Asset Level Modelling of RISKs In the Face of Climate Induced Extreme Events and ADAPTation (RISKADAPT)

Risk assessment of power transmission towers of a Nordic Region under wind and icing (Pilot 2 of RISKADAPT)

Workshop on “Risk assessment of structures under Climate Change ”

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RISKADAPT
Modeling of Risks and Adaptation

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Pilot 2 of RISKADAPT project

Objectives:

- Assess the risk of a power transmission line in a Nordic climate
- Investigate the potential use of adaptation measures such as carbon Fiber-Reinforced Plastic plates or High Strength Steel
- Evaluate engineering and social risks and impacts

Risk of a Structure

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

- **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– **Structure-Specific**

- **Hazard:** Probability of occurrence of the intensity measure(s) – **Site-Specific**

Line Description

Power Line:

110 kV Kontiolahti - Uimaharju line

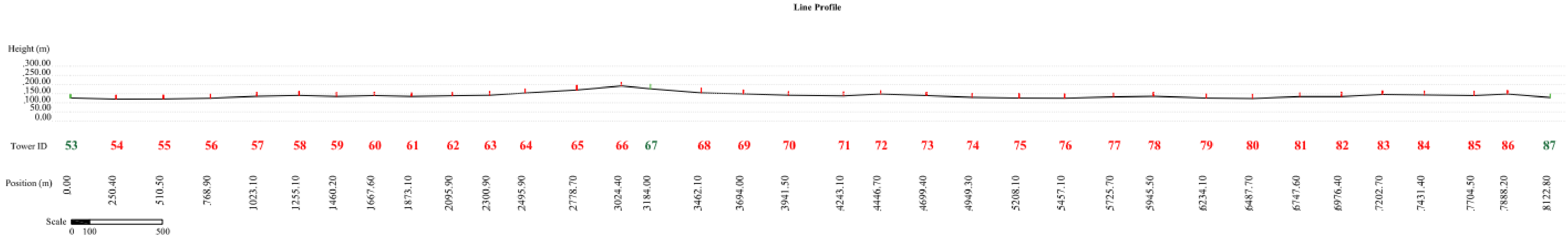
Total Length (m): 8122.7 m (~8 Km)

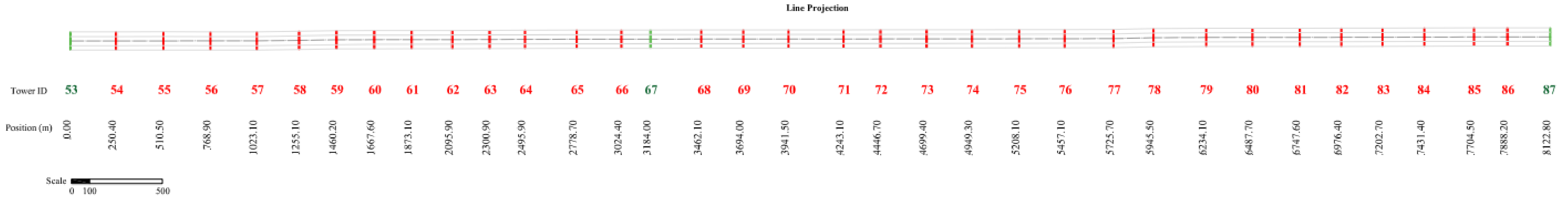
Location: East Finland

Climate Hazards:

a) Extreme Wind Speed
b) Icing accretion
c) Combination of (a) and (b)

Line Characteristics





Towers:

- 35 towers
- 32 suspension/support towers
- 3 tension towers

Line:

- It can be considered as straight
- Even level assumption – No difference in heights between adjacent towers

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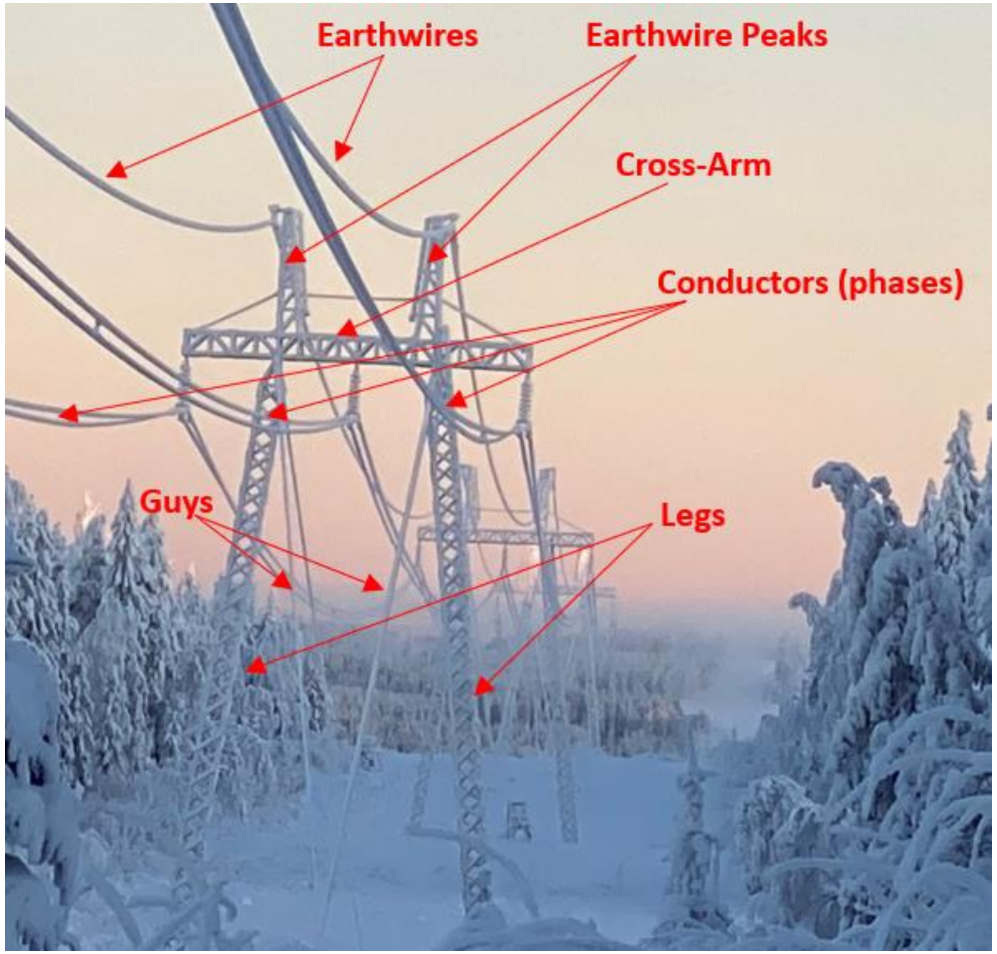
Line Configuration



- **Towers:** Guyed portal towers (up to 24m height)
- **Phases:** 3 phases of 2-bundled conductors
- **Earthwires:** 2 slightly different earthwires
- **Guys:** Each tower is supported by 4 pretensed guys
- **Span:** Ruling span = 246 m

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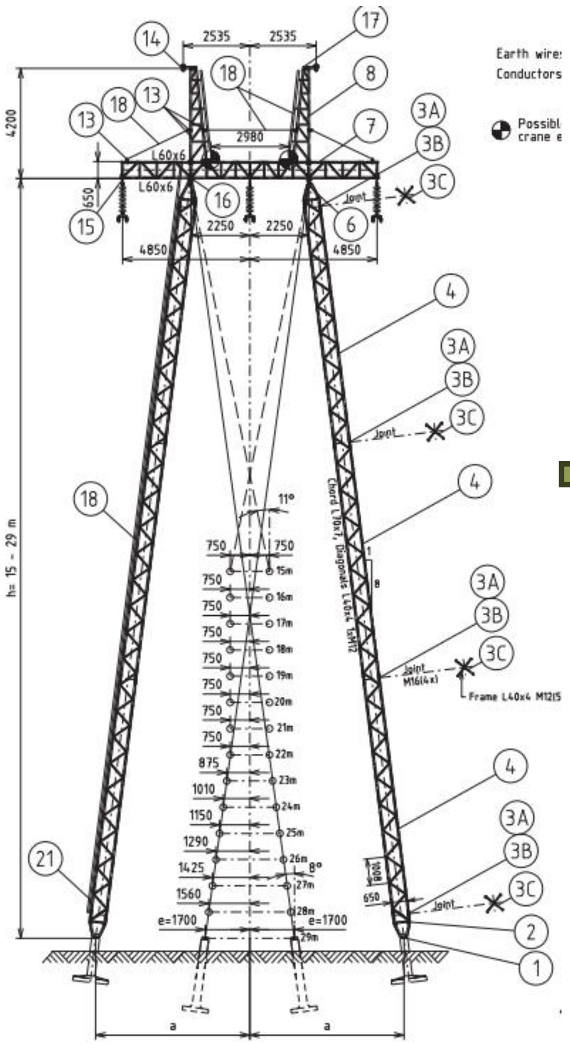
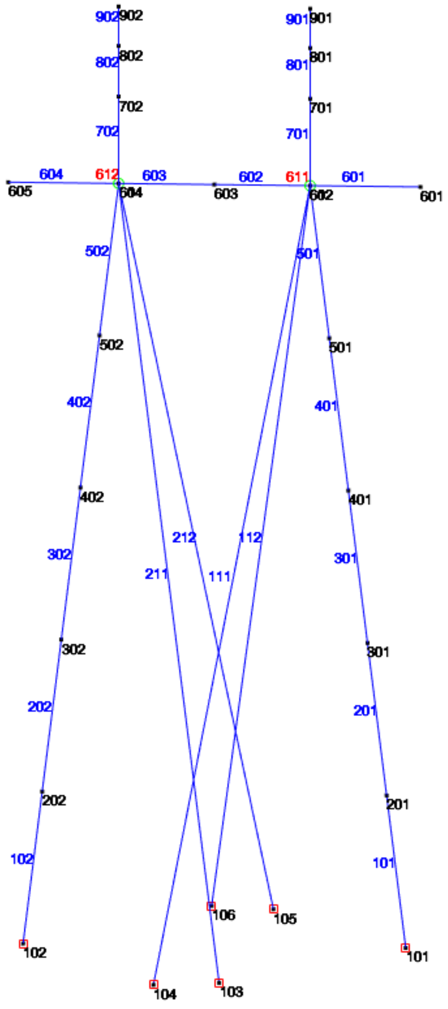
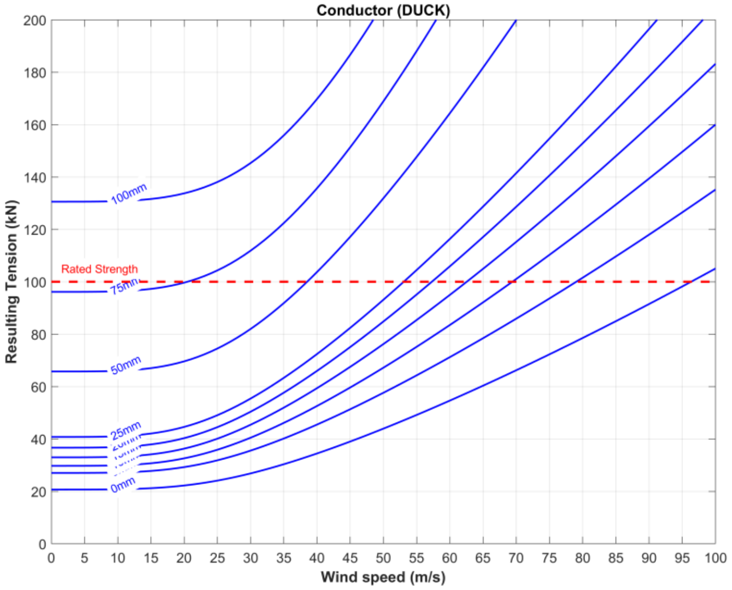
Tower Analyzed

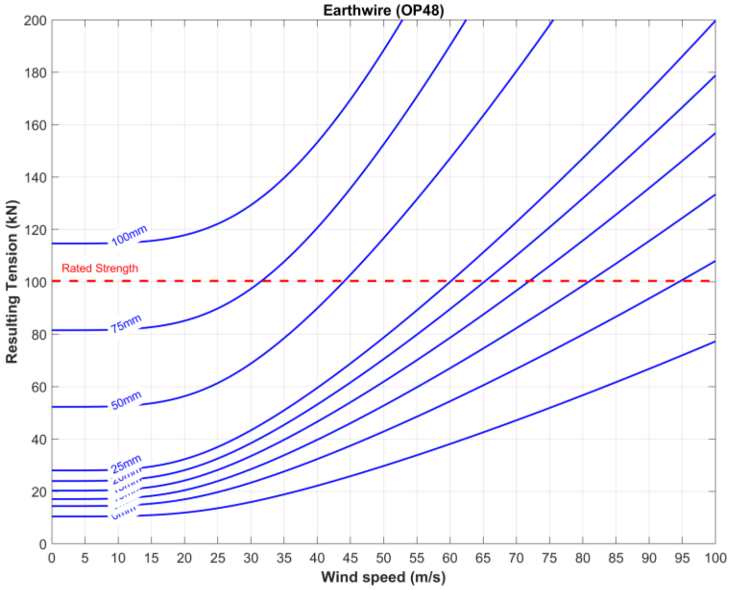
- **Type:** Support Tower
- **Height (h):** 18m (it is the most used in the selected line section)
- **Modeling Software:** OpenSees
- Simplified model – reduce computational cost
- The trusses were modelled as built-up members as per EC3

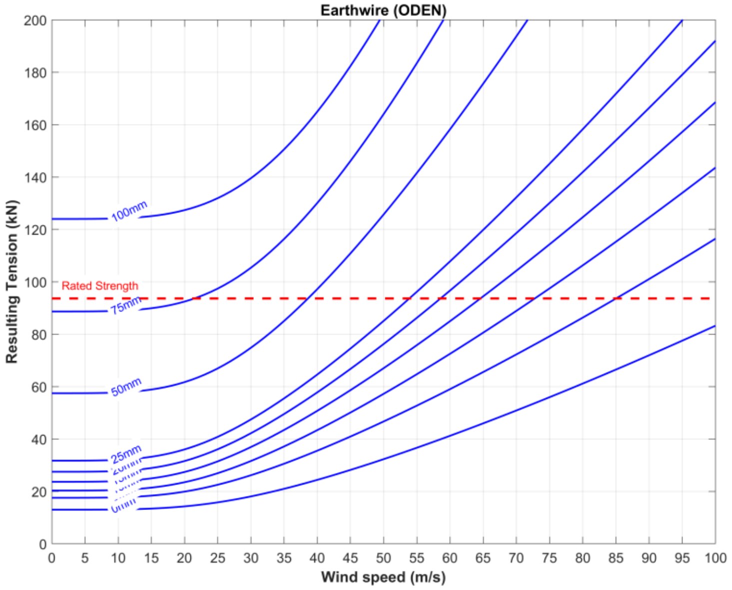




Conductor’s & Earthwire Strength







- The tension of conductors/earthwires were estimated for various combinations of wind speed & icing thickness assuming a catenary curve
- All the conductors/earthwires can sustain up to 75-80 mm of ice before reaching their rated strength
- For icing scenarios >75 mm, we consider that the tower has failed due to unbalanced load caused by broken conductors and/or earthwires

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Tower Versions Considered

- **Initial tower:** “as-built” or according to initial design specifications (steel class S355)

- **Corroded Tower:** considering a loss of 0.5mm per side in each cross-section

- **Adaptation Options:**
  I. Strengthening the angles L70x7 of the legs of the corroded tower with **FRP plates:**
     a) **Single strengthening:** apply carbon FRP S512 (50mm x 1.2mm) plates only externally
     b) **Double strengthening:** apply carbon FRP S512 (50mm x 1.2mm) plates both externally & internally
  II. Replace the (corroded) tower with a new one **made by HSS** of class **S460**:
     a) **Scenario 1:** All L70x7 angles of the initial are now made by L65x6 & all L60x6 by L50x5
     b) **Scenario 2:** All L70x7 angles are now made by L60x6, all L60x6 by L50x5 and all L50x5 by L40x4
     c) **Scenario 3:** Same as Scenario 2 but all L70x7 angles are now made by L55x5

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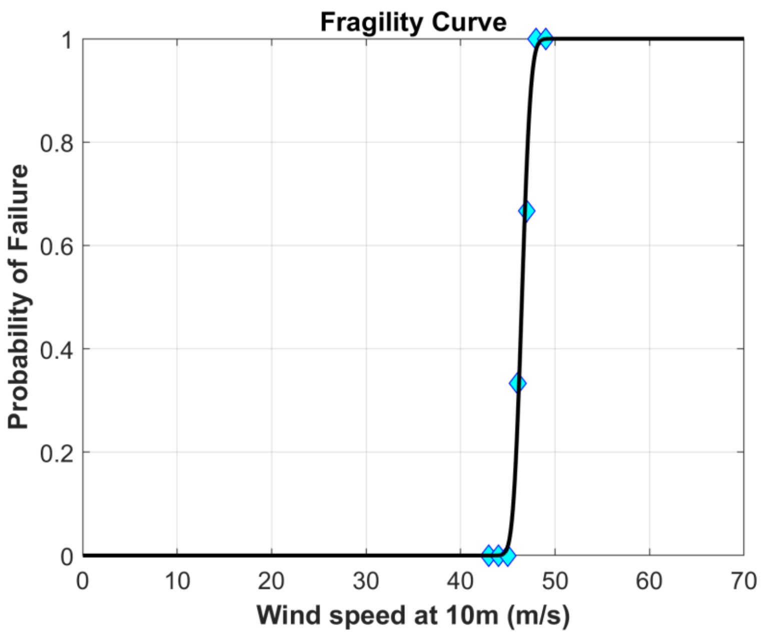
Fragility Estimation

- Multiple **non-linear dynamic analyses** were performed for various combinations of wind speed and ice thickness
- Ice thickness scenarios: 0mm, 25mm, 50mm, 75mm (in some cases the tower could not sustain 75mm of thickness)
- Linear interpolation will be used for intermediate values of ice thickness in the risk analysis
- Wind direction was considered always perpedicular to the line (worst-case) for simplicity
- The probability of failure for each combination of wind speed and ice thickness was estimated
- A fragility curve was developed by lognormal fitting on the probabilities of failure
- The **process repeated for the 7 tower versions** considered: 1 initial, 1 corroded, 2 FRP strengthened and 3 HSS



Lognormal Function

$$P(D > C|u, t_{ice}) = \Phi\left(\frac{ln(x/u_{50})}{\beta}\right)$$

u_{50}: median wind speed of failure
β: dispersion

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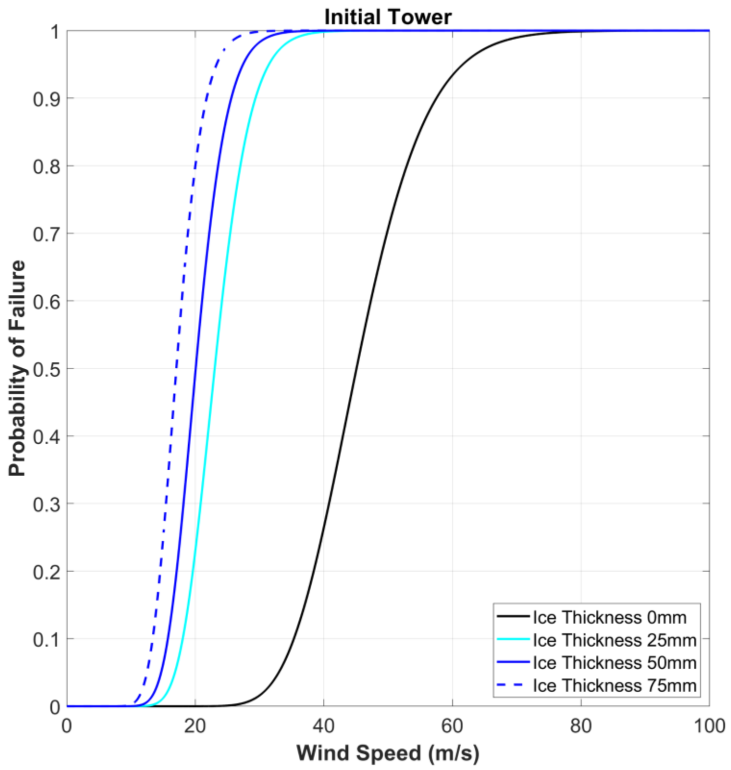
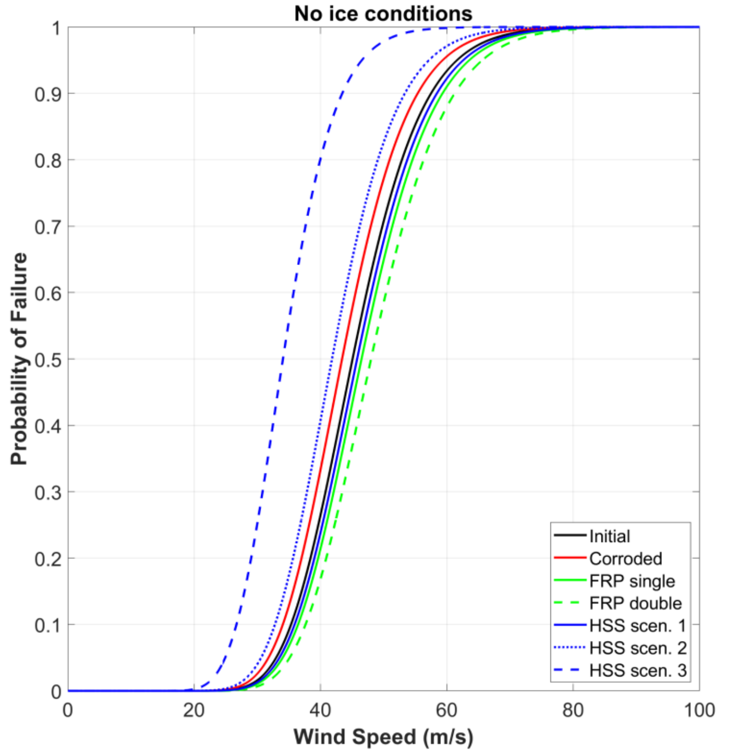
Fragility Results





- **Probability of failure** for the same wind speed **increases as ice thickness increases**
- The **different adaptation options** result in different wind speeds of failure => **different fragility curves**

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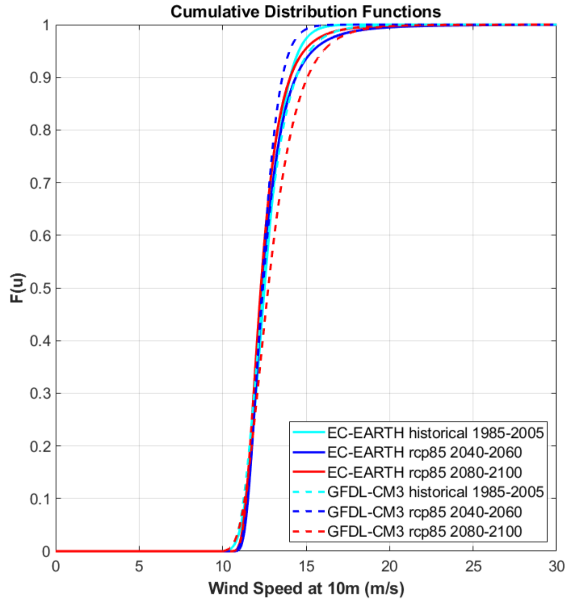
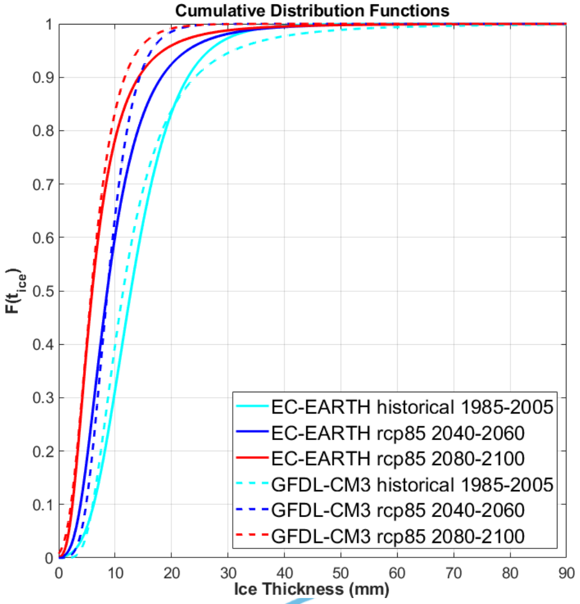
Hazard

- Hazard was assessed based on data provided by FMI
- **Six climatic models** were considered over different past and future periods
- **Generalized Extreme Value (GEV)** Distributions were assumed for wind speed and ice thickness

Model	Period	GEV Parameters: Wind Speed μ	σ	ξ	Ice Thickness μ	σ	ξ
EC-EARTH	1985-2005	12.17	0.925	-0.095	40.80	5.475	-0.016
EC-EARTH rcp85	2040-2060	12.11	0.778	0.224	37.06	4.091	0.166
EC-EARTH rcp85	2080-2100	12.00	0.760	0.156	34.75	3.081	0.259
GFDL-CM3	1985-2005	12.08	0.990	0.041	39.60	4.744	0.262
GFDL-CM3 rcp85	2040-2060	12.11	0.696	-0.057	37.50	3.128	-0.025
GFDL-CM3 rcp85	2080-2100	12.30	1.179	0.041	34.67	3.029	0.028





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Risk Estimation

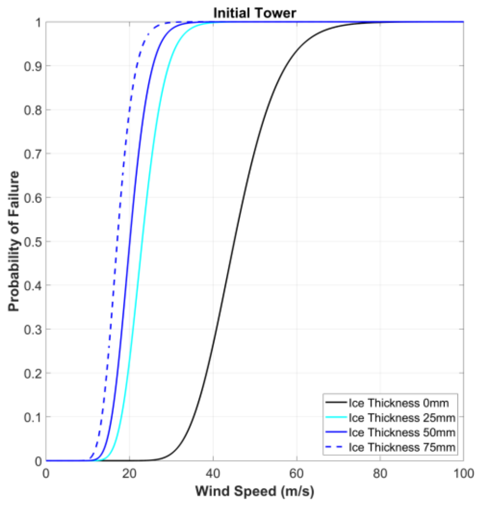
- For **each tower version** and **climatic model** the corresponding **risk** was estimated
- Expressed in terms of **annual probability of failure** and the **corresponding return periods**

$$P_{f,annual} = \sum_{i=1}^{N_{t_{ice}}} \sum_{j=1}^{N_u} P(D > C|u, tice) \cdot f(u) \cdot f(t_{ice}) \cdot \Delta u \cdot \Delta t_{ice}$$

where:
$P(D > C|u, tice)$: probability of failure given u and t_{ice} (fragility)
$f(u), f(t_{ice})$: pdf of u and t_{ice} (hazard)

- **Return Period:**

$$T_r = 1/P_{f,annual}$$



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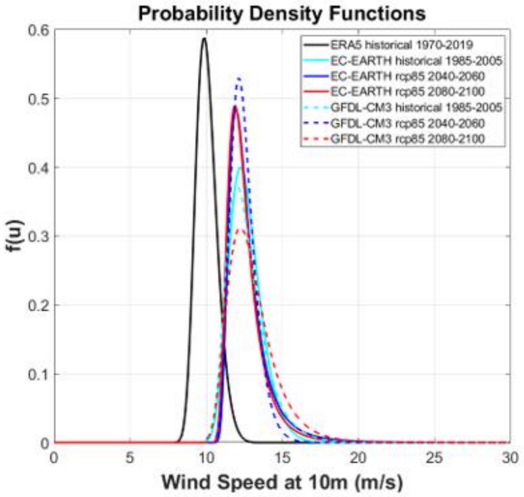

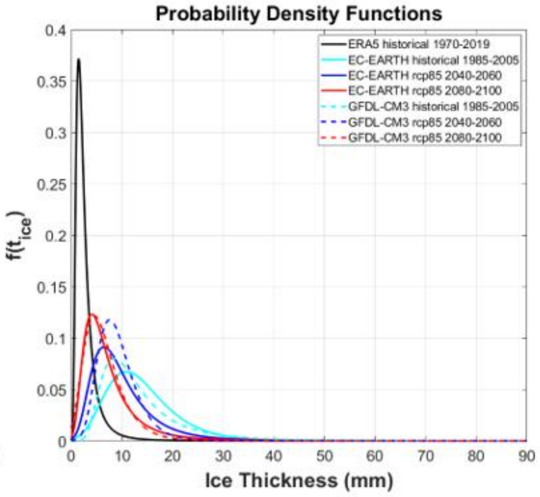

→ **Annual Probability of Failure ($P_{f,annual}$)**

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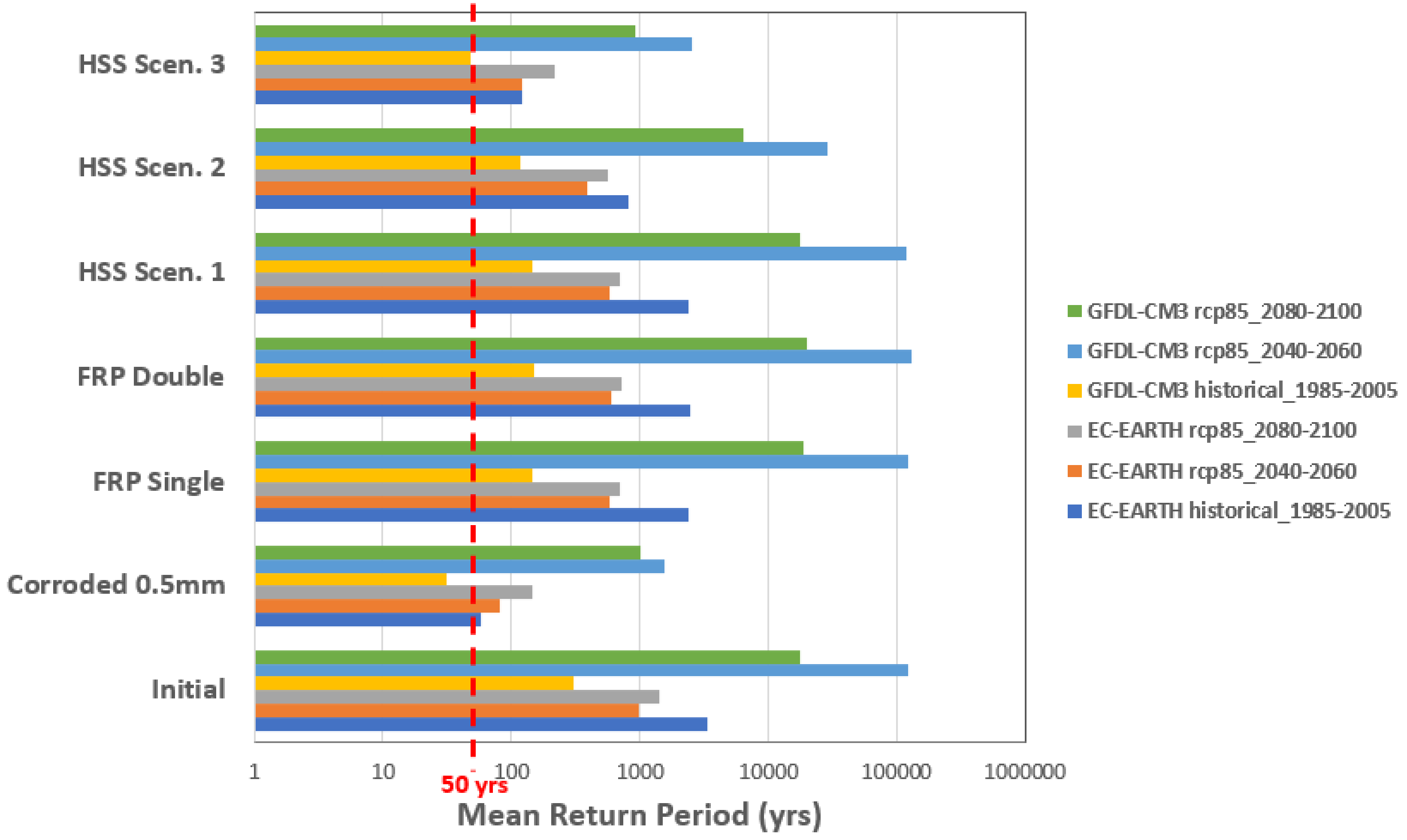
Risk Results



- **Tr = 50 yrs** is the accepted (design value) return period
- The results **are sensitive to the climate model selected** and
- EC - EARTH model seems to be more conservative than GFDL-CM3 when future periods are considered

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Pilot 2 Outcomes

- The corroded tower (as expected) shows greater probability of failure and shorter return periods than all the other towers in all climate scenarios. – although in most climate scenarios the return periods are accepted
- Some climate scenarios show that the risk of failure might be decreased in future years, a fact that could be attributed to the lower icing loads that are expected due to temperature rise – **CC may have a positive effect in this case!**
- Large variability in resulting risk between various climatic models – caution is needed
- All the adaptation options achieve restoration to the performance of the initial tower
- FRP scenarios achieve performance close or even better than the initial tower
- HSS scenario 1 shows risk results similar to the initial tower although uses 11.28% less steel
- HSS scenarios 2, although it shows larger risk than the initial, it still has acceptable return periods, so it can be considered as a potential alternative option (cheaper than HSS scenario 1).
- The replacement of the corroded tower with one according to HSS scenario 3 may not lead to significant improvement – this option might not be efficient

THANK YOU!

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http://riskadapt.eu/

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