Risk Assessment of Lattice Towers

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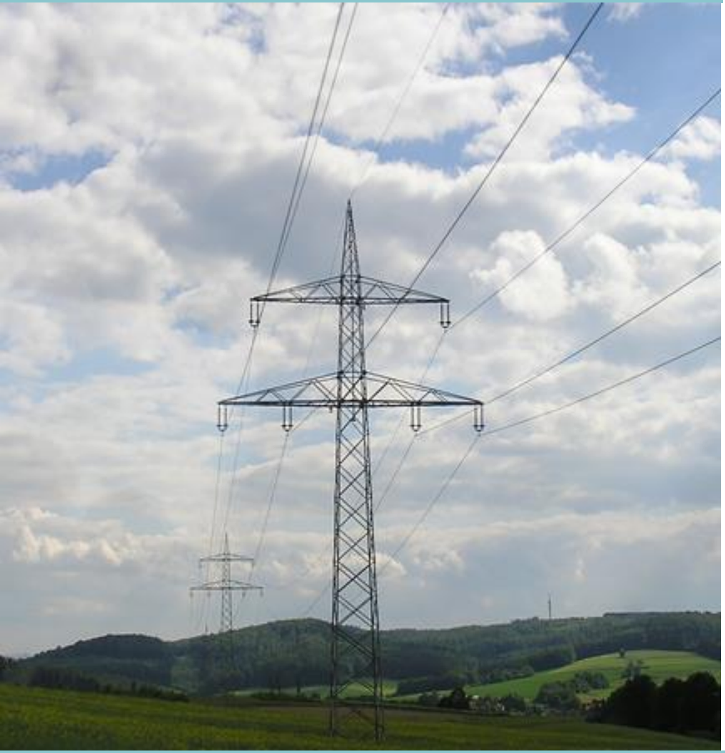

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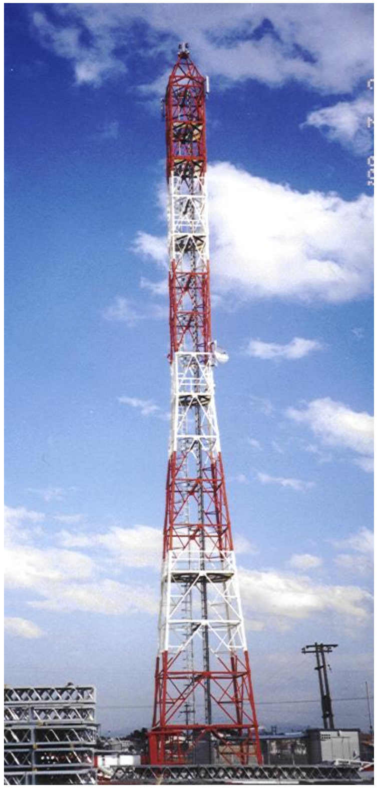
8 December 2020 – Innovative Developments and Solutions for Steel Lattice Towers

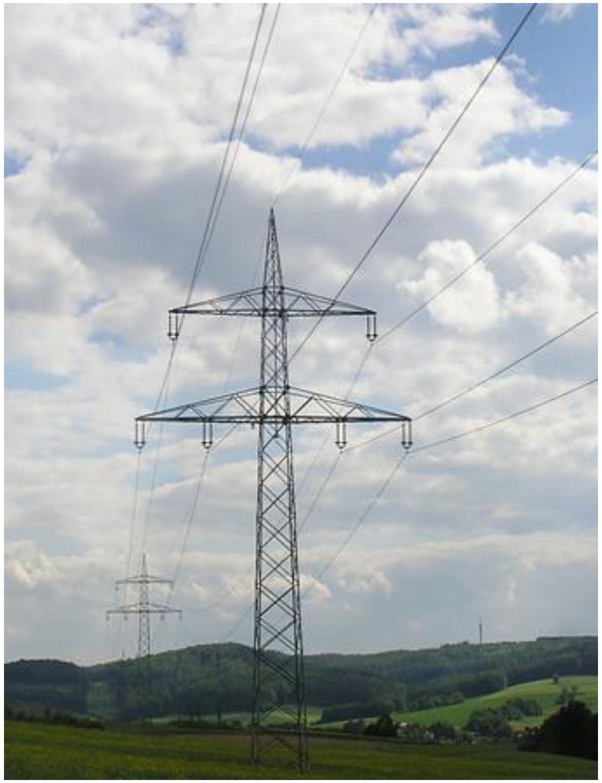
Outline

- Types of Lattice Towers
- Performance Based Design Basics
- Case study - Suspension Transmission Tower
- Risk Estimation for two locations in Germany

Types of Steel Lattice Towers



Telecommunication Tower



Suspension Transmission Tower

Dead-End Transmission Tower

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Performance – Based Assessment

$$Risk = \int Fragility \cdot dHazard$$

- Risk: Probability of failure of a structure given its characteristics and the hazard of its location
- Fragility: Probability of failure of the structure under a specific level of one or more intensity measures (e.g. wind speed, ice etc.) – Structure-Specific
- Hazard: Probability of occurrence of the intensity measure(s) – Site-Specific

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Risk Assessment in Steel Lattice Towers

Parameters of Interest

- Environmental Hazards:
  - ✓ Extreme Wind Speed & Ice Accretion
  - ✓ Estimated by meteorological data from weather stations
- Structural Response - Fragility:
  - ✓ Estimated by parametric non-linear dynamic analyses of a 3D FEM model for various combinations of wind speed and icing conditions

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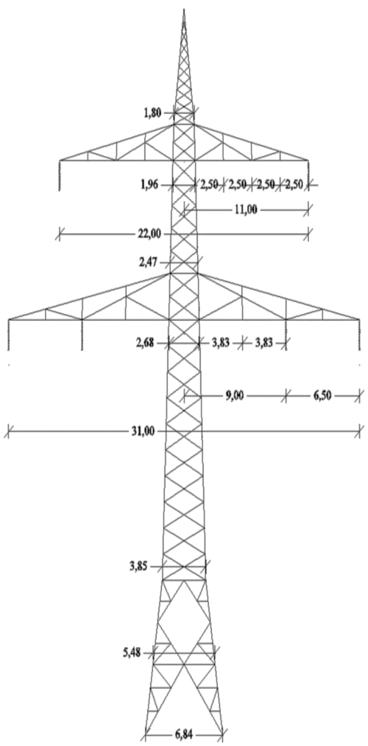
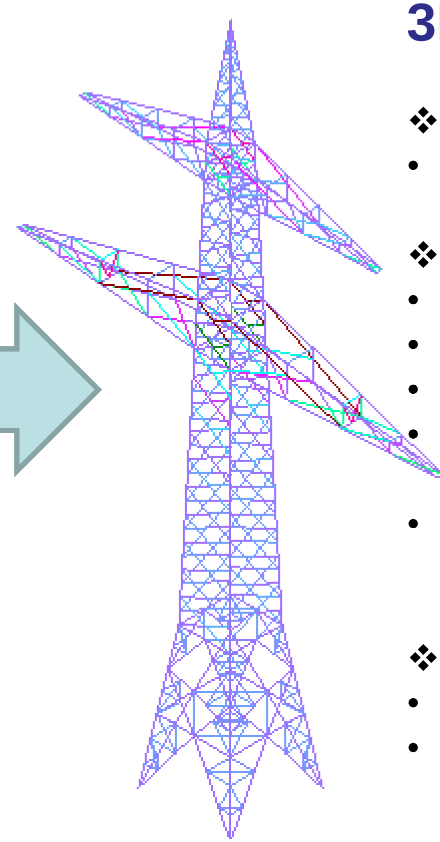
Suspension Transmission Tower



Geometry

- ❖ H = 50.20 m
- ❖ Two Cross Arms
- ❖ Lower Cross Arm
  - Length = 31 m
  - 4 Conductors
- ❖ Upper Cross Arm
  - Length = 22 m
  - 2 Conductors
- ❖ Earth-wire on Top
- ❖ Angle Sections only
- ❖ Span = 350 m

Modeling



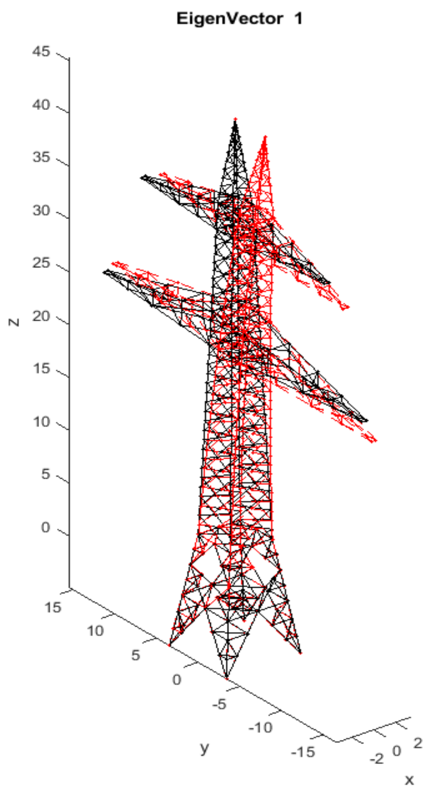
3D FEM Model

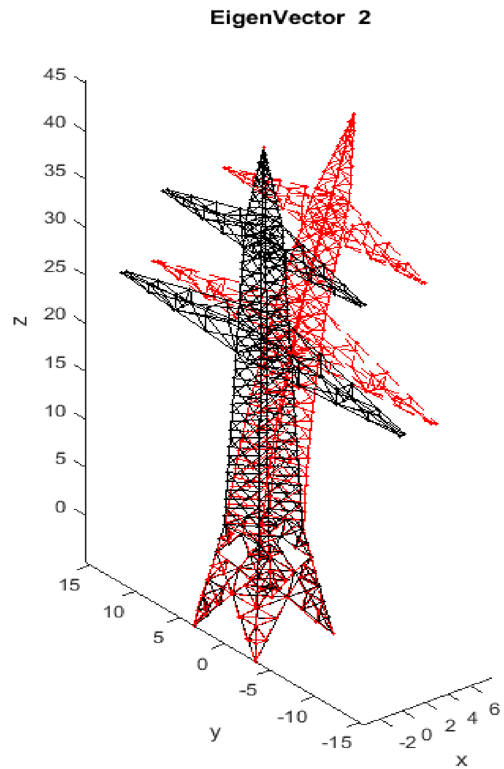
❖ <u>Software:</u>
- OpenSees

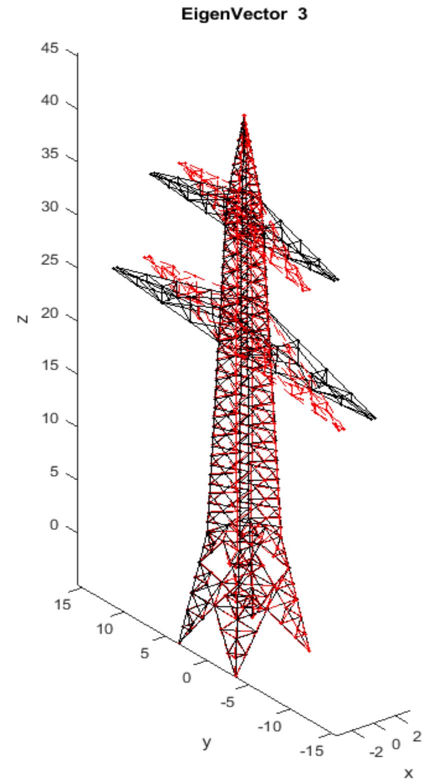
❖ <u>Specifications:</u>
- 982 members
- Fiber Sections
- Legs: Beam Elements
- Rest of members: Truss Elements
- Earth-wire: Spring Element

❖ <u>5 ice thickness scenarios:</u>
- No ice
- Ice layer thicknesses: 1, 5, 10, 15mm

Modal Analysis







1st Mode
$T_1 = 0.510$ s

2nd Mode
$T_2 = 0.503$ s

3rd Mode (Torsional)
$T_3 = 0.434$ s

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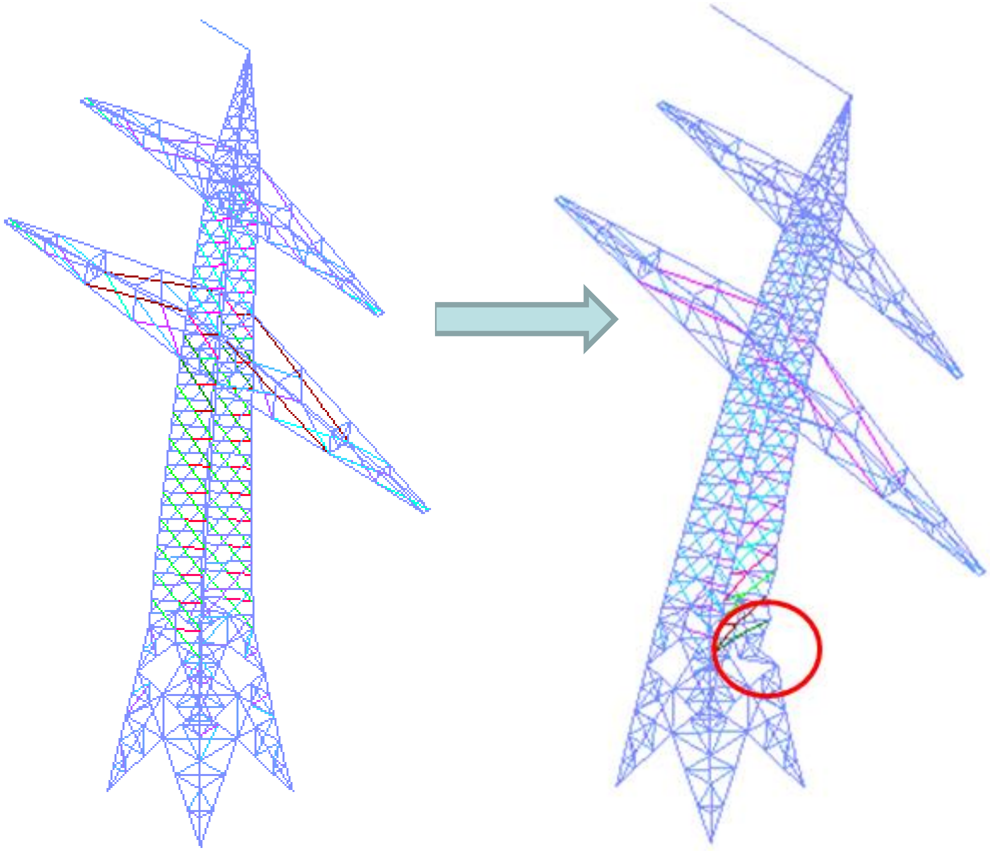
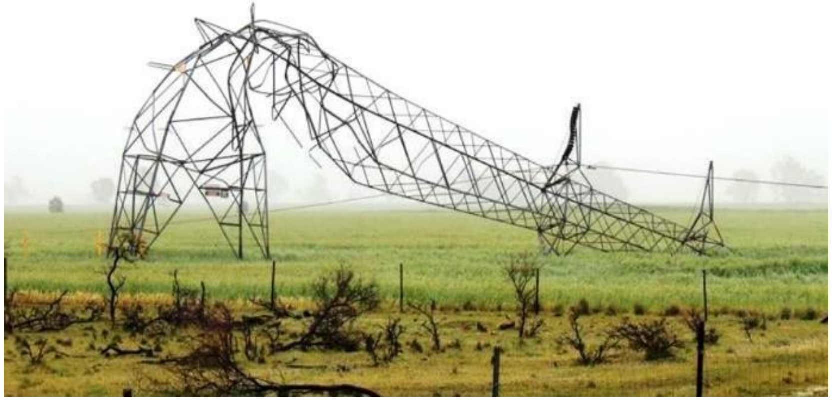
Failure Mode



Notes:

- First failure occurs close to the base (at rhombus)
- Similar to realistic failures



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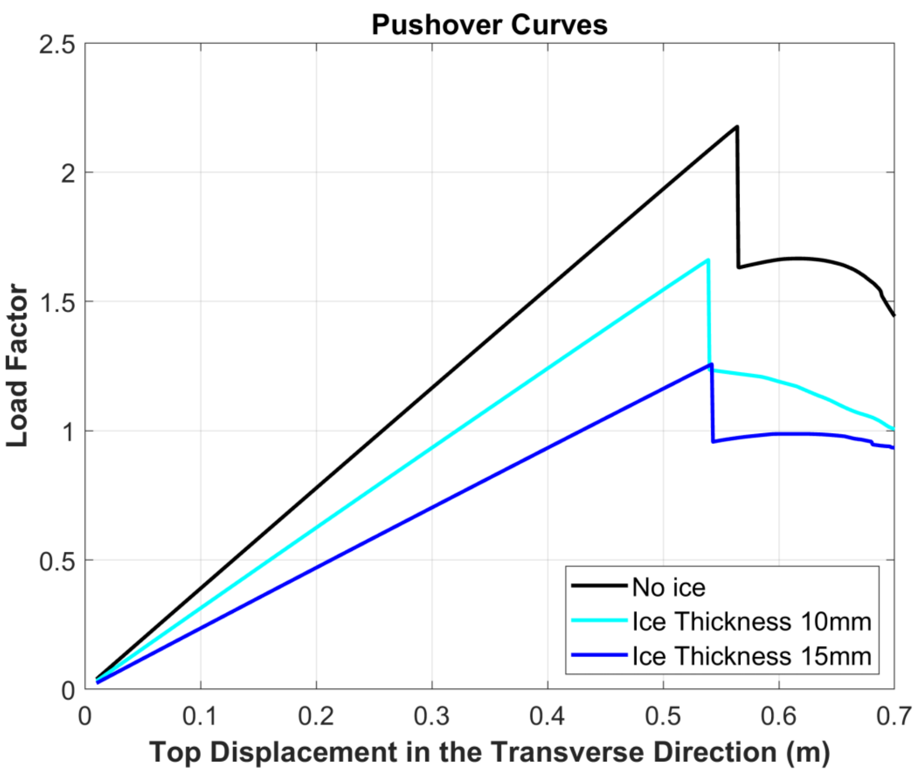
Pushover Analysis



Notes:

- $LF = 1$ corresponds to lateral loads calculated with the basic wind speed at 10m $V_b = 25$ m/s
- First failure occurs for a load 2.18 times greater than basic wind speed's load (for no ice conditions)
- As ice thickness increases, the load factor (and the corresponding wind speed) of first failure decreases

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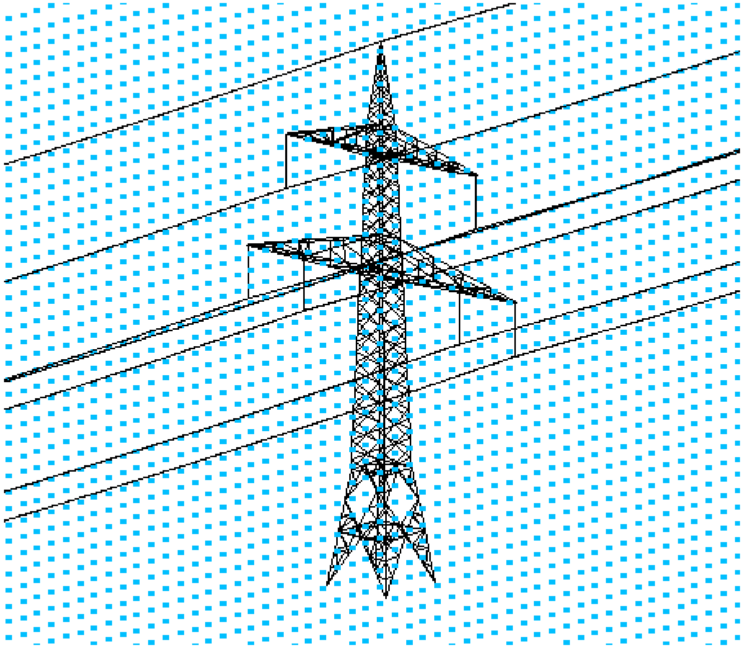
Effect of Wind

- ❖ Simulation Wind Speed Field
- ❖ Use of TurbSim Software provided by National Renewable Energy Laboratory (USA)
- ❖ Simulation of a 2D Wind Field with a length equal to 2 spans
- ❖ Wind Speed Timeseries at different heights in 3 directions (x, y, z)
- ❖ Estimate the Wind Forces on the tower body and conductors



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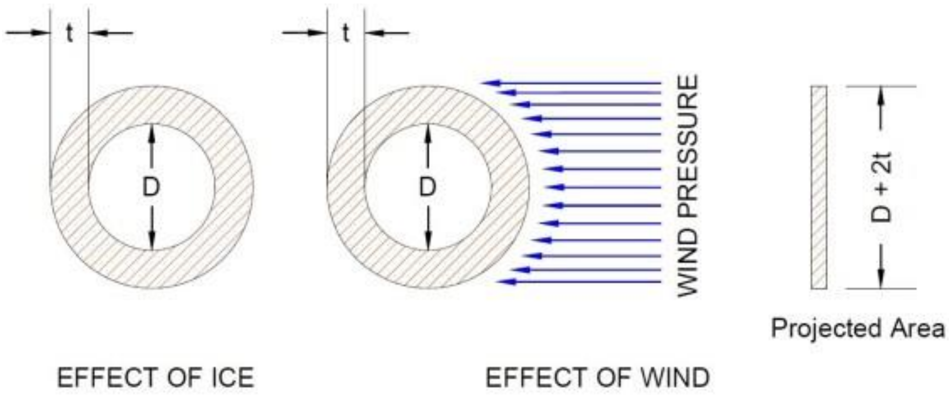
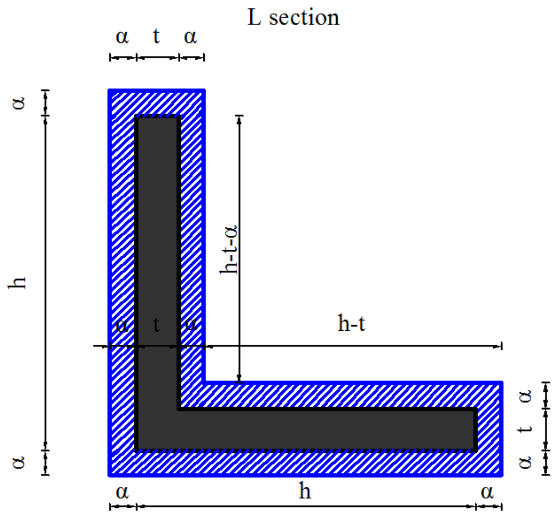
Effect of Ice

- Ice affects both the dead loads of the tower and conductors and the areas of projection increasing wind forces



- A layer of uniform thickness was assumed on the surfaces of tower members and conductors

- Four scenarios of thickness: 1, 5, 10 and 15 mm



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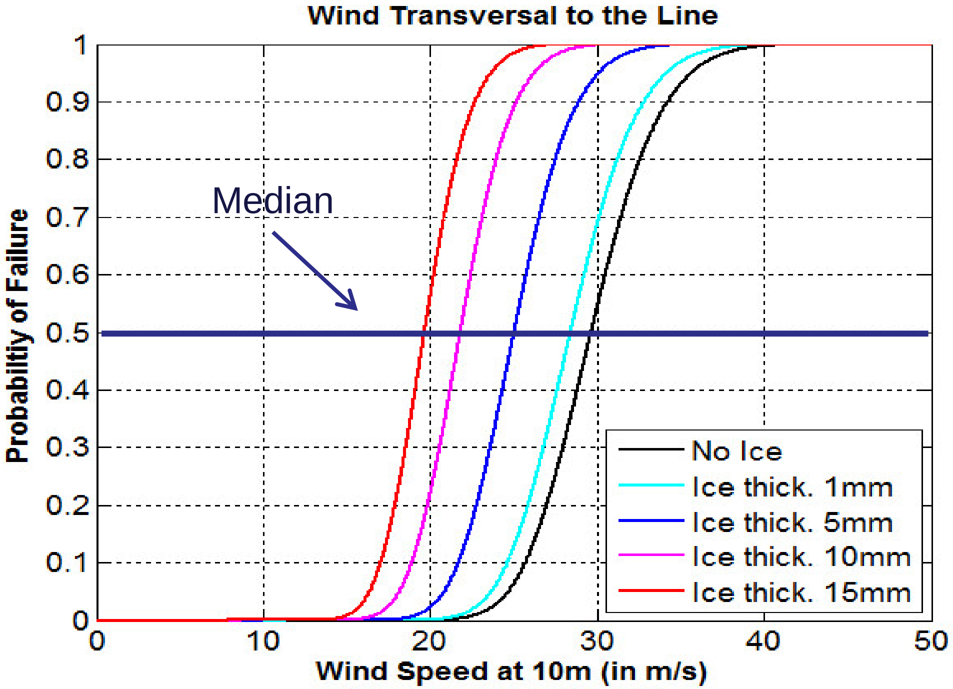
Probabilistic Assessment of Fragility

- ✓ Simulate a large number of timeseries of wind speed for specific mean values lying in a interval (e.g. 15 – 35 m/s) with a specific step (e.g. 1.0 m/s) in TurbSim
- ✓ Estimate the corresponding wind forces on the tower and the conductors for the various ice thicknesses and wind angles of attack
- ✓ Perform the dynamic analysis in OpenSees for each of the timeseries
- ✓ Estimate the Engineering Demand Parameter (EDP) of failure, e.g. max top displacement in the transverse direction for each timeseries
- ✓ Based on the OpenSees results estimate the number of failures for each wind speed and thus the corresponding probability of failure
- ✓ Estimate the fragility curve

Suspension Tower's Fragility



- Provides the probability of failure against wind speed
- Lognormal distribution assumed
- One fragility curve per each combination of wind speed, angle of attack and ice thickness
- As ice thickness increases the median wind speed of failure decreases

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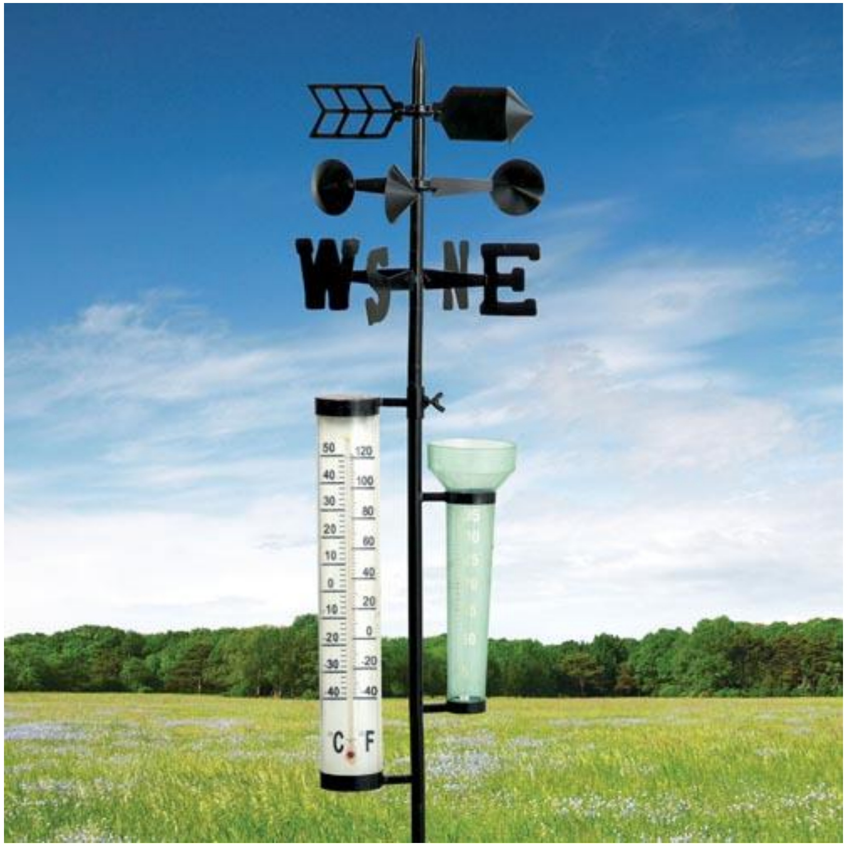
Hazard Estimation

- ❖ Probability of occurrence of combinations of wind and ice conditions
- ❖ Meteorological Data from Weather Stations
  - Wind Speed
  - Temperature
  - Precipitation Rate
- ❖ Estimation of the wind speed distribution
  - Based on measured data from weather stations
- ❖ Estimation of the ice thickness distribution
  - Based on an empirical model (Jones 1998)



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Hazard Estimation

- Hazard depends on the site of installation

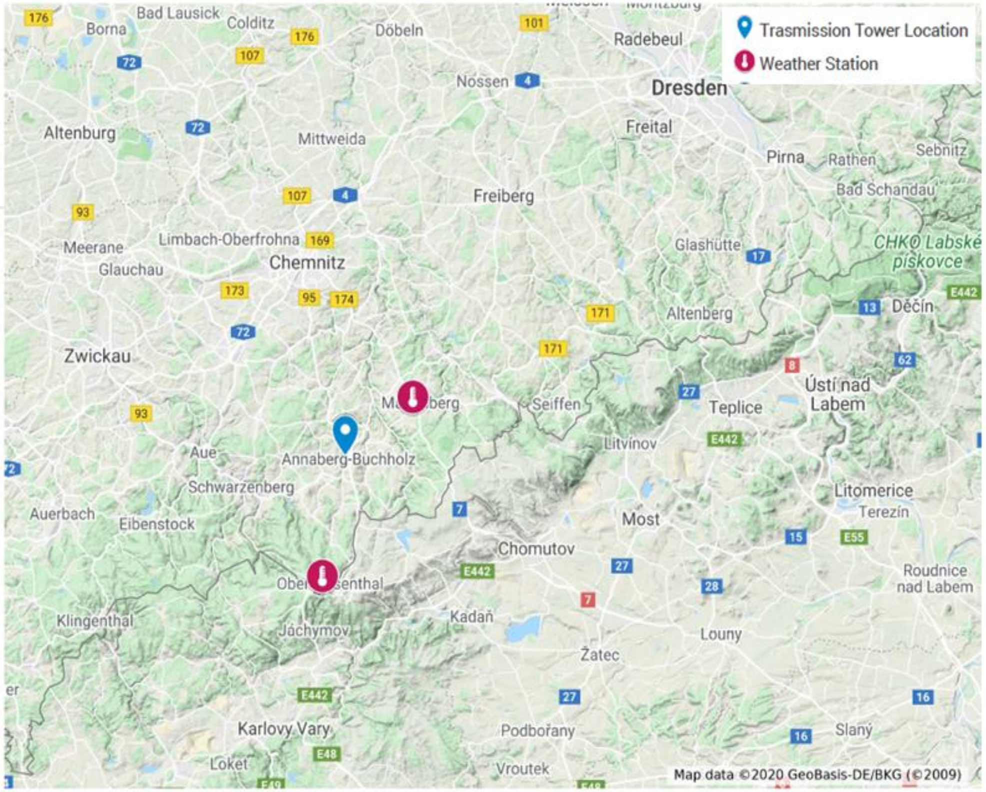
- **Potential Tower Sites :**
  1)Marienberg

  Period of Data: 1/9/1995 - 31/12/2018

  2)Fichtelberg

  Period of Data: 1/9/1995 - 31/12/2019

- Same Basic Wind Speed (25 m/s) according to the German National Annex of EN 50341-1:2012



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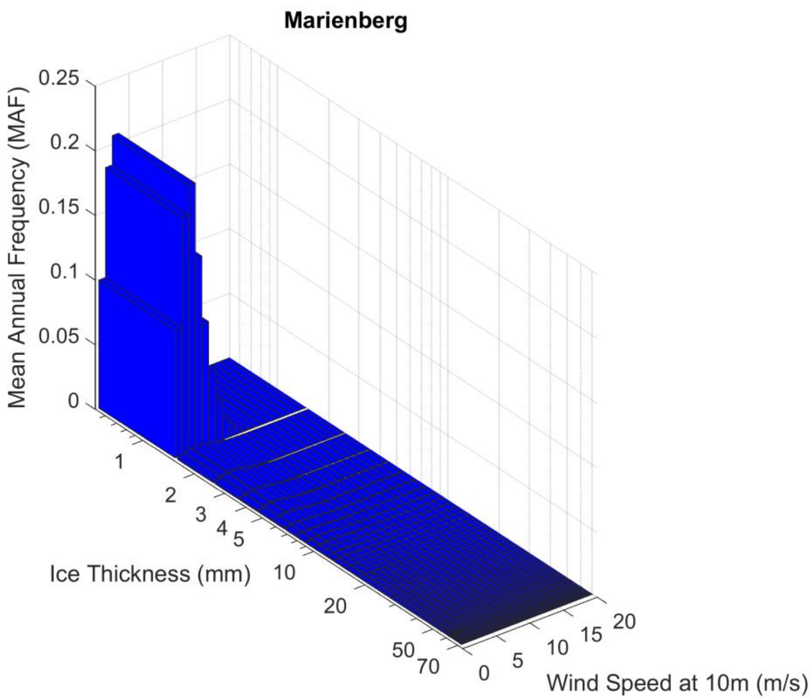
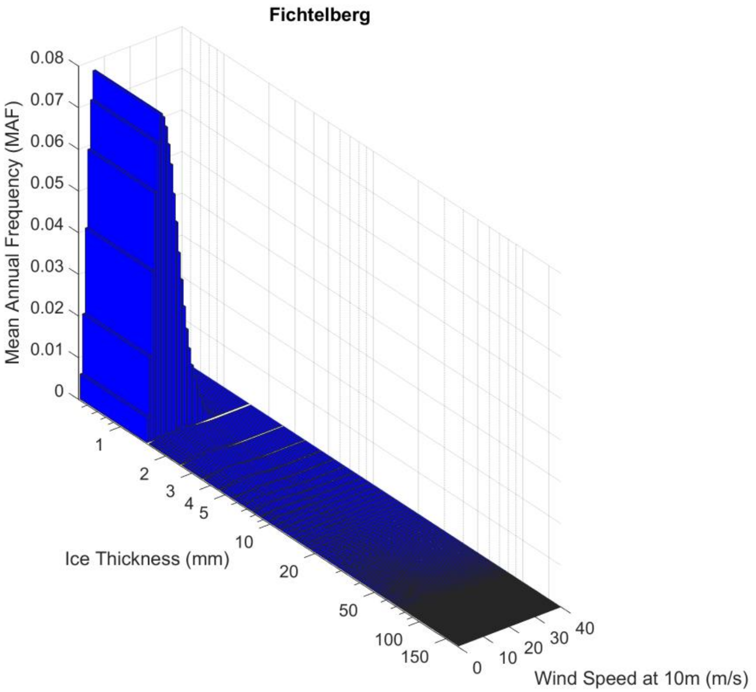
Joint Wind Speed and Ice Thickness Distribution





<u>Note:</u>

- More adverse weather conditions are expected in Fichtelberg

Risk Estimation

- **Fragility function:** Probability of failure (structure-specific)
- **Hazard:** Probability of occurrence of wind speed and ice thickness combinations (site-specific)
- **Risk:** probability of failure during the tower's service life
- **Risk estimation:** Integrate fragility function with hazard:

$$\lambda = \int_{U=0}^{+\infty} \int_{R_{eq}=0}^{+\infty} P\left(D > C | U, R_{eq}\right) f\left(U, R_{eq}\right) \, \mathrm{d}U \, \mathrm{d}R_{eq}$$

Where:
λ: is the (annualized) probability of failure
$P\left(D > C | U, R_{eq}\right)$: is the probability of failure for a given combination of wind speed U and ice thickness R_{eq} (fragility)
$f\left(U, R_{eq}\right)$: probability of occurrence of the combination of wind speed U and ice thickness R_{eq} (hazard)

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Risk Estimation Results

❖ Marienberg:

Annualized Probability of Failure: $\lambda = 0.0030\ yr^{-1}$

Return Period: $\frac{1}{\lambda} = \frac{1}{0.0030} = 333.25\ yrs$

❖ Fichtelberg:

Annualized Probability of Failure: $\lambda = 0.0481\ yr^{-1}$

Return Period: $\frac{1}{\lambda} = \frac{1}{0.0481} = 20.79\ yrs$

Note:

Same tower assumed in both locations, despite stronger winds at Fichtelberg

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