m</td>
<td>L250x30</td>
<td>3,378</td>
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<td>L150</td>
<td>3,139</td>
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<td>9</td>
<td>35,25-42,813m</td>
<td>L250x28</td>
<td>3,157</td>
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<td>L160x15, L150x15</td>
<td>3,343</td>
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<td>8</td>
<td>42,813-50,375m</td>
<td>L250x28</td>
<td>3,157</td>
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<td>L160x15, L150x15</td>
<td>3,102</td>
<td>38</td>
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<tr>
<td>7</td>
<td>50,375-57,94m</td>
<td>L250x24</td>
<td>2,729</td>
<td>37</td>
<td>L180x16, L160x15</td>
<td>3,275</td>
<td>44</td>
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<tr>
<td>6</td>
<td>57,94-65,5m</td>
<td>L250x24</td>
<td>2,729</td>
<td>41</td>
<td>L130, L120</td>
<td>2,507</td>
<td>38</td>
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<tr>
<td>5</td>
<td>65,5-73,06m</td>
<td>L200x24</td>
<td>2,164</td>
<td>40</td>
<td>L150x12, L130, L120</td>
<td>2,303</td>
<td>43</td>
</tr>
<tr>
<td>4</td>
<td>73,06-80,63m</td>
<td>L200x18</td>
<td>1,641</td>
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<td>L150</td>
<td>2,709</td>
<td>54</td>
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<td>3</td>
<td>80,63-85,545m</td>
<td>L200x18, L160x15</td>
<td>0,890</td>
<td>26</td>
<td>L160, L120</td>
<td>1,665</td>
<td>49</td>
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<td>2</td>
<td>85,545-90,47m</td>
<td>L150x15</td>
<td>0,665</td>
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<td>L120</td>
<td>1,261</td>
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<tr>
<td>1</td>
<td>90,47-99,255m</td>
<td>L150x12, L130x12</td>
<td>0,969</td>
<td>35</td>
<td>L130, L120, L100, L90</td>
<td>1,421</td>
<td>51</td>
</tr>
</tbody>
</table>

Total tonnage Main Legs: **38,635 to**

Total tonnage Main Diagonals: **37,856 to**

Total tonnage for section 1–section 14: **100,576 to**

Total tonnage for the whole tower: **112,116 to**
Optimisation of a lattice tower model for 400KV

- The same structure with the same load assumptions will be optimized by using high-strength steel for the main legs and for the main diagonals

- 1st Possibility: Optimization of main legs with high-strength steel in S420M, S460M

- 2nd Possibility: Optimization of main legs and main diagonals with higher steel grades compared to the original structure

- Ultimate limit states analysis for the structure according to EN 50341
  - Check of: compression, tensile stress, shear stress, overall stability, local stability of an angle (local buckling, flexural buckling, torsional-flexural buckling)

- Serviceability limit states analysis for the structure according to EN 50341

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Height of Section 1: 99.26m
Width at the bottom of this Section: 4.09m

Total height of the tower: 102.43m
Width at the bottom of the tower: 15.11x15.11m
Total tonnage for the whole tower: 112,116t
Optimisation of a lattice tower model, total height 102.43m, with the use of higher steel grades compared to the original structure

1st Possibility: Optimization of main legs with high-strength steel in S420M, S460M

Original design concerning the main legs

L300x35, S355J2

L250x30,
L250x28,
L250x24,
S355J2

Optimised structure concerning the main legs

L200x28,
S460M

L250x26,
S420M

L300x26,
S420M

L300x28,
S420M

Total Leg Weight reduction: 15.2%
1st Possibility for a lattice structure, total height 102.43m: Optimization of main legs with high-strength steel in S420M, S460M

<table>
<thead>
<tr>
<th>Section</th>
<th>Height of the tower</th>
<th>Main Legs – ORIGINAL</th>
<th>Weight Main Legs [to] ORIGINAL</th>
<th>Main Legs – after Optimization</th>
<th>Steel Grade – after Optimization</th>
<th>Weight Main Legs [to] –after Optimization</th>
<th>% weight reduction due to Optimization</th>
</tr>
</thead>
<tbody>
<tr>
<td>14,13</td>
<td>0 - 12.56m</td>
<td>L300x35</td>
<td>7,784</td>
<td>L300x28</td>
<td>S420M</td>
<td>6,318</td>
<td>18.8</td>
</tr>
<tr>
<td>12,11</td>
<td>12.56 - 27.7m</td>
<td>L300x35</td>
<td>9,373</td>
<td>L300x26</td>
<td>S420M</td>
<td>7,060</td>
<td>24.7</td>
</tr>
<tr>
<td>10,9</td>
<td>27.7 - 42.81m</td>
<td>L250x30, L250x28</td>
<td>6,535</td>
<td>L250x26</td>
<td>S420M</td>
<td>5,886</td>
<td>9.9</td>
</tr>
<tr>
<td>8,7,6</td>
<td>42.81 - 65.5m</td>
<td>L250x28, L250x24</td>
<td>8,614</td>
<td>L200x28</td>
<td>S460M</td>
<td>7,49</td>
<td>13</td>
</tr>
<tr>
<td>5,4</td>
<td>65.5 - 80.63m</td>
<td>L200x24, L200x18</td>
<td>3,805</td>
<td>L200x22, L200x18, L180x20</td>
<td>S460M</td>
<td>3,627</td>
<td>4.7</td>
</tr>
<tr>
<td>3</td>
<td>80.63 - 85.545m</td>
<td>L200x18, L160x15</td>
<td>0.890</td>
<td>L180x19, L150x13</td>
<td>S460M, S355J2</td>
<td>0.794</td>
<td>10.8</td>
</tr>
<tr>
<td>2,1</td>
<td>85.545 - 99.255m</td>
<td>L150x15, L150x12, L130x12</td>
<td>1.634</td>
<td>L150x15, L150x12, L130x12</td>
<td>S355J2, S460M</td>
<td>1.592</td>
<td>2.6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>38,635</td>
<td>32,767</td>
<td><strong>15,2</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Leg Weight reduction: **15.2%**
2nd Possibility for a lattice structure, total height 102.43m: Optimization of main legs and main diagonals with higher steel grades compared to the original structure

- The same structure with the same load assumptions will be optimized
- The main legs are optimized as shown in the 1st possibility

**Original design concerning the main diagonals**

L180x16, L160x15, S235JR
L160x15, L150x15, S235JR

**Optimised structure concerning the main diagonals**

L150x14, S460M
L140x12, L150x12, S355J2

**Total Main Diagonal Weight reduction:** 10.4%
# 2nd Possibility for a lattice structure, total height 102.43m: Optimization of main legs and main diagonals with higher steel grades compared to the original structure

<table>
<thead>
<tr>
<th>Section</th>
<th>Height of the tower</th>
<th>Main Diagonals – ORIGINAL</th>
<th>Weight Main Diag. [to] – ORIGINAL</th>
<th>Main Diagonals – after Optimization</th>
<th>Steel Grade – after Optimization</th>
<th>Weight Main Diag. [to] – after Optimization</th>
<th>% weight reduction due to Optimization</th>
</tr>
</thead>
<tbody>
<tr>
<td>14-11</td>
<td>0-27.6875</td>
<td>L160x15, L150</td>
<td>13,132</td>
<td>No Optimization done</td>
<td></td>
<td>13,132</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>27.6875-35.25</td>
<td>L150x15, L150x12</td>
<td>3,139</td>
<td>L150x12, L140x12</td>
<td>S355J2, S235JR</td>
<td>2,711</td>
<td>13.6</td>
</tr>
<tr>
<td>9.8</td>
<td>35.25-50.375 m</td>
<td>L160x15, L150x15</td>
<td>6,445</td>
<td>L150x12, L140x12</td>
<td>S355J2</td>
<td>4,864</td>
<td>24.5</td>
</tr>
<tr>
<td>7</td>
<td>50.375-57.94m</td>
<td>L180x16, L160x15</td>
<td>3,275</td>
<td>L150x14</td>
<td>S460M</td>
<td>2,603</td>
<td>20.5</td>
</tr>
<tr>
<td>6.5</td>
<td>57.94-73.06m</td>
<td>L150x12, L130x12, L120x12</td>
<td>4,810</td>
<td>L120, L110</td>
<td>S355J2</td>
<td>4,009</td>
<td>16.7</td>
</tr>
<tr>
<td>4.3</td>
<td>73.06-85.545 m</td>
<td>L160x15, L150, L120</td>
<td>4,374</td>
<td>L140x12, L130, L120</td>
<td>S355J2, S235JR</td>
<td>3,920</td>
<td>10.4</td>
</tr>
<tr>
<td>2.1</td>
<td>85.545-99.255 m</td>
<td>L130, L120, L100, L90</td>
<td>2,682</td>
<td>No Optimization done</td>
<td></td>
<td>2,682</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>37,856</strong></td>
<td></td>
<td></td>
<td><strong>33,921</strong></td>
<td><strong>10.4</strong></td>
</tr>
</tbody>
</table>

Weight reduction for the main legs + main diagonals: **12.8%**
POWER LINE Pylons

Conclusion

Based on the chosen geometry and on the chosen load assumptions for a 400KV transmission tower

- The increase of yield strength shows benefits concerning the steel weight and the behavior of the structure
- S460M subjected to mill mill acceptance
Buckling curves for Angles

Berlin 2014
EC3 group meeting
In the standard prEN50341-1-1:2012: **Overhead electrical lines exceeding AC 1 kV**, section J5 the following buckling curves can be used for lattice transmission towers:

- either **buckling curve c** with imperfection factor $\alpha = 0.49$ shall be used
- or if the design is done by calculation and validated by documented full scale loading tests the **buckling curve b acc. to EN 1993-1-1** shall be used

$=>$ In the new standard prEN50341-1-1 the buckling curve for angles will be the same like in EN 1993-1-1
Buckling curves for Angles

Present EC3 recommendations

Design Rule only for hot-rolled angles following the drawing; but this is not explicitly mentioned:

- Feedback from market: Present Rules are also applied for welded L-sections.
- Recommended buckling curve: curve b (whatever the steel grade)

<table>
<thead>
<tr>
<th>Cross section</th>
<th>Limits</th>
<th>Buckling about axis</th>
<th>Buckling curve</th>
</tr>
</thead>
</table>
| Rolled sections | \( t_r \leq 40 \text{ mm} \) | \( y - y \) \( z - z \) | a | a_0 | S 235
|           | \( 40 < t_r \leq 100 \) | \( y - y \) \( z - z \) | b | c | S 275
|           | \( t_r \leq 100 \) | \( y - y \) \( z - z \) | b | a | S 355
|           | \( t_r > 100 \) | \( y - y \) \( z - z \) | d | c | S 420
| Welded I-sections | \( t_r \leq 40 \text{ mm} \) | \( y - y \) \( z - z \) | b | b | S 460
|           | \( t_r > 40 \text{ mm} \) | \( y - y \) \( z - z \) | c | d | |
| L-sections | any | | b | b | |
Buckling curves for Angles

1. EC3 recommendations:

- EN1993-1-1 covers “existing angles”, but nowadays larger sections exist (e.g. L250 and L300), which were not available when the rules have been developed.

EN 1993-1-1: Buckling curves for angles: curve \( b \) recommended, whatever the situation.
Buckling curves for Angles

**Studied angles**: subcontract with Universities of Ljublana and Liège.

a. Samples delivered for the measurements of residual stresses:

<table>
<thead>
<tr>
<th>Université</th>
<th>Ljubljana</th>
<th>Liège</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samples (length 1.8 m)</td>
<td><strong>Hot-rolled angles</strong>: (delivered by Rodange) L 180 x 180 x 15 L 180 x 180 x 20 L 250 x 250 x 20 L 250 x 250 x 28 L 300 x 300 x 25 L 300 x 300 x 35</td>
<td><strong>Hot-rolled angles</strong>: (delivered by Ostrava) L 140 x 140 x 12 L 140 x 140 x 15 L 200 x 200 x 15 L 200 x 200 x 24 L 300 x 300 x 25 L 300 x 300 x 35</td>
</tr>
<tr>
<td>Steel grade: S355</td>
<td><strong>Welded angles</strong> (delivered by Alliages SA) L 250 x 250 x 20 L 250 x 250 x 30</td>
<td><strong>Welded angles</strong> (delivered by Alliages SA) L 300 x 300 x 30 L 300 x 300 x 35</td>
</tr>
</tbody>
</table>
Buckling curves for Angles

Universities of Ljubljana and Liège.
Measurements of residual stresses on large hot-rolled & welded angles

Specimens of **hot-rolled**
angle profile
L300x300x35:

*Ljubljana*

Specimens of **welded**
angle profile
L300x300x35:

*Liège*

‡ 2 different techniques for the measurements of residual stresses in Liège and in Ljubljana
Buckling curves for Angles

 Numerical analysis of Uni Lubljana

**Hot-rolled L250/21; 70 MPa amplitude; 4 points idealized distribution**

Results for **S235**

Results for **S355**

Curve b is ok

Curve a is ok

Curve b
Buckling curves for Angles

Numerical analysis of Ulg

- FEM tool: code FINELG
- Classical 3D beam element with 7 dofs
- Properties of the numerical model ⇒ Boundary conditions
- Residual stresses 3 point distribution:

EC3 residual stresses: $\sigma_{\text{max}} = 70.5$MPa
Buckling curves for Angles

Numerical analysis of Ulg

Results for hot-rolled angles:

Steel S235 → Steel S420

Curve a is ok

Curve b is ok
Amendment of EC3

Table 6.2: Selection of buckling curve for a cross-section

<table>
<thead>
<tr>
<th>Cross section</th>
<th>Limits</th>
<th>Buckling about axis</th>
<th>Buckling curve</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rolled sections</td>
<td>any</td>
<td>S 235 S 275 S 355 S 420 S 460</td>
</tr>
<tr>
<td>L-sections</td>
<td>Welded sections tf≤40mm</td>
<td>any</td>
<td></td>
</tr>
</tbody>
</table>

=> Thanks to our involvement in standardization the buckling curves for hot rolled angles will be for EN50341-1-1 and for EC3 significantly improved
Thank you for your attention!