# Field measurements of ice loads on different conductor sizes

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***Abstract*—Ice loads during the winters November 2005 to March 2007 have been determined for a range of different sized distribution conductors from 50mm² to 666mm² cross-sections at EA Technology's extreme-weather site on Deadwater Fell in the UK. Monitoring was carried out using load cells to measure conductor tension and time-lapse video recording for a visual indication of ice type and also visibility. Meteorological data was also measured. The data have been analysed with reference to the accretion models in the BSEN50341-3-9 and the UK ENATS 43-40 standards. For the rime-ice incidents, the magnitudes of the observed loads were in fairly good agreement with the predictions based on BSEN50341-3-9, but not with the significantly lower predictions based on ENATS 43-40. The results explain why high level lines in the UK have had little trouble with ice loads over the last 60 years – the ice is present but at a lower density and at lower wind speeds than standards predict. Size for size, the smooth conductors have accreted 11 to 17% more rime ice load based on conductor diameter only than their equivalent stranded conductors but similar loads in wet snow situations. For the wet snow incidents, the magnitudes of the observed loads were closer to the ENATS 43-40 predictions than those of BSEN50423-3-9, but the variation with conductor diameter was more like that predicted by BSEN50423-3-9, i.e. there is very little difference in accreted load between large and small conductors. This implies that smaller conductors are substantially more likely to be overloaded than larger conductors and that current standards assume insufficient loads on the smaller conductors. Considering wind only data, there is no significant difference between the wind effects on the smooth and stranded conductors.**

## I. Reason for work

The experimental work on ice accretion at the EA Technology Deadwater Fell test site provides data for ice accretion modeling under a European Union COST727 project.

## II. Introduction

New OH lines in the UK have to be designed to the CENELEC UK NNA BS EN 50341-3-9 and 50432–3-9 standards [3], [4]. These standards also have to be used when reconductoring old structures with larger conductors. However, the weather maps in BS EN 50431 are derived from BS 8100 [6], based on 14 years weather data of doubtful accuracy, especially at high altitudes. The figures for conductor icing, particularly at higher altitudes, appear to be excessive, based on the survival rate of the existing UK network. Monitoring of actual ice loads on a range of conductor sizes along with meteorological parameters would help validate new ice models. The scope of the project is to:

Measure ice accretion and ice loads on seven conductors at the Deadwater Fell test site [1]

Analyse the data and compare with various ice accretion models.

The objective is to refine and validate an ice accretion model to predict ice loads on different conductor types in the UK from meteorological data. The improved model will allow more accurate ice-loadings to be incorporated into future revisions of BS EN 50341 and 50423

## III. Conductors and Test site

### *A. Conductors*

The conductors selected specifically for this project comprised three different sizes of AAAC distribution conductor: Hazel (50mm² nominal), Oak (100mm²) and Ash (150mm²). Concurrent with this project, a similar project was being carried out for a conductor manufacturer using four large conductors (cross-sectional areas in range 260 to 666mm²), two of them stranded AAAC conductors (Aster) and two of them smooth compacted ACSR conductors (Azalee). Details of the conductors are given in Table 3.1.

TABLE 3. I
Conductor Details

| **Conductor** | **Size (mm²)** | **Diameter (mm)** | **Span length (m)** | **Erection tension (kN at 5°C)** |
|---|---|---|---|---|
| Hazel | 59.9 | 9.9 | 100 | 4.0 |
| Oak | 118.9 | 13.95 | 190 | 4.79 |
| Ash | 180.7 | 17.4 | 190 | 8.45 |
| Aster 228 | 227.8 | 19.6 | 190 | 14.76 |
| Azalee 261 | 261.0 | 19.6 | 190 | 16.41 |
| Aster 570 | 570.2 | 31.05 | 190 | 37.17 |
| Azalee 666 | 666.0 | 31.5 | 190 | 42.31 |

The layout of the seven conductors on the southern H-pole (looking south) is shown in Fig. 3.1.

### *B. Deadwater Fell Test site*

The Deadwater Fell site is situated at a height of 580m on an isolated, exposed hill top near the Scottish/English border, equidistant between the East and West coasts of the UK. It consists of a 190m test span with terminal H-poles, each supported by 14 stay wires (Fig. 3.1), with a single intermediate pole at 100m span length for the Hazel conductor. The test spans are orientated North-South and suffer from severe winds as well as ice incidents and blizzards. Load cells and video cameras are mounted on the southern H-pole platform to measure ice loads (Fig. 3.2), and a weather station is mounted nearby to monitor meteorological parameters. All the data are collected and stored at the site and down-loaded automatically via a mobile telephone to EA Technology at Capenhurst where they are analysed.

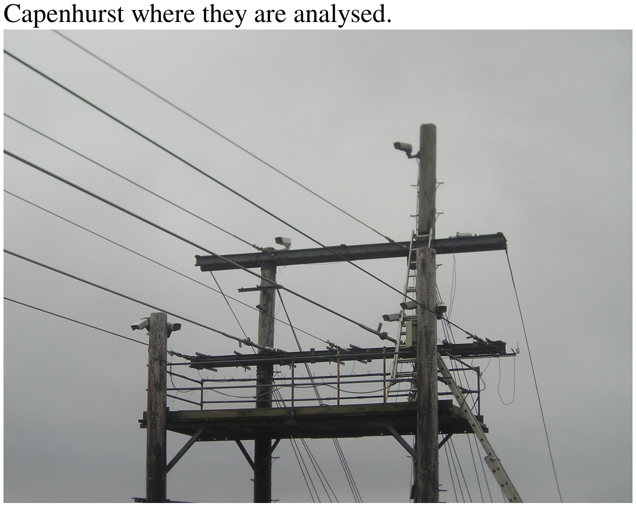

Fig. 3.1. The Southern H-pole on the Deadwater Fell test site.

Fig. 3.2. The video cameras and load cells on the Southern H-pole on the Deadwater Fell test site.

## IV. Analysis of Rime ice data

### A. *Ice loads and conductor diameter*

The heaviest rime ice loads of the winter occurred in December, 2006. This is shown against conductor diameter in Fig. 4.1 for each conductor. The response is essentially flat, showing that small conductors accrete as much load as larger conductors even though they are considerably weaker. The effect can be appreciated from a wet snow and rime ice period in January, 2007, which is plotted as load against percentage increase in conductor weight in Fig. 4.2. This shows that whatever the actual ice load, the percentage increase in tension for the smaller conductors is far greater then for the larger ones. At the highest loads in this episode, Hazel reaches a tension increase of 75% whilst the large Aster and Azalee conductors show increases of less than 10%. This is particularly relevant as Hazel should (under ENATS 43-40 2003) be treated as a wind only/no ice load.

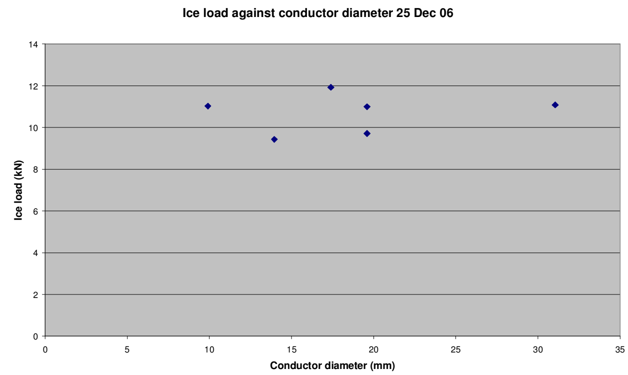


Fig 4.1 Conductor rime ice load against conductor diameter (Dec 2006)

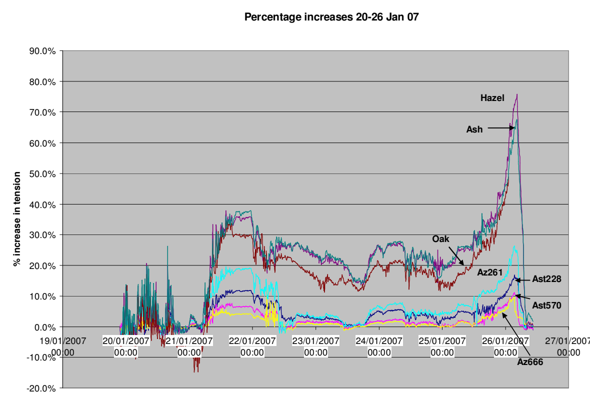


Fig.4.2 Percentage increases in tension for all conductors in January, 2007

### B. *Effect of conductor weight*

As the ice load in Fig. 4.1 shows a flat response compared with conductor diameter, it will obviously be very much higher for smaller, lighter conductors in relation to their weight/m. Fig. 4.3 shows the ice load against conductor weight (in kg/m) for the rime ice data. The Y-axis is normalised to 1 for Hazel. The considerably lower effect of ice load on the heavier conductors is very apparent.

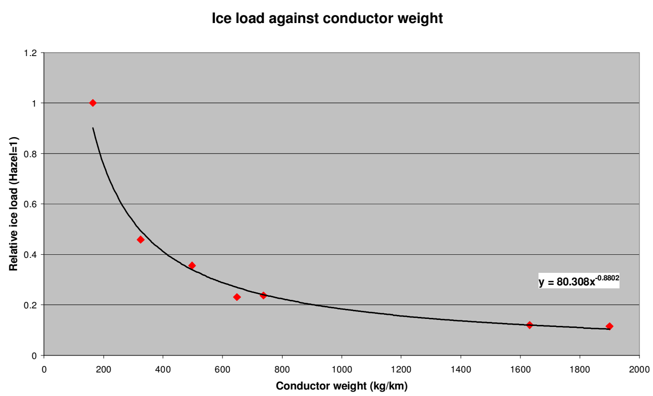


Fig.4.3 Ice load weight against conductor weight (kg/m) normalised to Hazel.

### *C. Rime ice thickness*

A comparison of the ice thickness against conductor diameter is given in Fig. 4.4. This has been calculated from the wind speed and load data and an ice density of 510kg/m³. Assuming a constant ice thickness would therefore underestimate the ice load on the small conductors and overestimate the ice loads on the larger conductors. This includes all the tested conductors, including the Azalee smooth conductors which both gave higher ice thickness than the equivalent stranded conductor.

Excluding the Azalee conductors, the relationship between radial rime ice thickness and conductor diameter is shown in Figure 4.6 and is given by:

Radial ice thickness = 38 x (Conductor diameter)$^{-0.44}$ or approximately ~ $40/\sqrt{D}$

where D is the conductor diameter. Overall wind speeds were only up to around 8 m/s in all the rime icing incidents. This is equal to a gust wind pressure of around 100N/m² and well below the UK standard of 570 N/m². So the wind contribution in all the icing incidents has been much lower than allowed for in the standards.

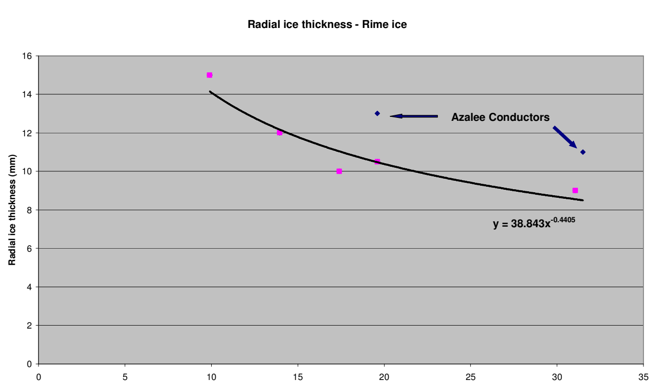


Fig. 4.4 Radial ice thickness against conductor diameter

### *D. Effect of stranding*

The two Azalee conductors have approximately the same diameter as the equivalent Aster conductors. Size for size, however, the smooth Azalee conductors accrete 11 to 17% more ice based on conductor diameter only. However, when allowance is made for the conductor weight, both sets of Aster/Azalee conductors accrete about the same amount. So the design stress would be the same for both conductor types based on a weight/metre basis.

## V. Analysis of Wet Snow Data

### *A. Ice loads and conductor diameter*

The mean snow loads are shown against conductor diameter in Fig. 5.1. The relationship is very similar to that for rime ice, the snow loads increasing slightly with conductor diameter. The two small Aster/Azalee conductors (19.6mm diameter) gave almost identical loads but the larger Azalee gave higher loads than the equivalent large Aster.

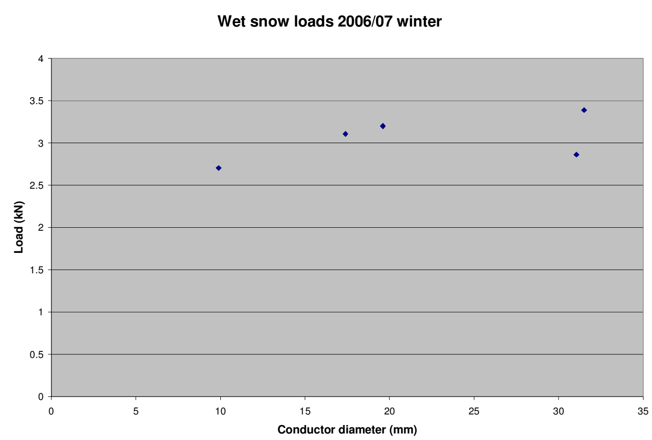


Fig. 5.1 Mean wet snow loads against conductor diameter for winter 2006/07

### *B. Effect of conductor weight*

The wet snow load against conductor weight is shown in Fig. 5.2. The data is again normalised to Hazel. The relationship is similar to that for rime ice with the load being dependent on (conductor weight)$^{-0.94}$ compared with a power of -0.88 for rime ice. As the overall number of incidents was quite small, it is likely that taking a simple inverse relationship would prove to be reasonably accurate in both cases, i.e.:

Ice load ~ K/(conductor weight)

Where K is a constant that may vary with ice type (rime ice, wet snow).

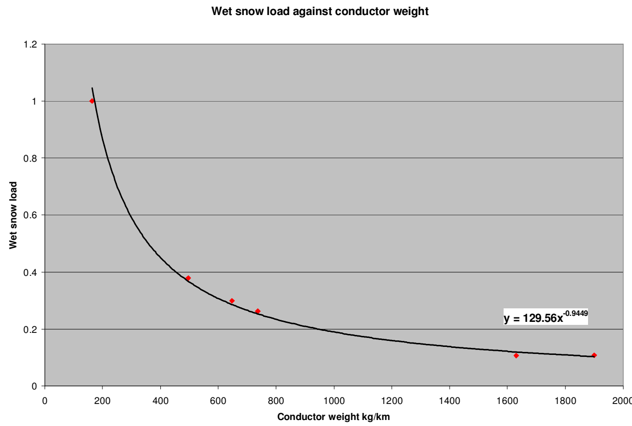


Fig. 5.2 Variation of wet snow load with conductor weight (normalized to Hazel)

### *C. Wet snow radial ice thickness*

A comparison of the (wet snow) ice thickness against conductor diameter is given in Fig. 5.3. This has been calculated from the wind speed and load data and an ice density of 850kg/m³ (from BSEN 50341-3-9). The lack of sufficient wet snow incidents and the very low loads mean that interpretation of the data is a little difficult. However, the three episodes all show a decreasing radial ice thickness with increasing conductor diameter. The three episodes were all at different wind speeds so this helps to support the general pattern. Assuming a constant ice thickness would therefore underestimate the ice load on the small conductors and overestimate the ice loads on the larger conductors. This includes all the tested conductors, including the Azalee smooth conductors which both gave higher ice thickness than the equivalent stranded conductor (see below).

The relationship between wet snow radial ice thickness and conductor diameter (D) is essentially linear, in contrast with the rime ice thickness which varies as ~ 1/√D. Wind speeds, though, were significantly higher (up to 17m/s) than in the rime ice incidents.

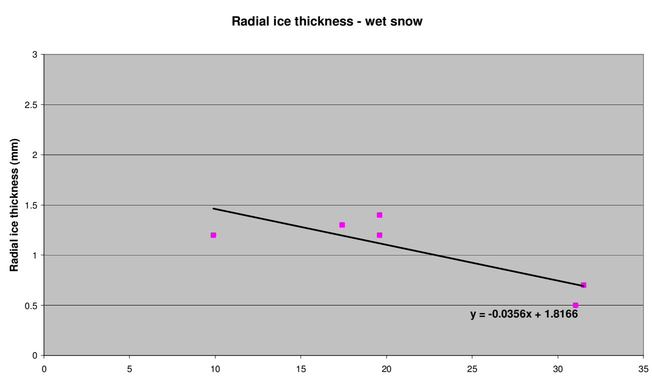


Fig. 5.3 Wet snow radial ice thickness against conductor diameter

### *D. Effect of stranding*

The snow loads on the pairs of smooth and compacted conductors (at 19mm and around 31mm diameter) were essentially very similar. There seems to be no difference between these types therefore for wet snow accretion. The actual loads, though, were very low and wind forces were a more significant factor than ice load. As the wind forces are dependent on conductor diameter, this is probably why the loads for similar size conductors of different structures are very similar.

## VI. Effect of Wind Only

Data on wind only, with no ice present, was determined from the data in order to see whether a smooth conductor surface does actually affect the wind loading. In order to look at wind speed only, data was taken for the windiest month (January, 2007) for temperatures above 2ºC. This means that no rime ice or wet snow would be present. Precipitation was not allowed. Fig. 6.1 shows the effect on the smaller pair of conductors – the stranded Aster 228 and the smooth Azalee 261 – both 19.6mm diameter but with the Azalee being 14% heavier. The increases in tension were obtained using temperature corrected data and the tension value at 1m/s (the lowest wind speed measured). Despite the scatter in the data, the only difference appears to be slightly higher loads on the stranded conductor but essentially there appears to be no significant difference between the conductors.

Fig. 6.2 shows the same wind data with the larger Aster 570 and Azalee 666 conductors. The Azalee is 17% heavier and strung at a higher tension that the Azalee. However, there is again very little to choose between the wind effects between the two conductors as in this case although the smooth Azalee appears to suffer a slightly higher wind load, it is actually slightly larger, being 31.5mm diameter as compared with 31.05 for the Aster conductor.

In summary, it is not considered that there is any significant difference between the wind effects on the two types of conductor.

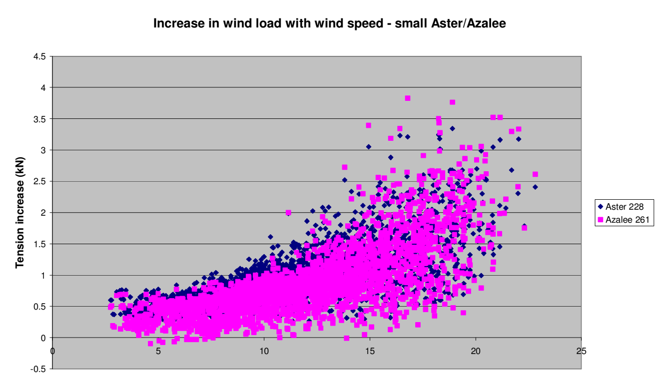


Fig. 6.1 Comparison of wind effects on small Aster and Azalee conductors

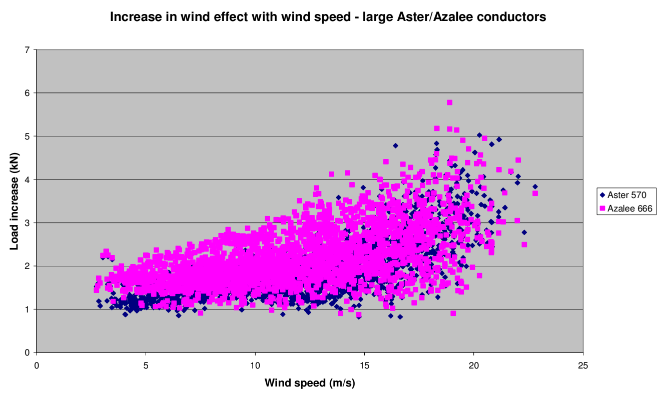


Fig. 6.2 Comparison of wind effects on large Aster and Azalee conductors

## VII. Conclusions

Small conductors accreted as much ice load as larger conductors even though they are considerably weaker. In the worst rime ice incident in the 2006-07 winter, Hazel reached a tension increase of 75% whilst the large Aster and Azalee conductors show increases of less than 10%.

The measured loads show a dependence of ice load on conductor diameter that is similar to UK standard ENATS 43-40 [5] although at a much lower magnitude. One reason for the lower magnitudes is that the wind speeds are far lower than allowed for in 43-40. This is because the situation is rime ice accumulation from water particles within clouds and not from blizzard wet snow conditions. It can certainly explain why high level lines in the UK have had little trouble with ice loads over the last 60 years – the ice is present but at a lower density and at lower wind speeds. This has implications for future line design for such lines. The wind contribution in all the icing incidents has been much lower than allowed for in the standards.

Assuming a constant ice thickness underestimates the ice load on the small conductors and overestimates the ice loads on the larger conductors.

Excluding the smooth Azalee conductors, the relationship between radial rime ice thickness and conductor diameter is approximately ~ $40/\sqrt{D}$ where D is the conductor diameter.

Size for size, the smooth Azalee conductors have accreted 11 to 17% more rime ice load based on conductor diameter only than their equivalent stranded Aster conductors. However, when allowance is made for the conductor weights, both sets of Aster/Azalee conductors accrete about the same amount.

The relationship between wet snow load and conductor diameter is very similar to that for rime ice, the snow loads increasing slightly with conductor diameter

The wet snow load against conductor weight again has a relationship similar to that for rime ice with the load being dependent on ~ K/(conductor weight) where K is a constant that may vary with ice type (rime ice, wet snow).

There is a tendency is for the wet snow load to increase with conductor diameter in a similar fashion ENATS 43-40. Wind speeds were closer to the standard of 570N/m² than in the rime ice incidents.

Wet snow radial ice thickness appears to decrease with increasing conductor diameter. Assuming a constant ice thickness would therefore underestimate the ice load on the small conductors and overestimate the ice loads on the larger conductors.

The relationship between wet snow radial ice thickness and conductor diameter (D) is essentially linear, in contrast with the rime ice thickness which varies as ~ $1/\sqrt{D}$.

The snow loads on the pairs of smooth and compacted conductors were essentially very similar indicating that there is no difference between these types for wet snow accretion.

Considering wind only data, there is no significant difference between the wind effects on the smooth and stranded conductors.

## VIII. Acknowledgment

This paper is based on an EA Technology report on work carried out for the UK utilities [2].

## IX. References

*Technical Reports:*

[1] Wareing J B, Bertinat M P, ‘Icing on seven distribution conductors at Deadwater Fell during Winter 2005/6’ EATL Report 5872, Sept 2006

[2] Wareing J B, ‘Validation of ice accretion models using Deadwater Fell data’ EATL Report 6053, July, 2007

*Standards:*

[3] BSEN50341-3-9 ‘Overhead lines exceeding 45kV’ UK National Normative Annex, 2001

[4] BS EN 50423-3:2005 "Overhead electrical lines exceeding AC 1 kV up to and including AC 45 kV. Set of national normative aspects", 9 UK National Normative Annex, 2005.

[5] ENATS 43-40 ‘Specification for Wood Pole Overhead Lines for use at high voltage up to and including 33kV’ Issue 2:2004

[6] BS 8100: Part 1 Lattice Towers and Masts: Part 1 Code of practice for loading