# Ice load measurements in test spans for 30 years

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***Abstract*— In this paper, the authors describe ice load measurements in test spans in Iceland which started 1972. From 1972, 84 test spans have been erected at 54 locations. Measuring methods are explained as well as the purpose of the measurements. Data from test spans where measurements have been taken for more than 20 years are presented. Examples are given of results from selected sites, showing variability of annual maximum loading from different locations. Finally, it is explained how the results have been used to improve load criteria of new overhead transmission lines.**

## I. Introduction

Ice loading on overhead conductors is one of the most important parameter influencing the investing and performance of overhead transmission lines (OHTL) in Iceland. Therefore, measurements of ice loading have been made in test spans for more than 30 years. The first test span for measuring ice loads on conductors was built in 1972. A test span built the following year is still in operation today. Since 1972, a total of 84 test spans have been erected at 54 locations, see Fig.2. Today, 53 of them at 35 locations distributed all around the country are in operation and 43 spans at 26 locations have been in operation for more than 20 years. Most of the test spans are located in uninhabited areas in the highlands at altitudes ranging from 350 m to 1000 m above sea level.

The weather conditions vary significantly between locations, based on the topography, altitude, distance to sea and prevailing wind direction. Ice load is infrequent and hardly measurable at some sites, while many icing events are measured every year at other sites.

It is well recognized that atmospheric icing has great variability depending on site conditions. From the beginning, the main aim of operating the test spans has been to locate and map areas where high ice load can be expected on overhead transmission lines, especially in areas where experience of operating structures is non-existent. Most of the test spans are therefore located on planned transmission line routes but also on existing line routes where the policy has been to operate each span for at least 30 years for statistical purpose.

## II. Test spans, Setup and measurements

Each test-measuring site has one, two or three spans lying in a straight line, at right angles or in a triangle. The spans are standardized, being 80m long. The conductors are strung on poles 10m above ground. Two types of conductors are used, 28 mm (AAAC) is most common, but 18 mm (AAAC) is used at few locations.

During the first years, only mechanical maximum recording dynamometers were used and manual readings were taken three times a year. In 1988, electronic force recorders were first installed and since then, a few have been installed every year. Since 2005, all the operating test spans have been equipped with electronic force recorders. Precision and reliability of the recorders have improved greatly. The recorders measure tension at 0.5-1 Hz and store maximum, minimum and mean values within each 10 minutes. For a more detailed description of the set-up of the test spans and the force recorders, see references [4]. The original maximum recording dynamometers are still operated in all the test spans to ensure calibrations between old and new measuring methods. Since 2005, ambient temperature measurements are

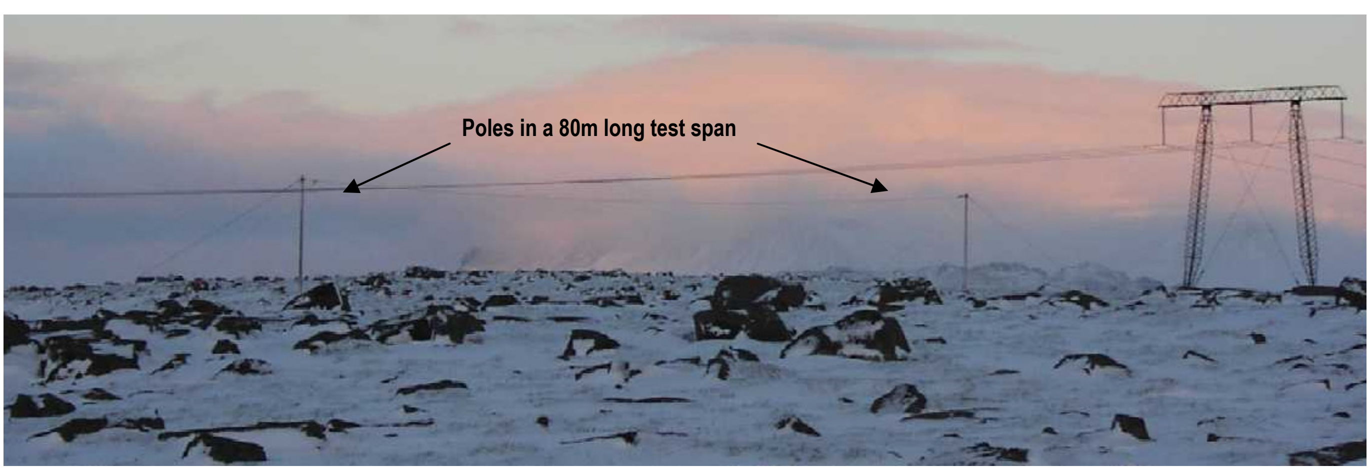



*Fig. 1. Test span 77-5 parallel to 220 kV transmission line, erected 5 years before the OHTL. Length of span is 80m.*

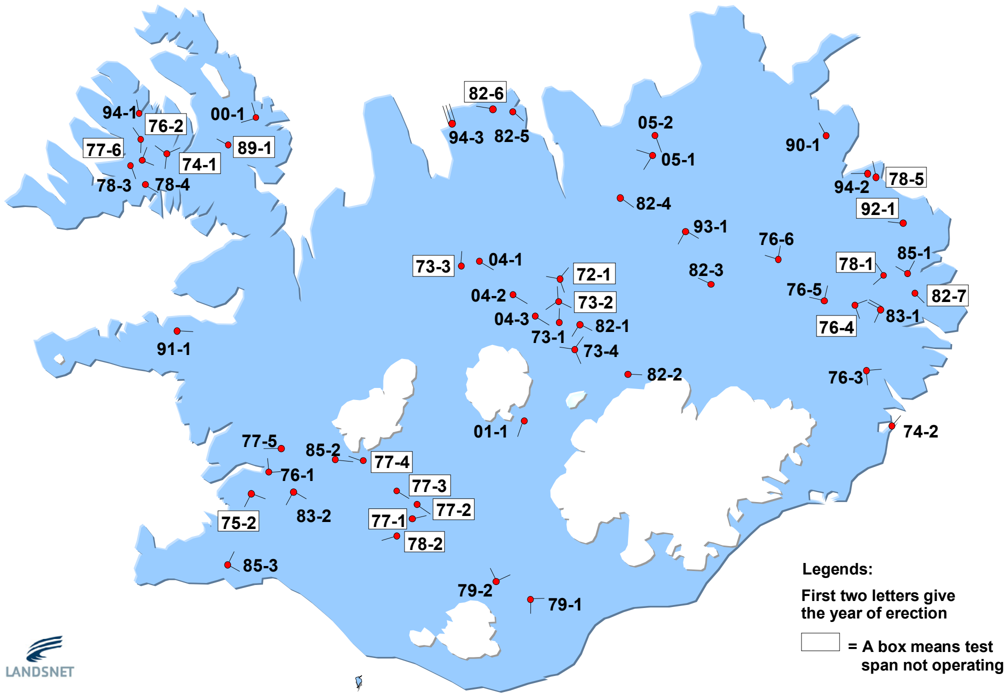



*Fig. 2. Location of all test spans 1972-2007.*

also made every 10 minutes at all the sites. In some locations, additional weather parameters are continuously measured as well.

Measurements of the conductor's end tension are taken. They are then converted into external load per unit length, using the geometry of the test span and mechanical properties of the cable and guys. The underlying assumption is that loading is equally distributed along the span. The measurement's horizontal and vertical components cannot be accurately distinguished since wind-speed measurements are usually not made. The load analysed is therefore the conductor's total load, consisting of both vertical and horizontal components.

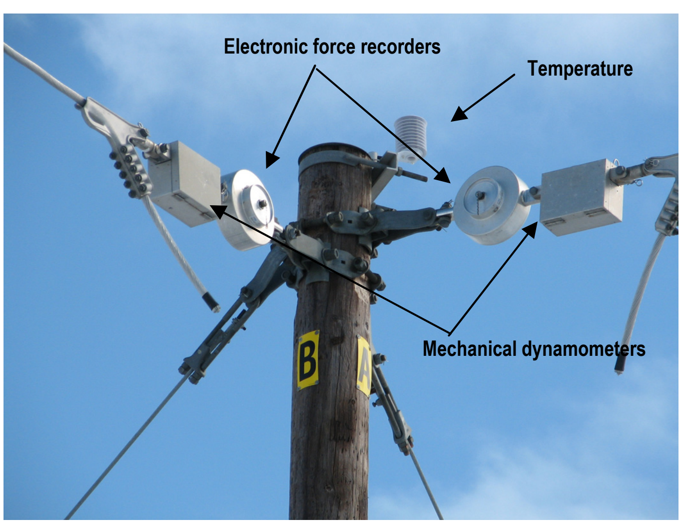



*Fig. 3. Equipped central pole in a right angle test span.*

By the advent of the electronic force recorders, the data becomes more valuable wherein the process of loading and ice shedding can be analyzed in time.

*Fig. 4. A triangular test span (73-4), in-cloud icing on span 73-4-A.*

## III. Annual maximum loading in test spans measured 20 years or more

Below, measurements are presented of annual maximum load (AM) in test spans that have been operated for 20 years or more. The yearly measuring period is end of Aug.-Aug. It should be noted that the weight of the conductor is included in the loading presented here. The measurements also include both horizontal and vertical load component, i.e. wind loading is included. The estimated conductor weight and maximum wind load without ice may reach 35-60 N/m, lower values of AM are thus in many cases due to wind without any ice.

Table I gives an overview of measured AM loading for the spans.

Table 1. Results from test spans with 20 years of measurements

| Test span | Height above sea level | Direction | Weight of cond. | Numb. of meas. years | Max. meas. value | Average AM value | COV |
|---|---|---|---|---|---|---|---|
| | [m] | [°N] | [N/m] | [-] | [N/m] | [N/m] | [-] |
| **72-1-A** | 880 | 159 | 5,4 | 30 | 71,3 | 25,6 | 0,47 |
| **72-1-B** | - | 39 | 5,4 | 30 | 97,2 | 40,5 | 0,59 |
| **72-1-C** | - | 280 | 5,4 | 30 | 193,6 | 49,3 | 0,70 |
| **73-1** | 940 | 2 | 5,4 | 31 | 163,2 | 53,8 | 0,58 |
| **73-2-A** | 970 | 357 | 5,4 | 30 | 139,0 | 58,1 | 0,53 |
| **73-2-B** | - | 116 | 5,4 | 29 | 94,0 | 49,5 | 0,41 |
| **73-2-C** | - | 236 | 5,4 | 29 | 78,0 | 43,9 | 0,34 |
| **73-3** | 700 | 200 | 5,4 | 27 | 48,6 | 27,6 | 0,34 |
| **73-4-A** | 820 | 277 | 5,4 | 32 | 192,0 | 46,8 | 0,76 |
| **73-4-B** | - | 37 | 5,4 | 30 | 65,8 | 27,3 | 0,54 |
| **74-1-A** | 380 | 64 | 5,4 | 28 | 144,8 | 27,2 | 0,94 |
| **74-1-B** | - | 304 | 5,4 | 28 | 72,6 | 32,3 | 0,44 |
| **74-1-C** | - | 184 | 5,4 | 20 | 141,6 | 24,9 | 1,15 |
| **74-2** | 10 | 43 | 5,4 | 24 | 42,7 | 26,4 | 0,30 |
| **76-1-A** | 10 | 176 | 12,9 | 28 | 97,3 | 61,6 | 0,25 |
| **76-1-B** | - | 82 | 12,9 | 23 | 55,3 | 32,5 | 0,20 |
| **76-3-A** | 540 | 173 | 5,4 | 25 | 67,8 | 22,6 | 0,55 |
| **76-3-B** | - | 83 | 5,4 | 29 | 185,8 | 68,0 | 0,63 |
| **76-5-A** | 660 | 283 | 5,4 | 27 | 101,0 | 34,8 | 0,68 |
| **76-5-B** | - | 13 | 5,4 | 27 | 132,5 | 28,8 | 0,87 |
| **76-6-A** | 600 | 272 | 5,4 | 28 | 58,6 | 20,0 | 0,61 |
| **76-6-B** | - | 2 | 5,4 | 26 | 51,9 | 23,9 | 0,39 |
| **77-2(2)** | 590 | 124 | 12,9 | 27 | 112,4 | 58,1 | 0,37 |
| **77-3** | 430 | 120 | 13,4 | 26 | 98,9 | 42,1 | 0,49 |
| **77-4** | 480 | 288 | 13,4 | 28 | 71,4 | 36,3 | 0,30 |
| **77-5** | 400 | 270 | 13,4 | 28 | 71,6 | 38,1 | 0,36 |
| **78-3** | 820 | 175 | 12,9 | 26 | 244,8 | 66,2 | 0,67 |
| **79-1-A** | 370 | 269 | 13,4 | 25 | 124,9 | 30,7 | 0,66 |
| **79-1-B** | - | 157 | 13,4 | 26 | 152,8 | 50,8 | 0,52 |
| **79-2-A** | 670 | 154 | 12,9 | 26 | 121,4 | 59,2 | 0,32 |
| **79-2-B** | - | 243 | 12,9 | 26 | 161,1 | 81,8 | 0,29 |
| **82-1-A** | 890 | 28 | 12,9 | 21 | 70,1 | 42,2 | 0,31 |
| **82-1-B** | - | 298 | 12,9 | 23 | 150,6 | 76,9 | 0,43 |
| **82-2** | 990 | 93 | 12,9 | 21 | 270,4 | 58,3 | 0,86 |
| **82-3** | 700 | 295 | 12,9 | 23 | 77,5 | 42,6 | 0,39 |
| **82-4** | 560 | 126 | 12,9 | 23 | 201,9 | 72,4 | 0,48 |
| **82-5** | 10 | 129 | 12,9 | 23 | 61,5 | 31,9 | 0,40 |
| **83-1-A** | 570 | 117 | 13,4 | 22 | 370,7 | 136,6 | 0,52 |
| **83-1-B** | - | 27 | 13,4 | 22 | 239,2 | 88,6 | 0,48 |
| **83-2-A** | 580 | 30 | 13,4 | 22 | 99,7 | 54,8 | 0,31 |
| **83-2-B** | - | 300 | 13,4 | 21 | 92,4 | 62,3 | 0,24 |
| **85-1-A** | 900 | 120 | 12,9 | 20 | 208,7 | 121,2 | 0,34 |
| **85-1-B** | - | 210 | 12,9 | 20 | 627,9 | 254,5 | 0,53 |
| **Max** | 990 | 357 | 13,4 | 32 | 627,9 | 254,5 | 1,15 |
| **Min** | 10 | 2 | 5,4 | 20 | 42,7 | 20,0 | 0,20 |
| **Average** | 595 | 162 | 9,5 | 26 | 137,8 | 54,2 | 0,50 |

It should be noted that test spans starting with the same digits and distinguished with letters (A, B, C), are at same location but oriented in different directions. These test spans show in some cases that loading can be very dependent on direction, see for example 72-1, 73-4, 74-1, 76-3, 82-1 and 85-1.

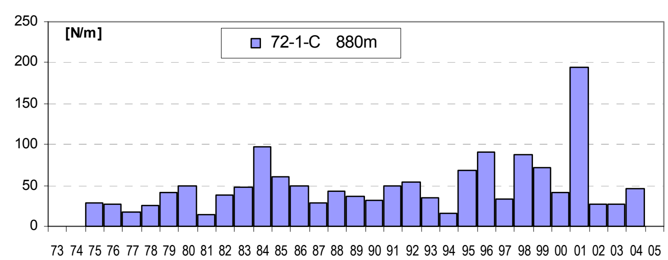
*Fig. 5. In-cloud icing on a test span close to shore, 650 m a.s.l.*

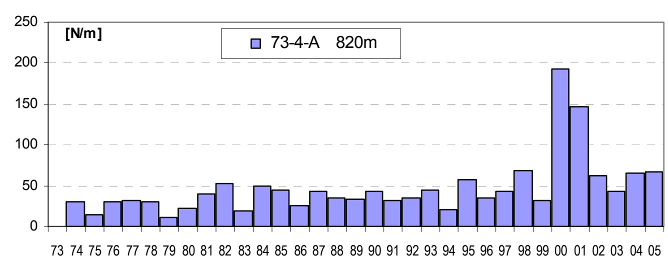
To simplify the analyses, chosen spans are grouped into three categories: (i) Test spans where the average AM is less than 60 N/m, (ii) test spans where the average AM is between 60-100 N/m and (iii) test spans where the average AM is above 100 N/m.

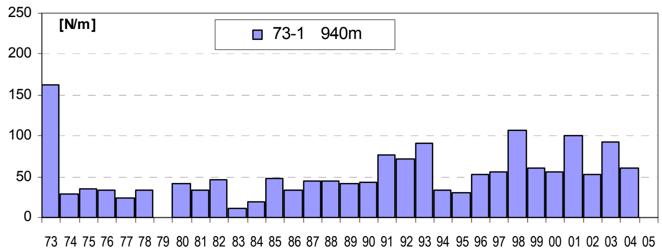
### *A. Test spans with average AM less than 60 N/m*

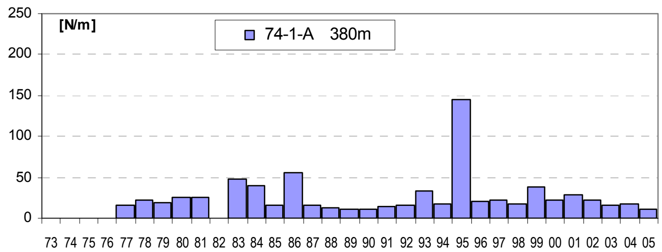
Approximately 73% of the spans are in this category. Icing is not expected to be a yearly incident in these spans and many AM loading values are dominated by wind in addition to the conductor weight.

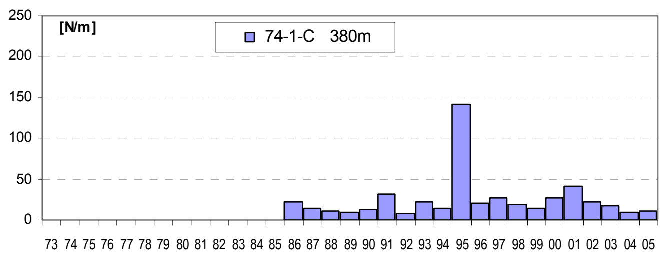
Approximately 34% of the spans in the category have one or two cases of annual maximum loading above 120 N/m. Following histograms show such examples.

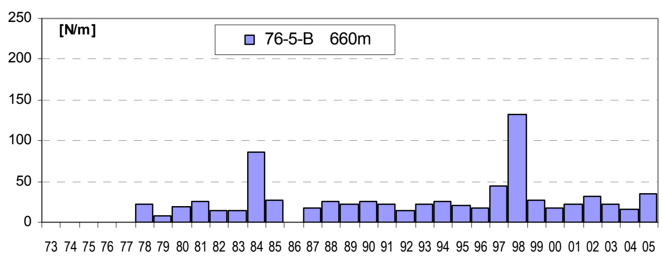


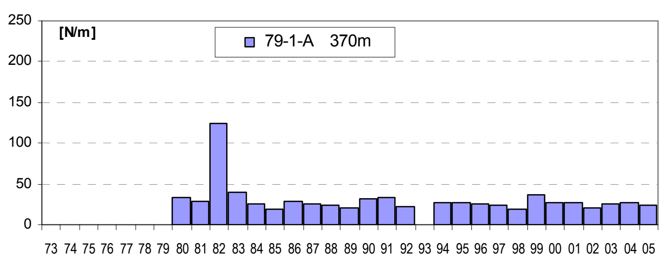



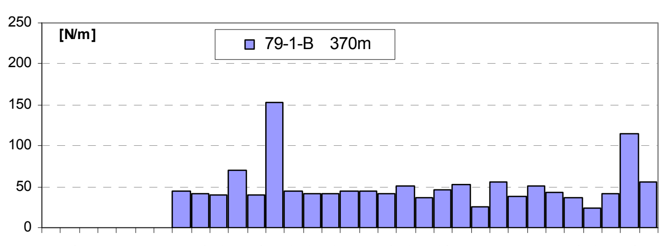


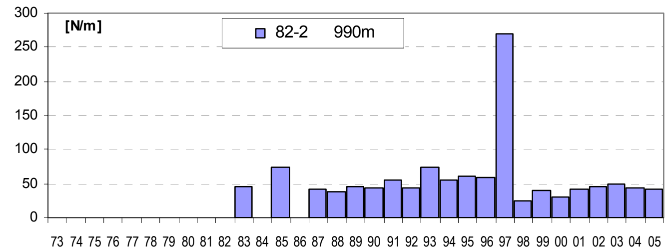




*Fig. 6. Annual maximum loading of spans with maximum average below 60 N/m but one or two high values.*

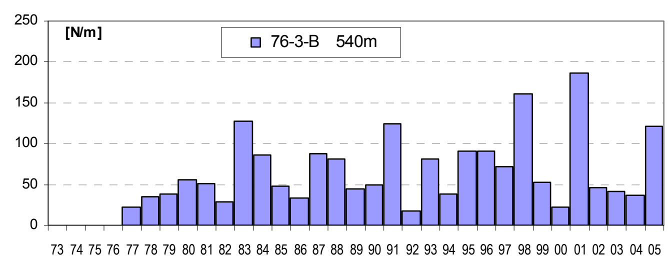
All these test spans are located far from sea shore and most of them are in the central highlands where clouds have a relatively low humidity after passing over mountainous areas from sea. The altitude of those measuring sites is in the range of 370 to 990 m.

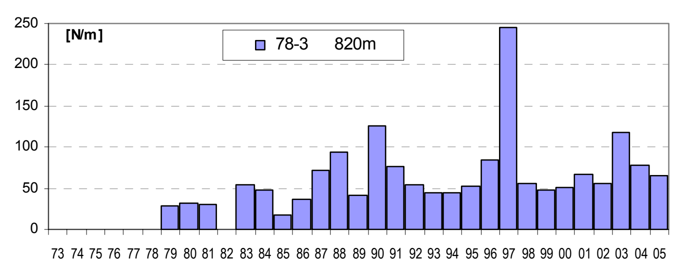
The high loading values (above 120 N/m) occurred in all cases before electronic force recorders were installed at those sites. It is not possible to determine with certainty the type of icing in each event, but they were presumably in-cloud icing, except in 79-1-B where wet snow is most likely.

The samples show that in some locations, a single high AM load (120 – 270 N/m) can be expected although the load is on the average low for 20 – 30 years. Thus, sites without regular ice loading can be exposed to high ice load in certain situations. It can be argued that care is needed in evaluation of extreme statistics for a single test span for these sites and a reasonable estimate of ice load can only be made by evaluating a number of spans together and considering influence of topography and other factors.

### *B. Test spans with average AM between 60-100 N/m*

There are eight test spans (19%) with average values of AM in range of 60-100 N/m, four of them are shown below.



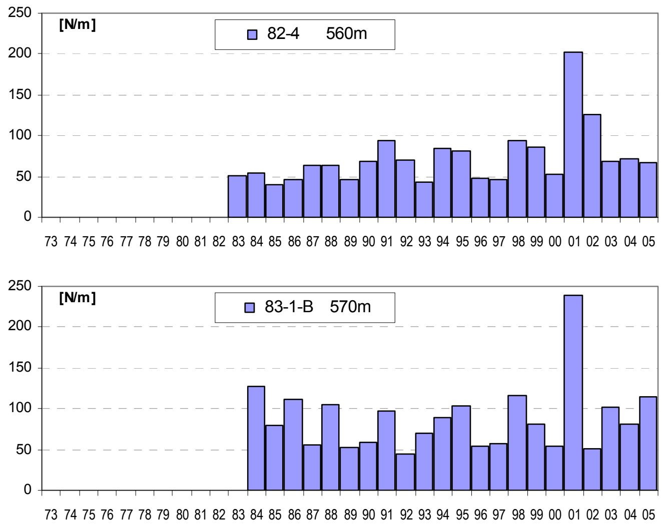


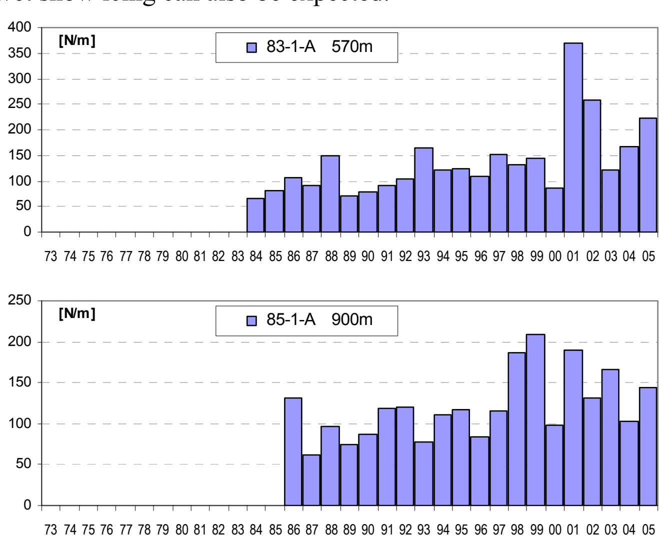

*Fig. 7. Annual maximum loading of spans with maximum average between 60-100 N/m*

Test spans where the average AM is between 60-100 N/m are distributed all around the country and at different altitudes, from 10 to 890 m. Most of them are inland in mountainous areas. Wet snow icing can be expected anywhere and in-cloud icing in all cases except at 76-1-A.

Icing events are more frequent in these test spans than in the previous ones. It should though be noted that the highest AM values in these test spans are similar to the one or two high values recorded in test spans with average AM less than 60 N/m.

*C. Test spans with average AM greater than 100 N/m*

The average AM load has been above 100 N/m in three of the test spans that have been in operation for more than 20 years. Two of the spans are located at the same measuring site, but the direction of the spans is different. Both measuring sites are in the eastern part of the country, rather close to sea where humid clouds moving from sea side, from northeast and east, have unlimited access. The altitudes are 570 and 900 m a.s.l. These spans usually experience many icing events every year. In-cloud icing is dominating for those test spans, thought wet snow icing can also be expected.



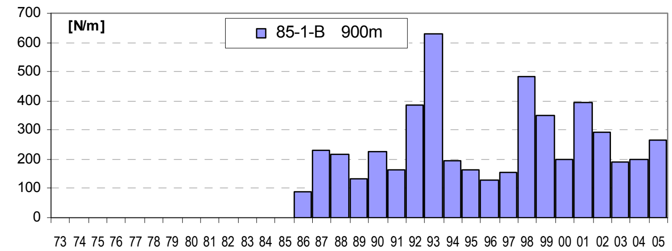




*Fig. 8. Annual maximum loading of spans with maximum average above 100 N/m*

The span 85-1-B includes the highest measured load (627 N/m), see fig. 9. The ice accumulation continued for approximately 3 days. It is notable that this event was near mid July. The hardware in the test span broke down before the ice accumulation stopped, and the maximum loading may thus have been somewhat higher. Temperature was not measured at site at time of accumulation but measurements shown are based on interpolation from nearby temperature recorders.

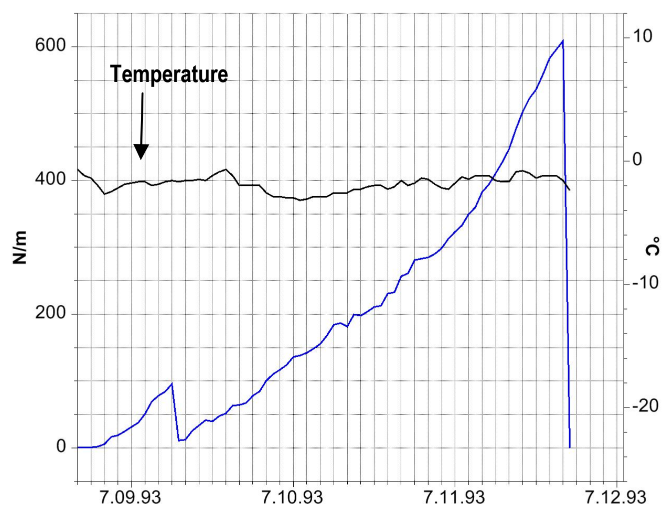



*Fig. 9. Maximum measured ice loading in test span (85-1-B). Temperature is estimated from nearby measurements. Test span broke down before accumulation stopped.*

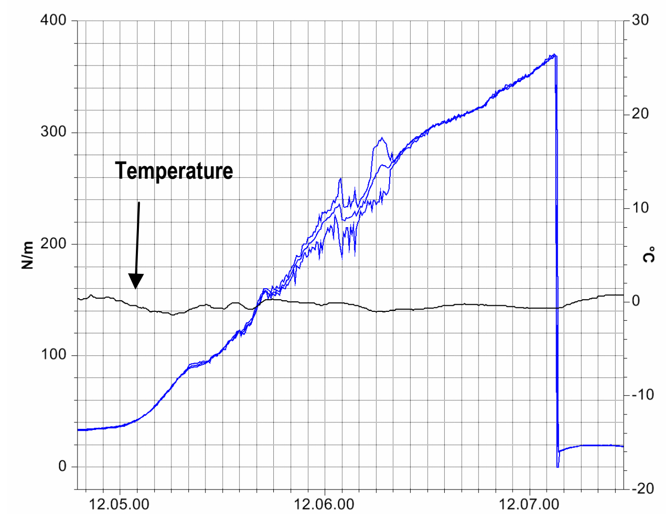



*Fig. 10. Maximum measured ice loading in test span 83-1-A. Accumulation is continuous for two days.*

## IV. USE OF ICE LOAD DATA FROM TEST SPANS

The main aim of measurements in test spans has, from the beginning, been to define areas where high ice load can be expected on OHTL. After operation of test spans distributed all around the country, the knowledge of the ice loading phenomena has improved significantly and more confident assumptions can now be made for ice loading.

Data from test spans have been used in determining design ice loading for all new OHTL the last two decades. The data has also been used to establish a database. Other information on icing has also been as bases to determine design ice loading. Such as database of known icing registered on distribution and transmission lines (see ref.5) and computer simulation of weather estimating risk of wet snow icing (see ref. 6).

In 2006, two new 400 kV OHTL were constructed passing an area with severe ice loading. Test span 83-1 had been operated on the line route since 1983 and the maximum measured ice loading was 36 kg/m. The measurements from the test spans were used for estimating design values of ice loading.

The use of these measurements for estimating ice load has been successful and no major failure of overhead transmission line has occurred in lines built during the last 25 years. Therefore, the main objective for operating the test spans has been achieved.

Line routes of OHTL may be forced to pass trough areas with severe icing. In 2006, a program of online monitoring was implemented wherein load cells and video cameras are used on two 400 kV lines. The aim is to increase the operational reliability of these two very important lines and prepare emergency plans possible for de-icing methods in case of extreme icing.

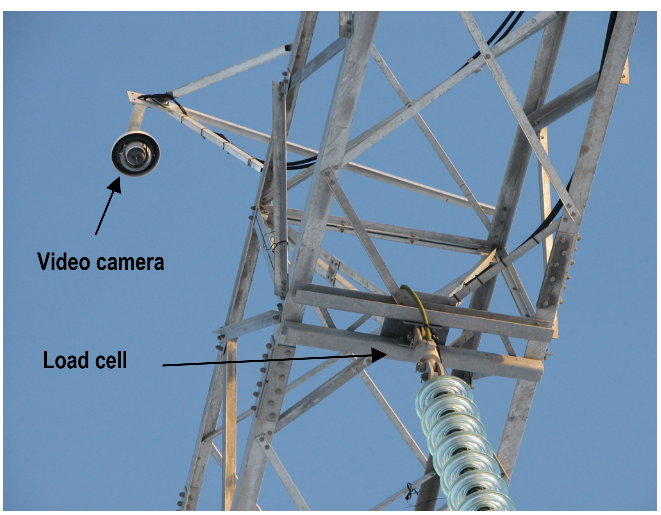



*Fig. 11. Installed video camera and load cell in a 400 kV OHTL.*

*Fig. 12. Monitoring equipment in a 400 kV line.*

## V. CONCLUSION

The results of measurements in the test spans have given important information on icing at different conditions ranging from 10m up to 1000m above sea level. Operational experience of OHTL designed and constructed during the last 25 years, based on ice loading founded on these measurements have been successful and no major failures have occurred and loss of supply during heavy icing periods are quite rare.

Hundreds of icing events, most f them in-cloud icing, have already been recorded since the test spans were equipped with tension recorders. Considerable amount of icing data is now available to analyze icing accumulation and ice shedding in more detail than before.

The next step in measuring and monitoring ice load has already started with an online connection of load cells and video cameras on OHTL to a control station. It is an important step, combined with preparation of an operational plan, for de-icing of OHTL in severe icing areas.

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