Comparison of ice accumulation on simplex and duplex conductors in parallel overhead transmission lines in Iceland.

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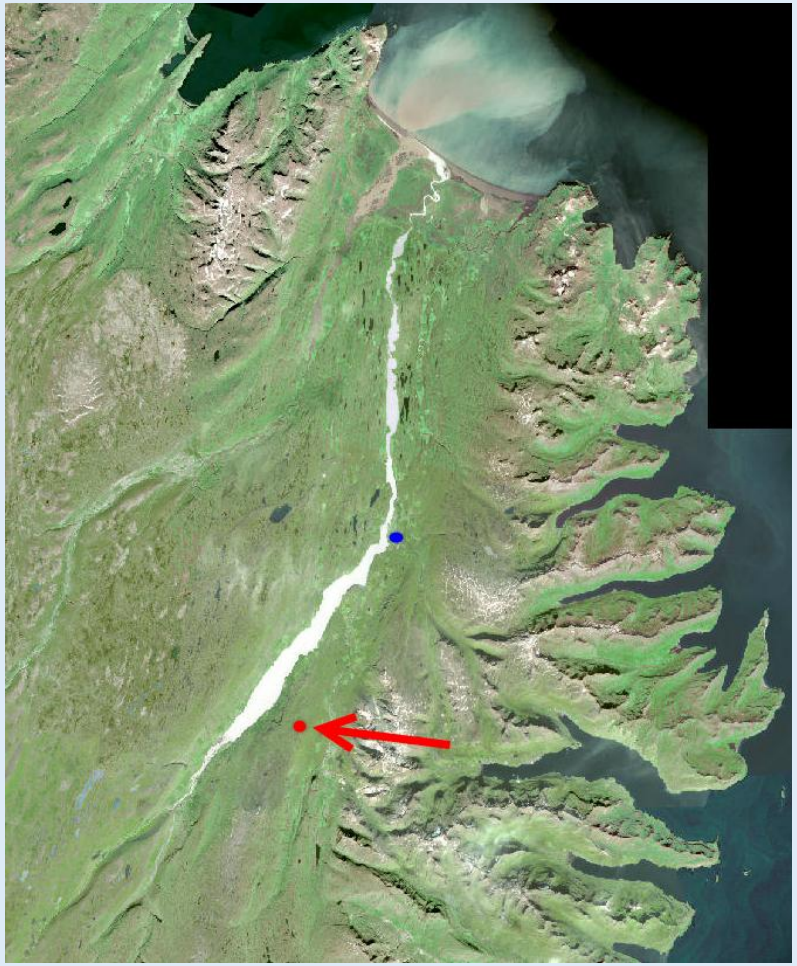
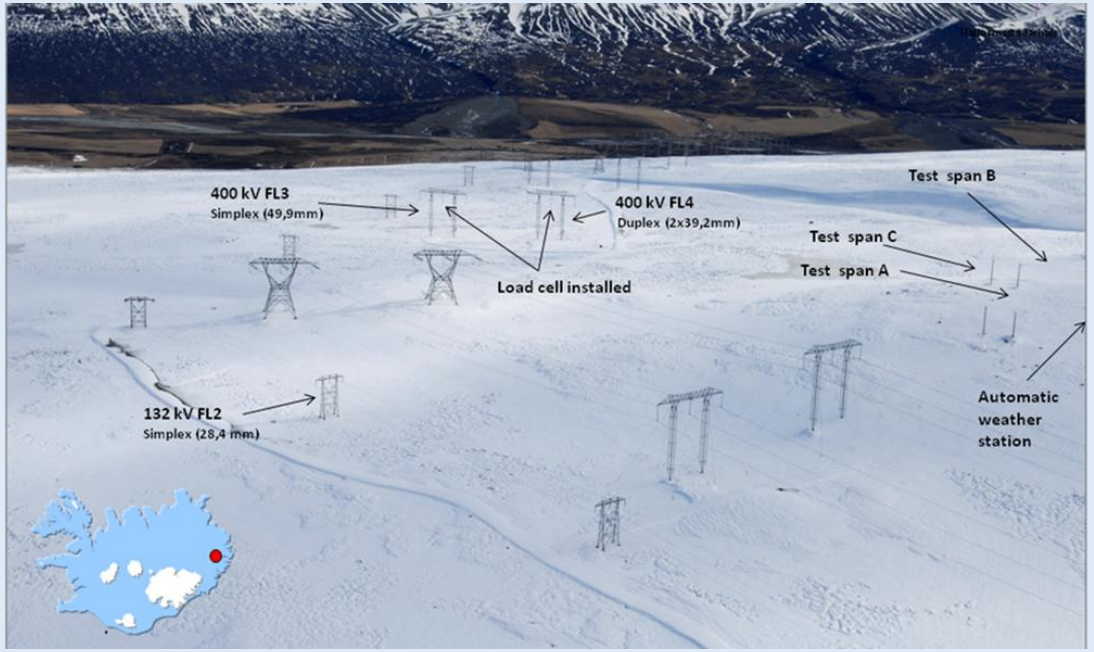
Measuring site



- Located on a ridge between two narrow valleys
- 65 km from the shore to NNE
- Unshielded against winds from NNE
- Mostly in-cloud icing, but wet snow icing occurs too



OHTL‘s characteristics

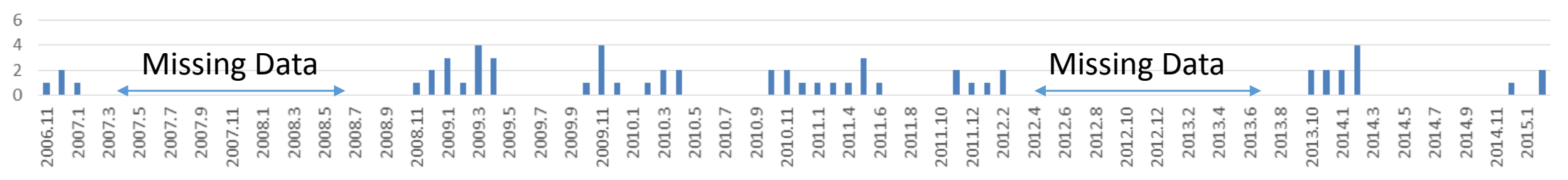
Parameter	*Unit*	*Austria 49.9 mm*	*AACSR 39.16 mm*
Diameter, d	[mm]	49.9	39.16
Cross section area, A	[mm^2]	1470.9	905.8
Modulus of elasticity, E	[N/mm^2]	70533	81099
Weight, g	[kg/m]	5.24	3.7
Tensile strength, Pu	[kN]	613	453
Temperature expansion coefficient, α_T	[$°C^{-1}$]	1.9 E-5	1.8 E-5
No wind and ice reading, $P_{LOAD\ CELL,0}$	[kg]	1452	1768

- Fljótsdalslína 3 OHTL is fitted with simplex Austria 49.9 mm Spans 205 and 192 m
- Fljótsdalslína 4 OHTL is fitted with duplex AACSR 39.2 mm Spans 175 and 192 m Subspans 30 – 46 m between spacers

Measuring equipment

- Load cells: CAT-1 Transmission Line Monitoring System – The Valley Group, Inc.
- Energized with in-feed from closest substation
- Data transfer to database by fiber optic cable
- Online camera

Data acquired

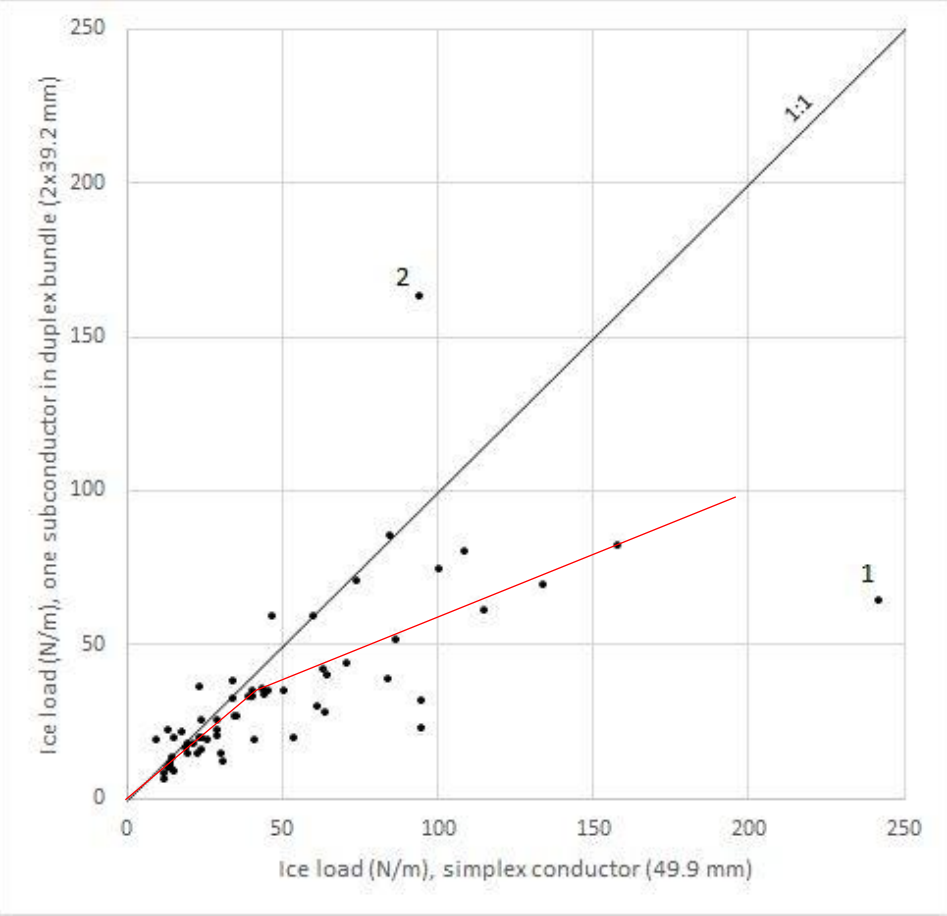


- Data was collected over 9 year period
- 2½ winters unusable (problems in measurements or communication)
- Temperature and load readings are taken every 5 minutes
- 61 well registered icing events observed
- Up to 242 N/m for simplex and up to 163 N/m for one in duplex were observed (100:67)

Wind effect

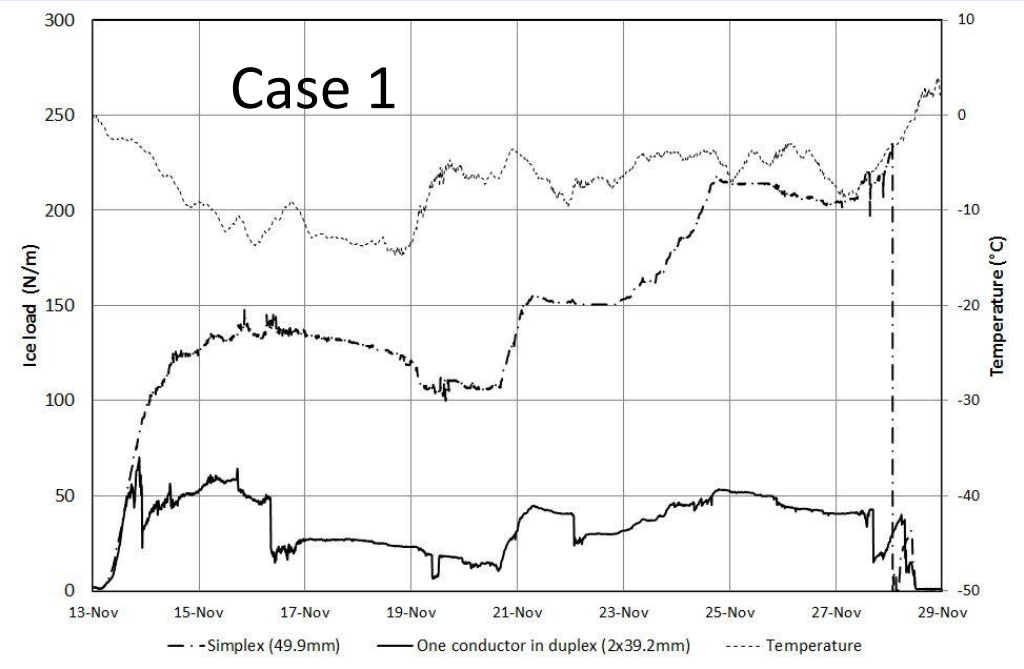
- Effect of wind on the readings was neglected in the analysis, thus the calculated ice load is a bit too high
- The effect was checked for 12 icing events (18 max-load points)
- 7 readings from the automatic weather station
- 11 readings from Egilsstaðir-airport weather station
- 10 min average wind 0 – 13.7 m/s
- Effect of wind < 1 N/m, (0.14 N/m on average).

Relationship between simplex and duplex

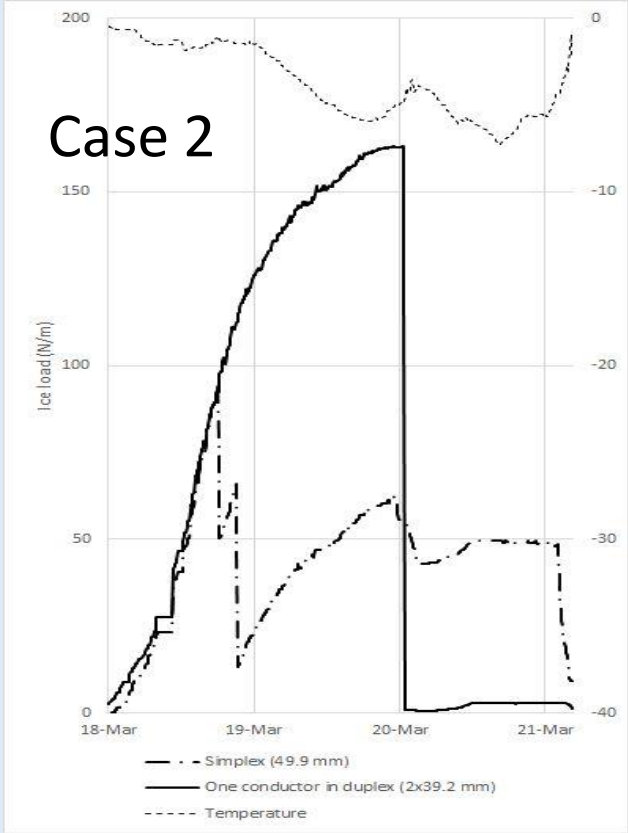


- Maximum ice load during icing event
- The maximum is not always at the same time for the two OHTL‘s
- In general the maximum is lower for one conductor in duplex
- Measurements are quite scattered
- Certain tendencies can be seen
- More observations in the higher load range needed to establish model

Maximum cases



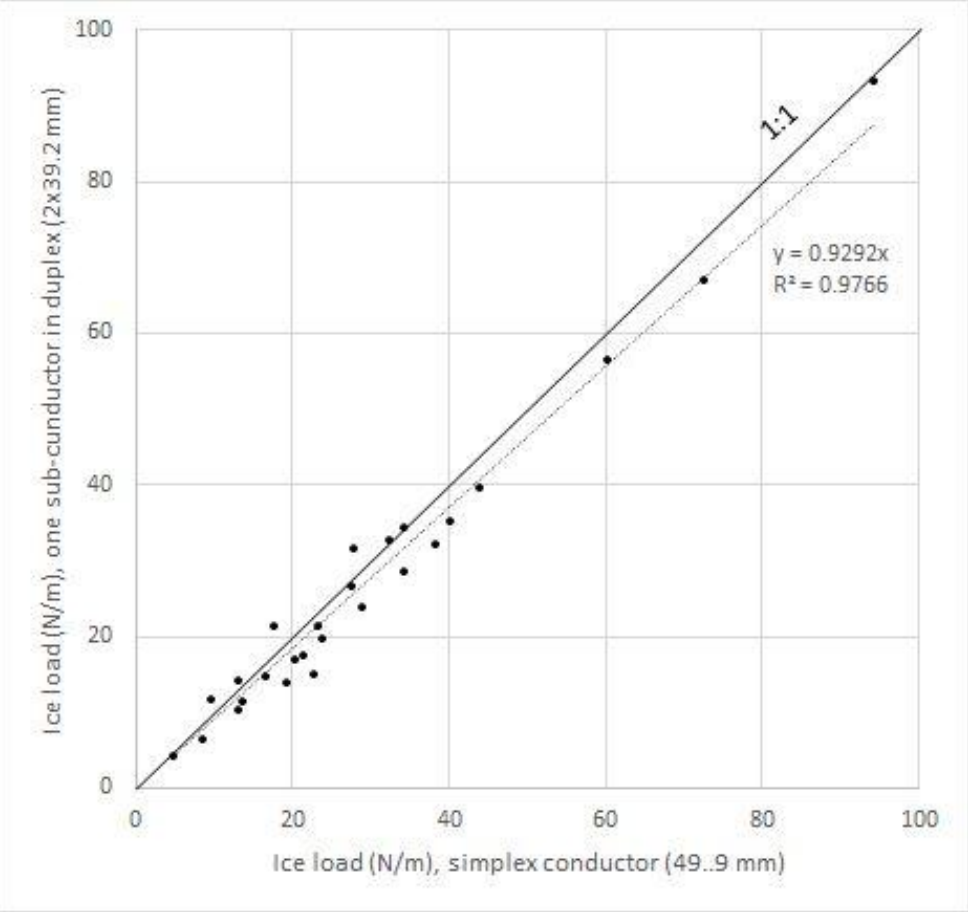
Form of the accumulation graphs shows that the accumulation is similar for duplex and simplex – just shifted downwards by the ice shedding



- 13-28 November 2006 – 16 days – before energizing
- Temperature: Begins just below 0°C, gradually lower during 3 days down to –14 °C. Raised a little – remained low –4 °C to –9 °C .
- Duplex: Ice shedding first after about one day, occurred again a few times
- Simplex: Ice shedding did not occur until at the end of the event

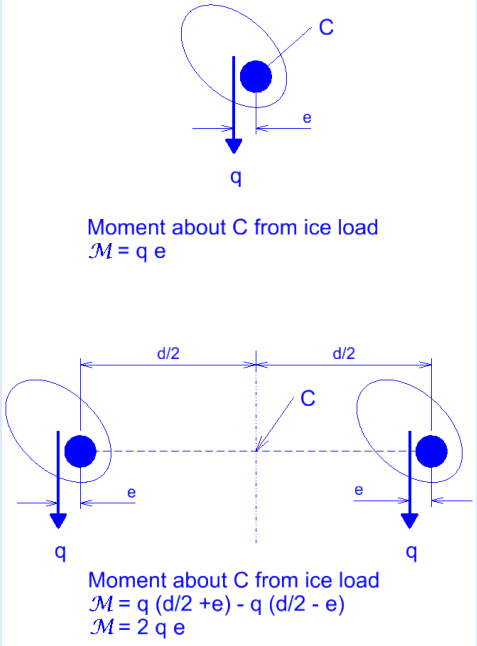
- 18-21 March 2010 – 4 days
- Temperature: Begins just below 0°C, gradually lower and remains at -2 °C for a day, then lowering down to -6 °C during the day after
- Duplex: Ice shedding first after a little less than two days, but no shedding until that time
- Simplex: Ice shedding first after approximately half a day

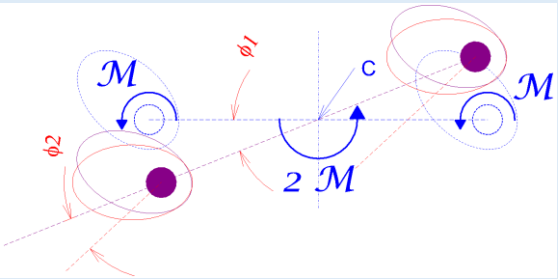
Undisturbed ice accumulation



- The icing events where ice accumulation was undisturbed
  - Up to the first ice shedding in either of the OHTL‘s
  - No obvious wind disturbances during the beginning of the icing process
- Ice accumulation is 7% less for one conductor in duplex

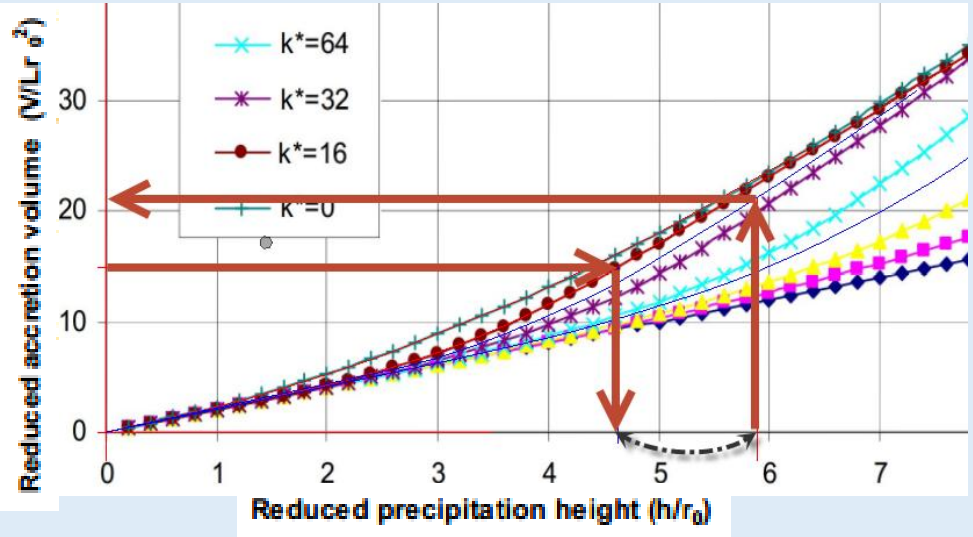
Torsional stiffness





- Theoretical model in:
  C. Hardy, A. Leblond and D. Gagnon, „Theoretical Assessment of Ice Loading of Cables as a Function of their Torsional Stiffness, IWAIS XI, Montreal, June 2005
- *Approximation to relate to the theoretical model:* $k_{eq} = 12GJ/L$
- *Precipitation at 45° angle*
- *Torsional stiffness for a bundle additionally involves effect of the conductor tension*
- *Effect of eccentric ice load on simplex and bundle of two*
- *Rotation of the bundle + rotation of the supspans*

Comparison to theoretical model

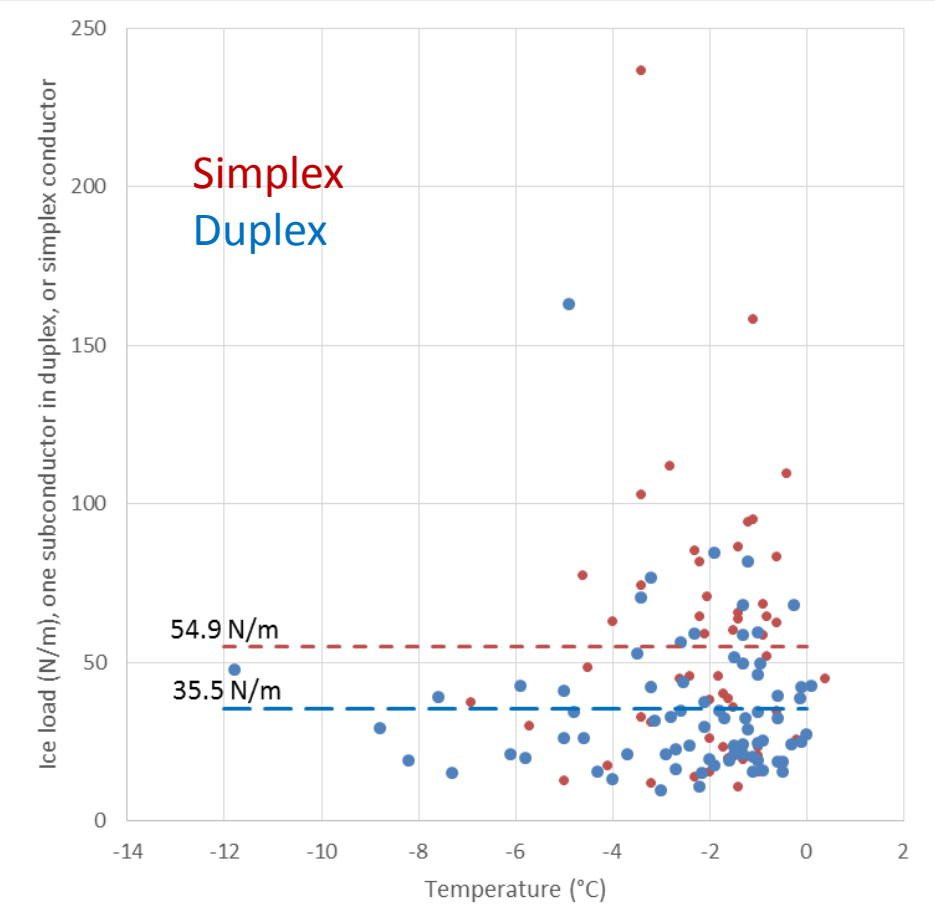


- Simplex k*=15, duplex k*=24
- Ice density 5400 N/m3
- Going out from 50 N/m on the simplex – reduced volume = 14.9
- Reading through the diagram gives reduced volume = 21.2 for the duplex – 43.7 N/m, i.e 87% of the load on the simplex
- Going to the k*=16 for both as if the torsional stiffness was the same gives ca 46.7 N/m – 93%, i. e. 7% less for the duplex. Is the difference just due to different diameters?
  No effect of torsional stiffness?

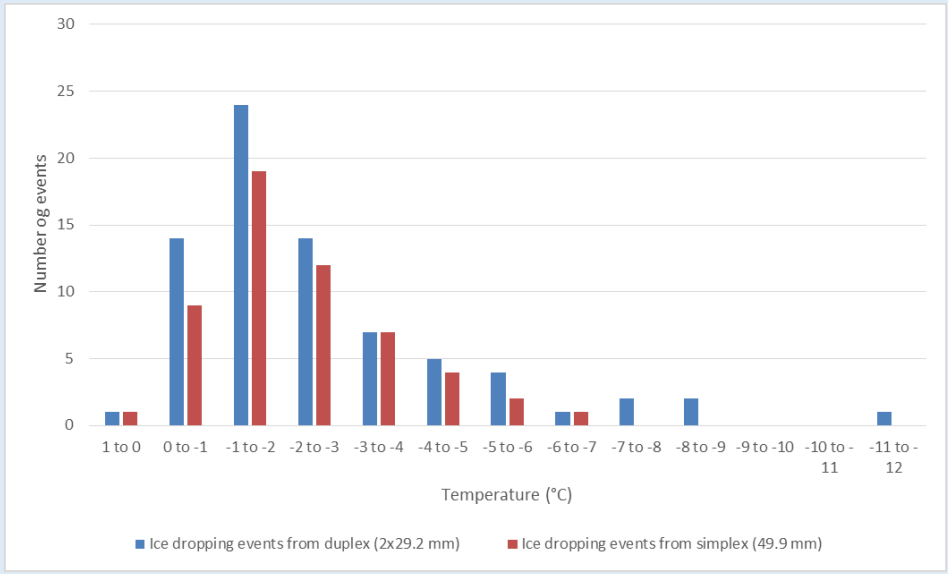
Theoretical torsional stiffness models versus reality

- Precipitation angle different from 45° - less moment
- The icing does not set on the conductors as a wing mostly on one side – less moment – may be the case for the in-cloud ice
- Torsional stiffness for the bundle system not correct – difficult to estimate

Effect of ice shedding



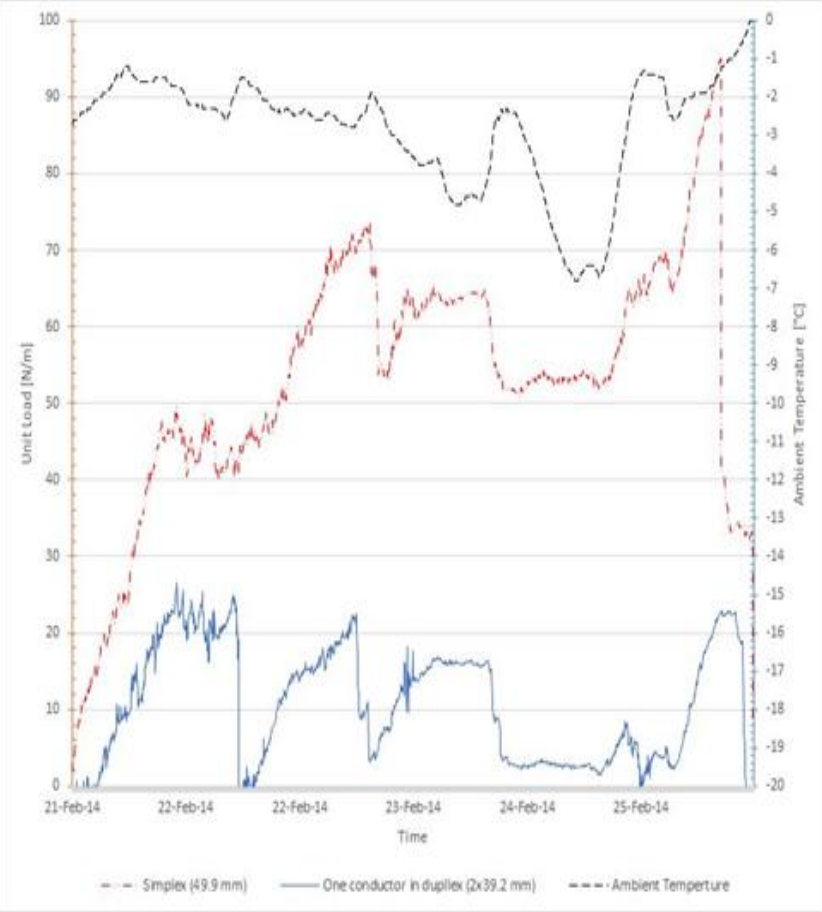
- On average the ice shedding starts at lower ice loads for the duplex
- Ice shedding is more frequent in case of the duplex
- Duplex 75 cases observed
- Simplex 55 cases observed



Reasons for ice shedding

- More wind motions of the duplex, hence dynamic forces
- Irregularities by the spacer may sometimes give weaknesses in the ice
- Relative motions in spacer connections cause ice to break off
- Energy considerations – ambient, solar, energy transfer
- Larger weak areas for duplex due to less rotation during icing – weaker ice coat on the leeward side

Temperature and energy considerations



- The icing event left shows that ice shedding happens when ambient temperature rises above -2.5°C to -2.0°C
- Possible reasons
  - Ambient temperature
  - Solar radiation may warn up the conductors, even through a coat of ice
  - Energy transfer of the OHTL's generates heat (6 W/m in each conductor in duplex, and 13.7 W/m in the simplex)
- If the conductors warm up the ice will at some point start melting and the bonds between ice and conductor become weak

Concluding remarks

- Undisturbed accumulation gave about 7% lower ice load on one in duplex compared with simplex in the Fljótsdalslína 3 and 4 OHTL´s
  - It could not be verified that this is due to difference in torsional stiffness
- Ice shedding, which lowers maximum loads for both simplex and duplex, has more effect on duplex
  - Is the main reason for lower loads on the duplex on average
  - Ice shedding is a complex unpredictable process affected by various reasons (ambient temperature, solar radiation, heat from energy transfer, wind loads, wind induced dynamic loads, irregularities by spacers or in ice formation)
  - One icing event (case 2) where duplex gets much greater ice load than simplex

Thank you for your attention !

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