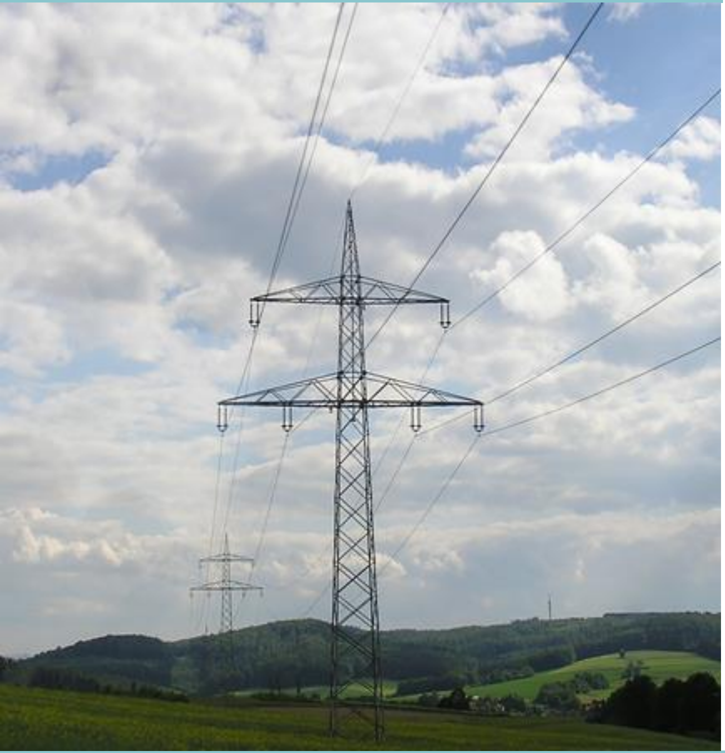
Case study design – Transmission tower

Mike Tibolt, ArcelorMittal Global R&D, Luxembourg



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supported by

European Commission

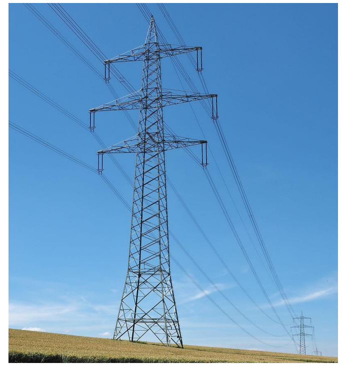
Research Fund for Coal & Steel

8th December 2020 – Innovative Developments and Solutions for Steel Lattice Towers

Objectives

- Identify a typical typology for transmission towers in Europe
- Design of one single tower
- Design according to EN 50341-1:2012
- Comparison to EN 1993-1-1, EN 1993-3-1 and nonlinear design methods
- Case study as basis for further research within the project ANGELHY

Danube tower - Typical tower typology

		
Danube tower • 2 cross arms • 2 circuits • One circuit/side -> 3 phases • Lower cross arm = longest • Upper cross arm = shortest • Height ≈ 30 – 50 m • Width ≈ 30 m	Barrel tower • 3 cross arms • 2 circuits • One circuit/side -> 3 phases • Middle cross arm = largest • Height ≈ 50 – 60 m • Width ≈ 20 m • Low environmental intervention	Single plan tower • One cross arm • 2 circuits • One circuit/side -> 3 phases • Height ≈ 30 – 40 m • Width ≈ 40 m • Big environmental intervention
Applications • Standard type in Europe • 220 kV/380 kV • Woods • Urban areas • Medium protection strips	Applications • 220 kV/380 kV • Woods • Rivers • Farms • Standard type in UK	Applications • Airports • Large protection strip • East-Germany for 110 kV

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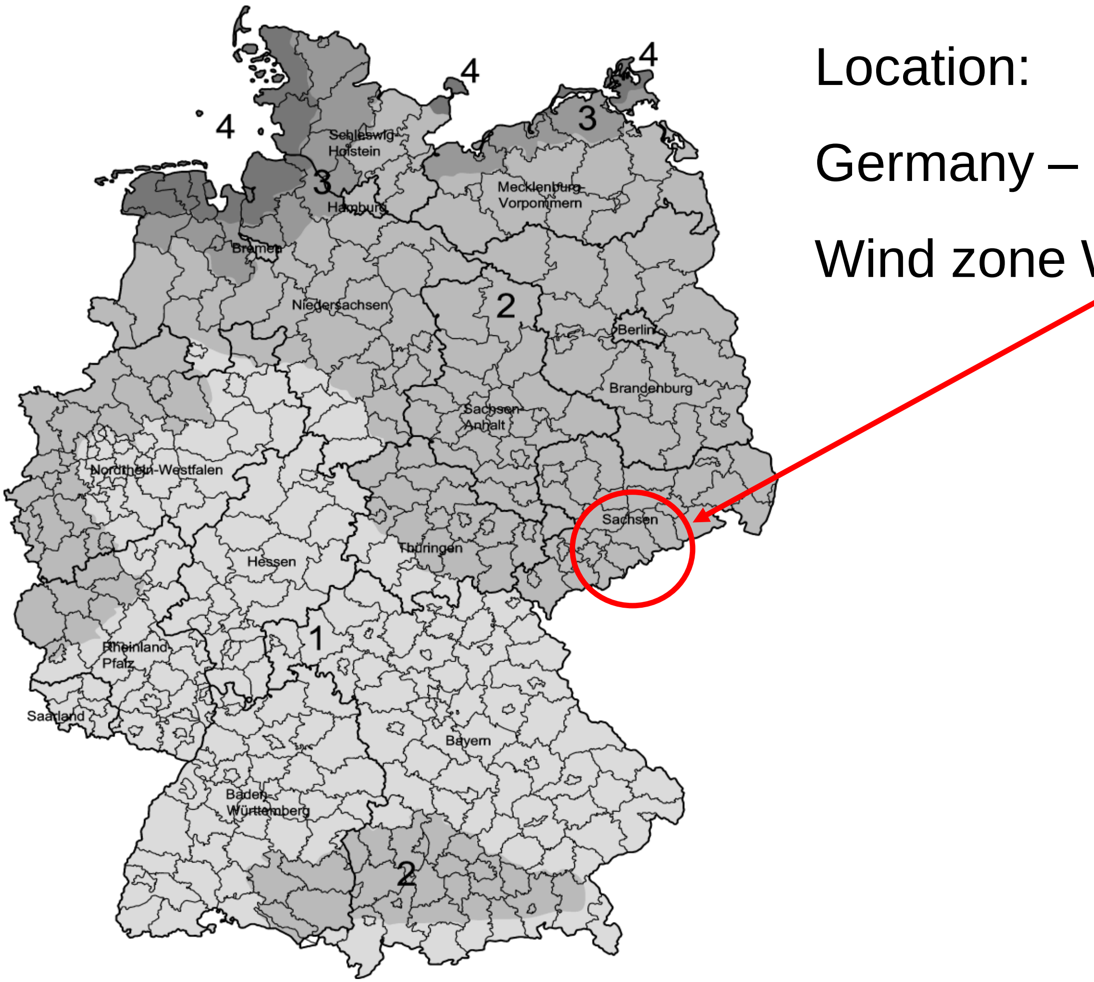
Suspension and Dead-end tower

Design for both types

 	<u>Suspension tower</u> • Hanging insulators • Self-weight +ice of conductors • Self-weight of tower body • Transverse wind loads • Light structure	<u>Applications</u> • Support of conductors • Reduction of span
  	<u>Dead-end tower</u> • Horizontal strain insulators • Self-weight +ice of conductors • Tension loads in conductors • Self-weight of tower body • Transverse wind loads • Longitudinal wind loads • Heavy structure	<u>Applications</u> • Change of line direction • Ends of lines • Transition to buried cables • Straight lines -> cascade failure

Location of case study tower



Location:

Germany – Erzgebirge

Wind zone WZ 2 + Ice zone EZ 2 (H < 750 m)

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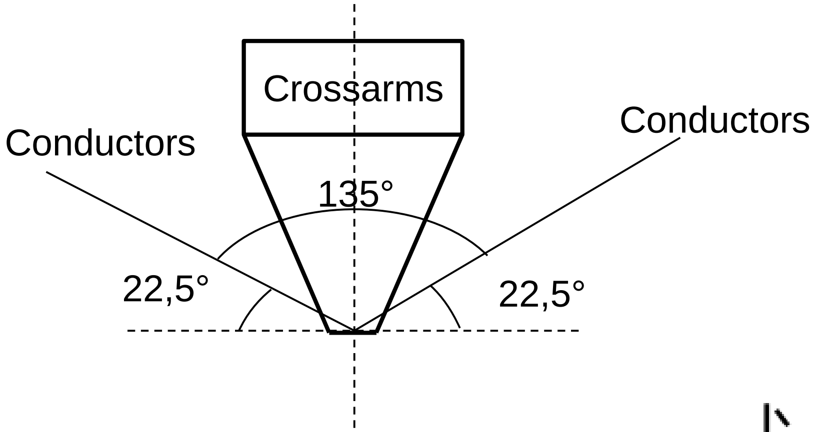
Case study - Layout of transmission line

Suspension tower: Straight line with elevation difference

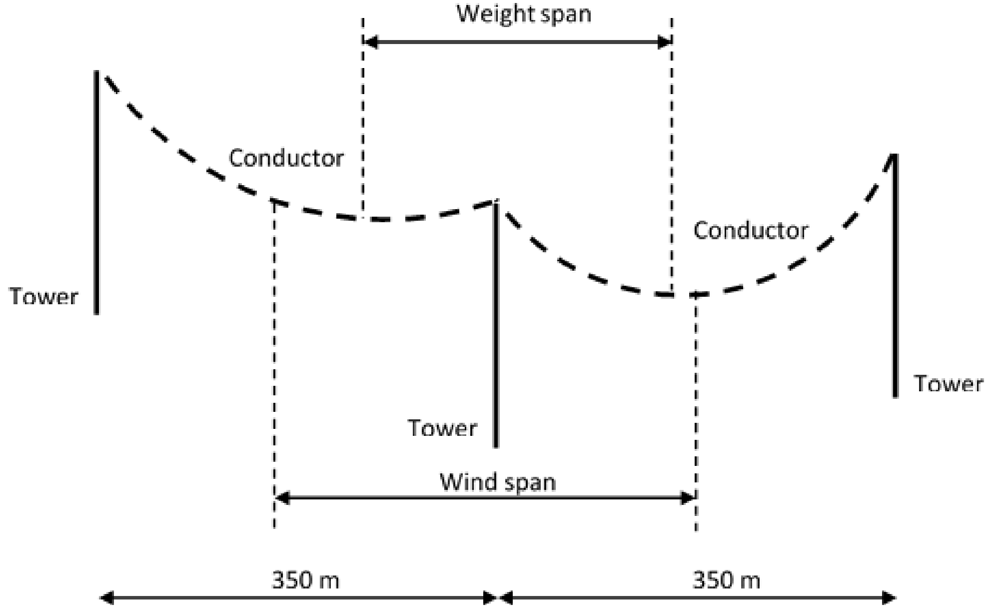
Dead-end tower: Inclined line (α = 22.5°) with elevation difference



Tower span: 350 m

Wind span: 350 m

Weight span: 525 m



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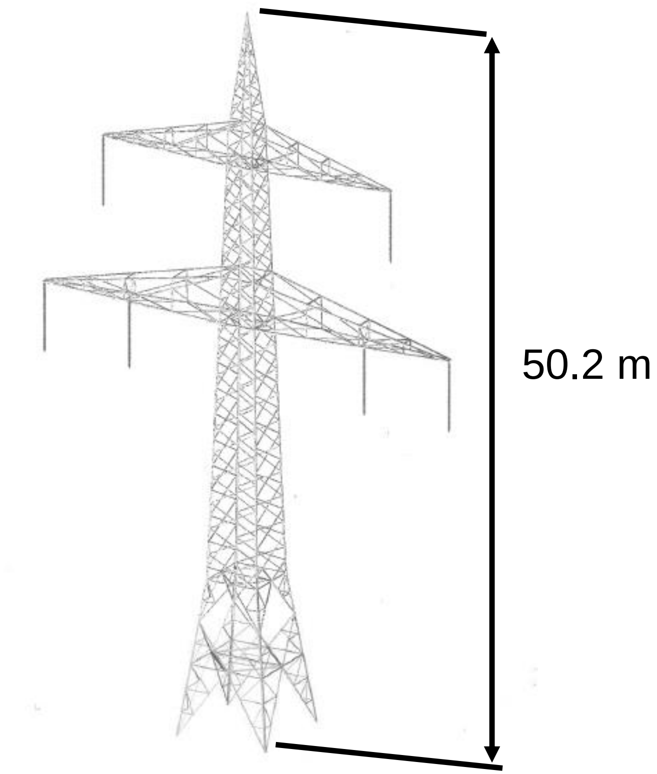
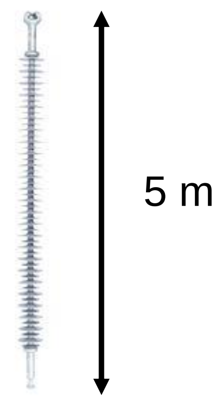
Case study - Tower geometry

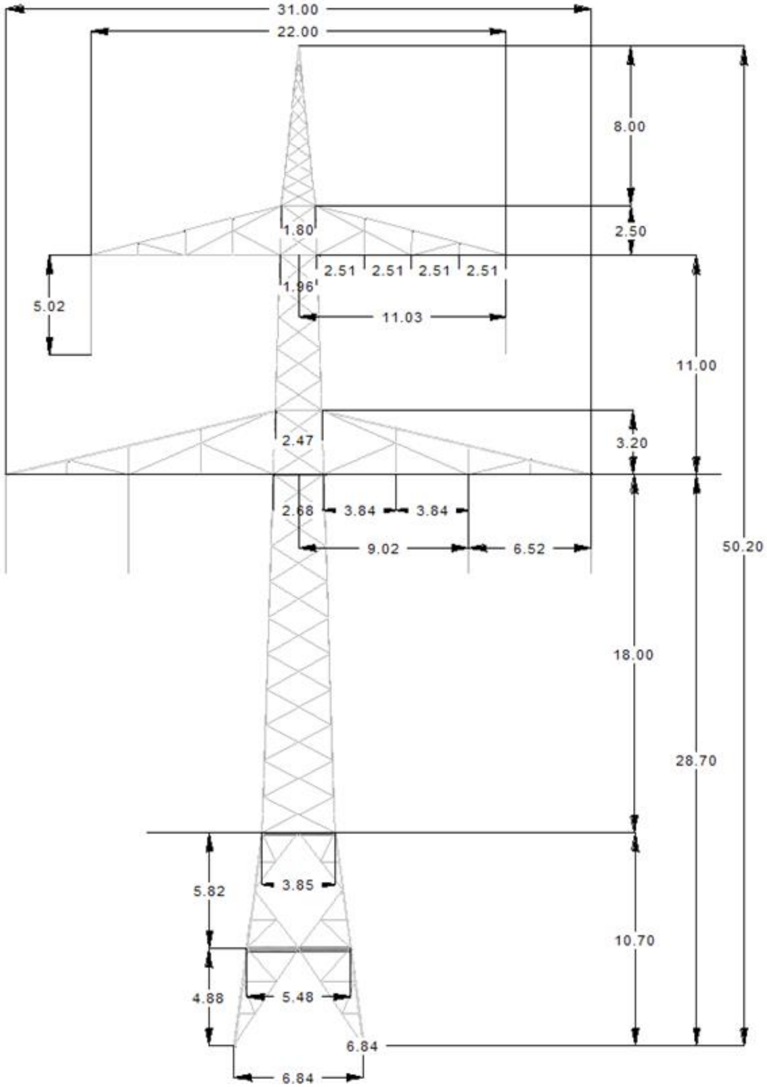
General information

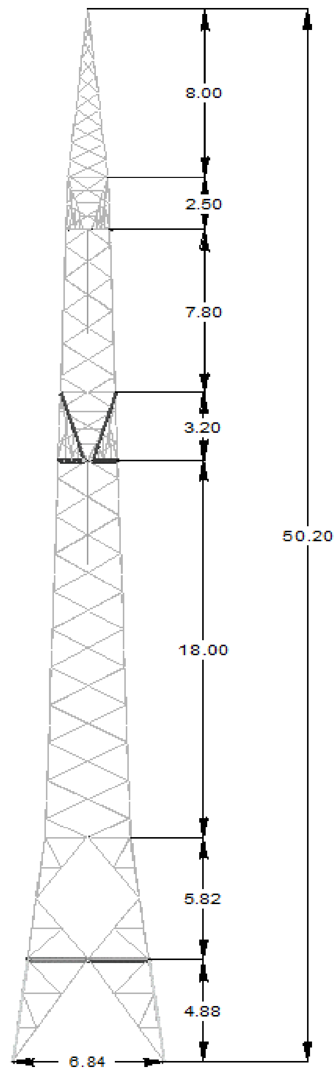


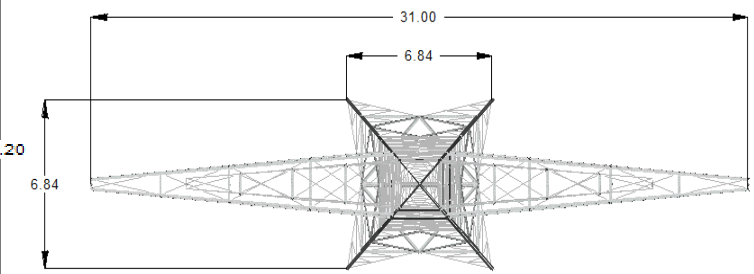
- Suspension tower and dead-end tower
- Two circuits of 380 kV
- Each circuit of 3 phases/side
- Conductors: 4* 264-AL1/31-ST1A
- Earth wire: 1* 94-AL1/15-ST1A
- Insulators: Quadri*Sil Insulators (HUBBEL)



Case study - Tower geometry







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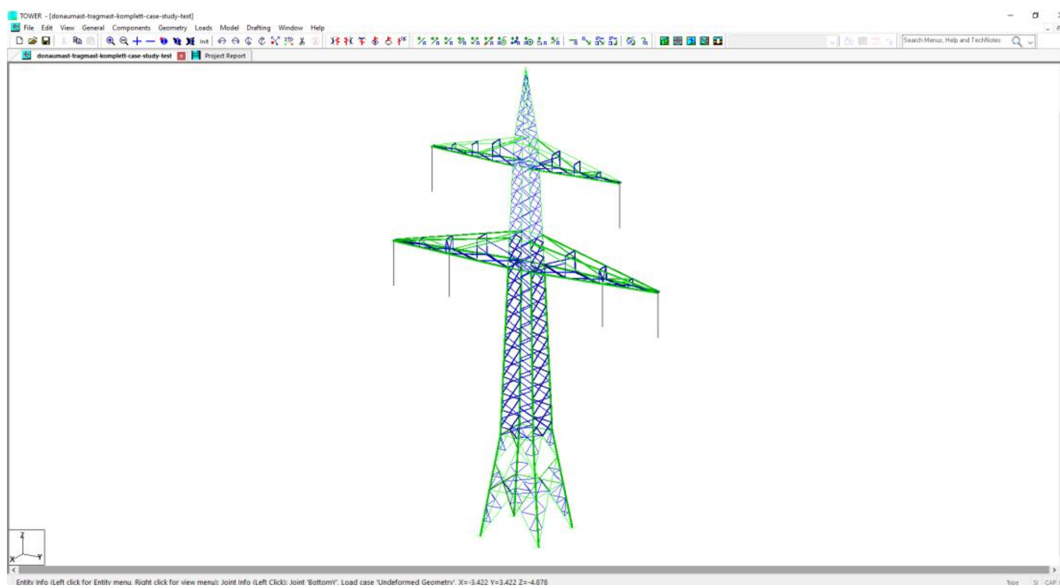
Case study - Design assumptions

Design by software TOWER (V 15.0) from Power Line Systems

- Loads and design according to norms: EN 50341-2-4:2016 (German NA)
- Only single tower design -> no transmission line design
- No conductor design -> point loads from self-weight an wind on insulators
- Linear-elastic design
- No connection design
- No foundation design
- Only single angles



Case study - Design assumptions

General Design Assumptions

- Linear elastic design and first order theory (EN 50341-1:2012, 7.3.5 b))
- Lattice tower is pin jointed truss structure (EN 50341-1:2012, 7.3.5 a)) -> truss + beam elements
- Foundations as pin supports (Own assumption)
- Eccentricities via effective non-dimensional slenderness λ_{eff} (EN 50341-1:2012, J.4.2.1)
- Only axial tension and compression forces acting in truss elements
- Buckling curve c (EN 50341-2-4:2016, J.4.1 DE.2)
- Wind loads according to Method 1 (wind on sections) of EN 50341-1:2012 (EN 50341-2-4:2016, 4.4.3.1)
- Wind and ice loads on insulators
- No ice loads on tower structure but only on conductors (EN 50341-2-4:2016, 4.5.2 DE.1)
- Ice loads on conductors by German Meteorological Services and long-term experience (Ice load zones)
- For dead-end tower: Calculation of tension forces (sags, temperature, ice loads) with Excel sheet
- Steel grade: S355J2 acc. to EN10025-2:2004

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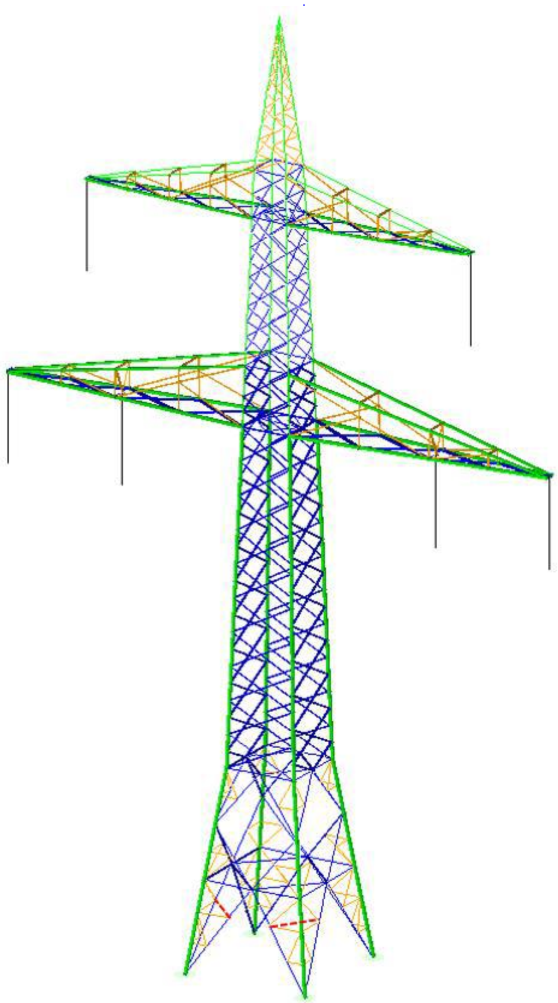
Case study - Numerical model in TOWER

- Model with primary and secondary bracing system
- No modelling of connections -> pinned connections
- No modelling of foundations -> pinned supports
- Truss elements (Blue) + Beam elements (Green)
- No modelling of conductors -> Loads applied as point loads on insulators
- Tower divided into 7 sections + 2 cross arms
- Only single angles
- Self-weight is calculated by TOWER
- Weight of gussets and bolts estimated by adjustment factor (20%)
- Wind loads on tower and insulators acc. EN 50341-2-4:2016 by TOWER
- Wind and ice loads on conductors acc. EN 50341-2-4:2016 by hand
- Ice load on insulators acc. EN 50341-2-4:2016 by hand
- Weight of lines men acc. EN 50341-2-4:2016 by TOWER
- Construction loads acc. EN 50341-2-4:2016 by hand
- Load combinations acc. EN 50341-2-4:2016



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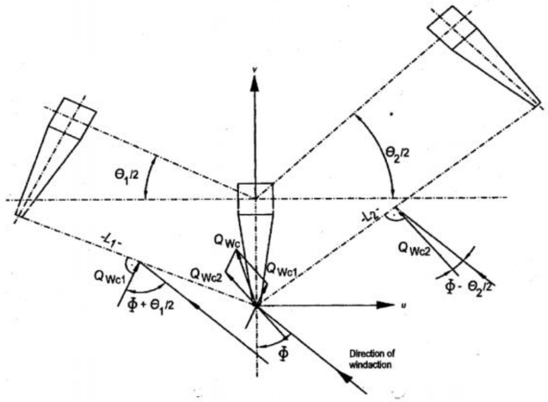
Case study – Load cases

- Load cases A to L (12 load cases) to cover:
  - Wind loads in three main directions: x-,y-direction and ϕ = 45° (A to C)
  - Extreme ice loads combined with wind (D to F)
  - Construction and maintenance loads (I)
  - Exceptional loads (unbalanced ice loads) (J to L)



- Suspension tower -> Load cases A to J
- Weight of lines men applied on members with α < 30°to horizontal: Point load of 1kN in the center of member
- The partial safety factors to be applied to the loads depend on the load case and are as follows:
  - $\gamma_G = \gamma_W = \gamma_I = \gamma_P = \gamma_C = 1{,}35$ for load cases A to I in case of unfavourable action
  - $\gamma_G = \gamma_I = 1{,}35$ for load cases A to F in case of favourable action
  - $\gamma_G = \gamma_W = \gamma_I = \gamma_P = \gamma_C = 1{,}0$ for load cases J to L (exceptional load cases)
  - $\gamma_P = 1{,}5$ for construction loads in load case I

Case study – Verifications

Design Checks acc. EN 50341-2-4:2016

- Only verification in ULS -> no SLS and FLS
- Section verifications: Tension + compression -> acc. EN 50341-1, Annex J.3
- Member verifications: Flexural and flexural torsional buckling -> acc. EN 50341-1, Annex J.4
- Crossing diagonal check for bracings without secondary bracings
- Verification of bracing inclination -> Inclination to horizontal $\alpha < 45°$
- Redundant member verification -> Hypothetical transversal force = 0.02 of axial force in braced members
- Verification for lines men for members inclined to horizontal $\alpha < 30$

Case study – Results

- Automatic optimization by TOWER: Angle size, Angle type
- Criteria: lightest structure with highest utilization degree

Suspension tower:

Group	Angle Type	Angle Size	Steel grade
Bottom-legs	SAE	AM 150x150x13-/+	S355J2
Segment 2	SAE	AM 140x140x15	S355J2
Segment 3	SAE	AM 120x120x16	S355J2
Segment 4	SAE	AM 80x80x10-	S355J2
Segment 5	SAE	AM 80x80x6	S355J2
Segment 6	SAE	AM 75x75x4	S355J2
Segment 7	SAE	AM 45x45x3	S355J2
Diagonal 1	SAE	AM 75x75x4	S355J2
Diagonal 2	SAE	AM 75x75x4	S355J2
Diagonal 3	SAE	AM 90x90x5	S355J2
Diagonal 4	SAE	AM 90x90x6	S355J2
Diagonal 5	SAE	AM 60x60x4	S355J2
Diagonal 6	SAE	AM 45x45x4	S355J2
Cross 1-bottom	SAE	AM 150x150x12-/+	S355J2
Cross 1-top	SAE	AM 120x120x7	S355J2
Cross 1-base	SAE	AM 130x130x8	S355J2
Horizontal 1	SAE	AM 80x80x5	S355J2
Horizontal 2	SAE	AM 90x90x5	S355J2
Horizontal 3	SAE	AM 100x100x7	S355J2
Horizontal 4	SAE	AM 76x76x4.8	S355J2
Horizontal 5	SAE	AM 75x75x6-	S355J2
Horizontal 6	SAE	AM 65x65x4	S355J2
Horizontal 1 base	SAE	AM 80x80x5	S355J2
Horizontal 2 base	SAE	AM 80x80x5	S355J2
Horizontal 3 base	SAE	AM 76x76x4.8	S355J2
Horizontal 4 base	SAE	AM 60x60x4	S355J2
Cross - Horizontal	SAE	AM 45x45x3	S355J2
Cross 2-bottom	SAE	AM 120x120x7	S355J2
Cross 2-top	SAE	AM 75x75x5	S355J2
Cross 2-base	SAE	AM 90x90x5	S355J2
Redundant 1	SAE	AM 90x90x5	S355J2
Redundant 2	SAE	AM 60x60x4	S355J2
Redundant 3	SAE	AM 90x90x5	S355J3

Total weight:
17 tons

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Case study – Results

- Cost reduction by using S460 for leg profiles and horizontal members in cross-arms

Dead-end tower in S355:

Group	Angle Type	Angle Size	Steel grade
Bottom-legs	SAE	AM 150x150x13-/+	S355J2
Segment 2	SAE	AM 140x140x15	S355J2
Segment 3	SAE	AM 120x120x16	S355J2
Segment 4	SAE	AM 80x80x10-	S355J2
Segment 5	SAE	AM 80x80x6	S355J2
Segment 6	SAE	AM 75x75x4	S355J2
Segment 7	SAE	AM 45x45x3	S355J2
Diagonal 1	SAE	AM 75x75x4	S355J2
Diagonal 2	SAE	AM 75x75x4	S355J2
Diagonal 3	SAE	AM 90x90x5	S355J2
Diagonal 4	SAE	AM 90x90x6	S355J2
Diagonal 5	SAE	AM 60x60x4	S355J2
Diagonal 6	SAE	AM 45x45x4	S355J2
Cross 1-bottom	SAE	AM 150x150x12-/+	S355J2
Cross 1-top	SAE	AM 120x120x7	S355J2
Cross 1-base	SAE	AM 130x130x8	S355J2
Horizontal 1	SAE	AM 80x80x5	S355J2
Horizontal 2	SAE	AM 90x90x5	S355J2
Horizontal 3	SAE	AM 100x100x7	S355J2
Horizontal 4	SAE	AM 76x76x4.8	S355J2
Horizontal 5	SAE	AM 75x75x6-	S355J2
Horizontal 6	SAE	AM 65x65x4	S355J2
Horizontal 1 base	SAE	AM 80x80x5	S355J2
Horizontal 2 base	SAE	AM 80x80x5	S355J2
Horizontal 3 base	SAE	AM 76x76x4.8	S355J2
Horizontal 4 base	SAE	AM 60x60x4	S355J2
Cross - Horizontal	SAE	AM 45x45x3	S355J2
Cross 2-bottom	SAE	AM 120x120x7	S355J2
Cross 2-top	SAE	AM 75x75x5	S355J2
Cross 2-base	SAE	AM 90x90x5	S355J2
Redundant 1	SAE	AM 90x90x5	S355J2
Redundant 2	SAE	AM 60x60x4	S355J2
Redundant 3	SAE	AM 90x90x5	S355J3

Total weight: 66 tons

Dead-end tower in S460:

Group	Angle Type	Angle Size	Steel grade
Bottom-legs	DAE	AM 300x300x28	S460M
Segment 2	DAE	AM 300x300x28	S460M
Segment 3	SAE	AM 250x250x34	S460M
Segment 4	SAE	AM 150x150x16-/+	S460M
Segment 5	SAE	AM 130x130x14	S460M
Segment 6	SAE	AM 75x75x6-	S460M
Segment 7	SAE	AM 65x65x4	S460M
Diagonal 1	SAE	AM 150x150x10-/+	S355J2
Diagonal 2	SAE	AM 140x140x12	S355J2
Diagonal 3	SAE	AM 180x180x13+	S355J2
Diagonal 4	SAE	AM 120x120x8	S355J2
Diagonal 5	SAE	AM 130x130x8	S355J2
Diagonal 6	SAE	AM 55x55x4	S355J2
Cross 1-bottom	SAE	AM 250x250x17	S460M
Cross 1-top	SAE	AM 120x120x7	S460M
Cross 1-base	SAE	AM 150x150x12-/+	S460M
Horizontal 1	SAE	AM 90x90x5	S460M
Horizontal 2	SAE	AM 130x130x9	S460M
Horizontal 3	SAE	AM 140x140x15	S460M
Horizontal 4	SAE	AM 75x75x4	S460M
Horizontal 5	SAE	AM 120x120x13	S460M
Horizontal 6	SAE	AM 55x55x4	S460M
Horizontal 1 base	SAE	AM 76x76x4.8	S460M
Horizontal 2 base	SAE	AM 80x80x5	S460M
Horizontal 3 base	SAE	AM 110x110x9	S460M
Horizontal 4 base	SAE	AM 90x90x7-	S460M
Cross - Horizontal	SAE	AM 75x75x7	S355J2
Cross 2-bottom	SAE	AM 180x180x13+	S460M
Cross 2-top	SAE	AM 90x90x5	S460M
Cross 2-base	SAE	AM 130x130x9	S460M
Redundant 1	SAE	AM 90x90x5	S355J2
Redundant 2	SAE	AM 100x100x6	S355J2
Redundant 3	SAE	AM 90x90x5	S355J2

Total weight: 56 tons