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RELEVANCE OF ISO ICE CLASSES TO TOWER STRUCTURES

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***Abstract**:* The International Standard ISO 12494 gives a method to assess rime ice loads on complex structures. We present an analysis of the applicability of the ISO method based on field data that include ice masses measured simultaneously on the ISO standard ice collector, a 7.5 m tall self supported lattice structure and a 127 m tall guyed lattice tower. We compare ice masses on these three objects in different ice classes and calculate the ice masses expected on the structures based on the ISO method. The results show that the ISO Ice Classes are a useful tool in assessing rime ice loads on the structures, but that inaccuracies arise, partly related to poorly known ice shedding mechanisms.

Introduction Rime ice loads caused by in-cloud icing are a major design criterion for tall structures in cold climates. The International Standardization Organization has issued the International Standard ISO 12494 "Atmospheric icing of structures" which presents a detailed methodology for assessing ice loads on structures. The standard defines Ice Classes which are defined in terms of ice mass per length of an object.

The ISO 12494 method has been insufficiently verified, however. It includes approximations, such as taking the rime ice masse as independent of the object dimensions and a height dependence formula based on very limited field data. Furthermore, different ice shedding mechanisms from different objects is not taken into account in the method.

Therefore, there is a need to verify the ISO method in practice and assess its applicability in estimating design rime ice loads, particularly in regard to tall lattice structures. Here we present results from simultaneous field measurements of rime icing on the ISO standard ice collector and two lattice structures, a 7.5 m tall self supported lattice tower and a 127 m tall guyed lattice tower. These data allow us to study the relevance of the ISO method in assessing rime icing on full-scale structures in a wide range of real ice loads.

1. RESULTS AND DISCUSSION

An example of the ice growth on the ISO collector and the two towers is shown in Fig. 1. The ice classes marked in the figure are based on ice mass on the ISO collector.

Ice masses on the structures at each ice class were compared with that on the ISO collector in six cases for the 7.5 m tower and four cases for the 127 m tower. The comparison was made as the ratio of the tower ice mass and the ISO collector ice mass. The results for the 7.5 m tower are shown in Fig. 2. The ratio between the ice loads decreases slightly with increasing Ice Class, except in the smallest classes, for which the relative measurement accuracy is poor.

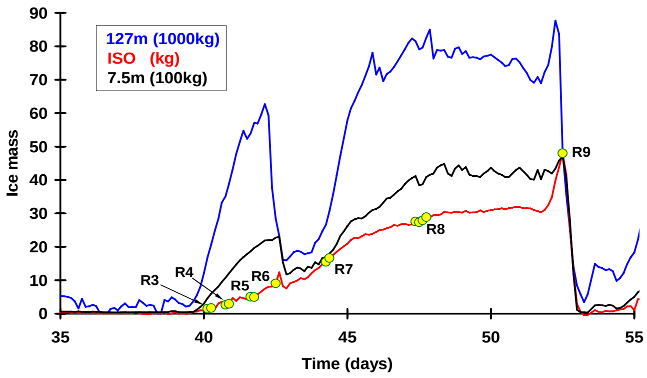

Figure 1: Ice growth on the ISO collector and the two towers.

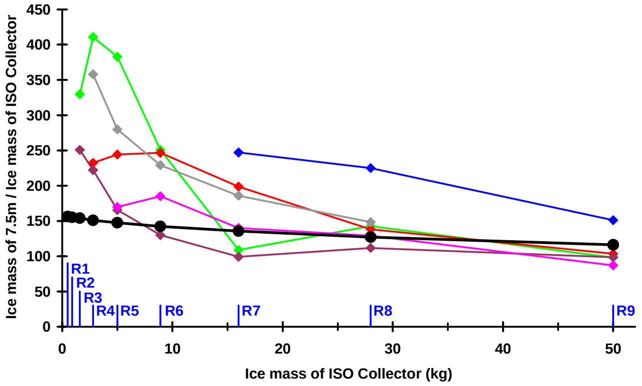

Figure 2: Ratio of ice masses on the 7.5 m tower and the ISO collector in different Ice Classes for six icing events. Black dots are the corresponding ratios calculated by the ISO method.

The results in the mean correspond quite well to calculations using the ISO method but there is large scatter.

2. CONCLUSION

The correlation between the icing rates on the ISO collector and the towers is strong. Ice shedding, particularly from the guy wires, makes the instantaneous ice loads more weakly correlated, however. The ISO Ice Classes determined by the ISO collector are reasonably well transferable to a complex full-scale structure at the same height. This is not quite so in regard to the 127 m tower. This is probably due to ice shedding from the guy wires and inaccuracy in the height dependence of the ISO method. Overall, our results support the relevance of the ISO 12494 Ice Classes to lattice tower structures but emphasize the need for further research on its accuracy and on icing of complex structures in general.

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***Abstract*—The International Standard ISO 12494 gives a method to assess rime ice loads on complex structures by ice classes that are based on measurements using a standard ice collector. The method has not been directly verified, however. Here we present the first analysis of the applicability of the ISO method based on field data. The data include ice masses simultaneously measured on the ISO standard ice collector, a 7.5 m tall self supported lattice structure and a full scale 127 m tall guyed lattice TV tower. We compare ice masses on these three objects in different ice classes and calculate the ice masses expected on the structures based on the ISO method. The results show that the ISO Ice Classes are a useful tool in assessing rime ice loads on the structures, but that inaccuracies arise. The errors tend to be on the safe side in regard to structural design and are, at least partly, related to poorly known ice shedding mechanisms.**

Keywords-icing; rime ice; in-cloud icing; ice loads; structural desing; towes; masts

I. INTRODUCTION

Rime ice loads caused by in-cloud icing are a major design criterion for structures located in mountainous regions and for tall structures in all cold climates. Lattice structures, such as TV-masts and power line towers are particularly vulnerable to rime icing. The associated wind load increases dramatically on a heavily iced lattice structure (Fig. 1) and this too must be taken into account in structural design.

Theoretical methods to estimate rime icing on tall structures have been developed [1-3]. However, the cloud physical data required by the modelling are not routinely measured and efforts to obtain them by high resolution atmospheric boundary layer models is only now taking its first steps [4]. Direct icing measurements have been made for assessing the loads in many countries for a long time [5]. However this approach includes problems, such as questionable representativeness of the measurement device in regard to large structures [6,7] and the poorly known height dependence of ice mass on tall structures [8,9].

In 2001 the International Standardization Organization issued an International Standard ISO 12494 “Atmospheric icing of structures” [10], which presents a detailed methodology for assessing ice loads on structures. The standard defines Ice Classes and the estimation methods (both ice load and combined ice and wind load) for rime and glaze. Here, we consider rime ice only. The ISO Ice Classes for rime ice are shown in Table 1. They are defined in terms of ice mass per length of an object.

According to ISO 12494, an Ice Class corresponds to a characteristic ice mass on a slowly rotating 30 mm diameter vertically oriented cylinder that is at least 0.5 m long. Such a standard collector is, thus, required to be used when determining the Ice Class for a site by direct icing measurements.

TABLE I. ISO RIME ICE CLASSES [10]

Ice Class	Ice mass (kg/m)
R1	**0.5**
R2	**0.9**
R3	**1.6**
R4	**2.8**
R5	**5.0**
R6	**8.9**
R7	**16**
R8	**28**
R9	**50**
R10	Extreme case

ISO 12494 provides a systematic approach for assessing ice loads on structures and is planned to be used worldwide. Considering its status and comprehensiveness, the method has been insufficiently verified, however. The ISO method assumes that the rime ice masses are independent of the object dimensions when applied to structural components. This is only a crude approximation based on numerical modeling [11], laboratory experiments [12] and field data [13,14]. The height dependence of rime ice mass is also an approximation based on very limited field data [14,15]. Furthermore, different ice shedding mechanisms [16] from different objects is not taken into account in the method.

Therefore, there is clearly a need to verify the ISO method in practice and assess its applicability in estimating design rime ice loads, particularly in regard to tall lattice structures. Here we present, results from simultaneous field measurements of rime icing on the ISO standard ice collector and two lattice structures, a 7.5 m tall self supported lattice tower and a 127 m tall guyed lattice TV-tower. These data allow us to study the relevance of the ISO method in assessing rime icing on complex full-scale structures in a large range of real ice loads.

II. MEASUREMENTS AND METHODS

A. Measurements

The measurements were made in 1998-2002 on top of Ylläs hill in Northern Finland. The site is at 700 m asl and about 500 m above the mean level of the surrounding terrain. The hill is of a rounded shape and the highest hill in the area.

The 127 m tall guyed TV tower at Ylläs is constructed standing on a specially prepared strain gage based vertical force measurement system. The 7.5 m tall self supported tower was constructed purely as a test structure for icing and wind load measurement purposes. It has the same structural details as a section of the 127 m tower. It was erected standing on strain gage based load cells.

A 1.0 m long ISO ice collector was constructed standing on a commercial load cell. The ISO collector is rotated by an electric motor and a gear at 4 rpm. All the ice load data, together with meteorological parameters such as wind speed and air temperature, are recorded using an automatic measurement system. The measurements are recorded as 10 minute mean values once every 3 hours. The iced up ISO collector and heated anemometers are shown in Fig. 2.

In all load cells, temperature compensated strain gages are used. Accuracy of the measurements is mainly determined by the maximum capacity of the load cells. Because of measured extreme ice loads up to 450 kg/m at Ylläs, the ISO collector has a load cell with the maximum capacity of 500 kg. Consequently, ice masses in the smallest Ice Classes R1 and R2 cannot be reliably measured by this system as they represent only 0.1% and 0.2 % of the maximum capacity of the load cell. Ice load measurements using the load cells of the two towers have a similar relative accuracy. In addition, the guy wires of the 127 m tower cause a temperature dependent error in the measured weight, because their tension increases with decreasing temperature. Also, the geometric nonlinearity of the guy wires causes errors to the measured load, which are proportional to the ice mass on the guy wires.

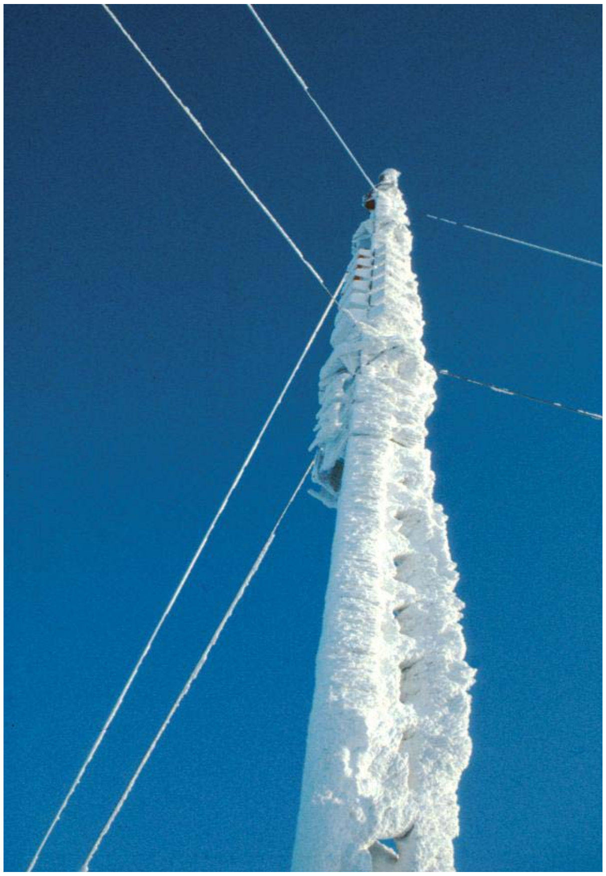

Figure 1. Rime ice on the 127 m latice tower at Ylläs, Finland

B. Comparisons and calculations

Our purpose here is to compare ice masses on the two full-scale tower structures and that simultaneously measured on the ISO ice collector. In particular, we wish to make comparisons of the ice masses that correspond to the ISO Rime Ice Classes. Following the ISO 12494 philosophy, the ice mass on the ISO collector is here used as a reference which determines the Ice Class for a comparison.

Although we have ample data covering all Ice Classes, it was not easy to find cases where the ice masses could be accurately compared within the Ice Classes. This is because, for a meaningful comparison at a small ice mass, one needs to be sure that the icing starts from zero mass on all the objects considered. This is rarely the case at the Ylläs site because during most of the icing season the air temperature is persistently below 0 ^{o}C, so that all the objects are very infrequently completely free of ice. Consequently, we could

Figure 2. The ISO ice collector iced up at Ylläs (right). Ice mass on the 1 m long ISO collector at this time was 117 kg. i.e. Ice Class is R10. The non-cylindrical shape ("ice cap" on the top) is typical for ice accretions this large, but not for smaller ones.

not use additional quality criteria, but all cases of significant ice growth where the data showed, within the accuracy of the measurement systems, zero mass on all three objects were utilized in this study. In addition, we included a few cases where there was in the beginning a small ice load on the 127 m tower, but no ice on the 7.5 m tower and the ISO collector. In these cases we made a correction to zero level by reducing the initial ice mass from the 127 m tower ice masses for that icing case. These corrections were too small to significantly affect comparisons in Ice Classes R4 to R9 but may affect the comparisons in Ice Class R3. In Ice Classes R1 to R2, the resolution of our measurement system is insufficient for accurate comparisons in any case.

In many icing cases there was only one observation that was within a certain Ice Class, i.e. the previous observed ice mass on the ISO collector was well below the limit given in Table 1 and the next observation well above it. There were, however, also cases, where the icing rate was so low that several consecutive observations fell within an Ice Class. In such cases, all observations, where the ice mass on the ISO collector was within ±5% of the mass specified in Table 1 for that Ice Class, were included in such a way that the mean of these observed ice masses was used in the comparisons. The corresponding mean was used to represent the ice mass on the two full-scale structures.

Ice mass calculations were made in order to compare the ISO-method as applied to lattice towers. The the7.5 m tower and the 127 m tower were both considered in detail, so that each tower component was included in the ice load calculation. This included antennas, cables, ladders etc. No shadowing effects were considered, but double-counting of ice mass at the intersections of tower components was eliminated in the calculation. For the diagonal elements of the towers, as well as for the guy wires of the 127 m tower, the effect of the orientation angle with respect to the vertical was taken into account according to the method given in ISO12494.

The Ice Classes adopted in the calculations were those at the ground level. The height correction given in the ISO 12494 was applied on the 127 m tower ice mass. This was done in such a way that the tower was divided into two 50 m tall and one 27 m tall vertical sections. The representative heights of these sections were taken to be at 2/3 of the section height. Finally, the sum of ice masses at the three sections was calculated and considered to represent the total ice mass on the 127 m tower in the respective ice classes.

III. RESULTS

An example of the ice growth on the ISO collector and the two towers is shown in Fig. 3

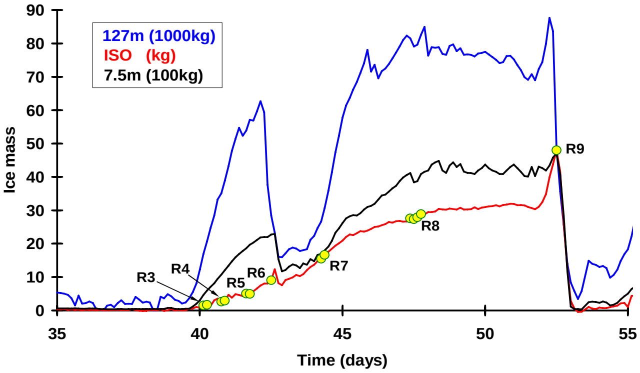

Figure 3. Example of ice growth on the ISO collector (red), the 7.5 m tower (black) and the 127 m tower (blue). The ISO Ice Classes are marked by yellow circles and are based on the ice mass on the ISO collector.

Ice masses at each Ice Class were compared to each other for six icing cases available for the 7.5 m tower and four icing cases available for the 127 m tower. The comparison was made in terms of the ratio of the tower ice mass and the ISO collector ice mass. These results are shown in Figs. 4 and 5 respectively.

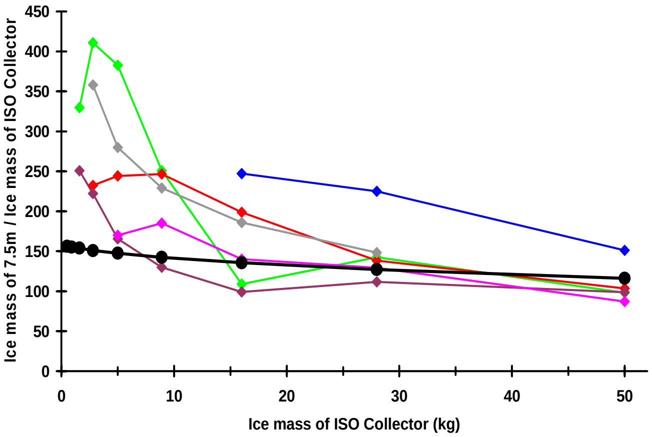

Figure 4. Ratio of ice masses on the 7.5 m tower the ISO collector in different Ice Classes in six icing cases. The black curve connects results obtained by calculation using the ISO 12494 method.

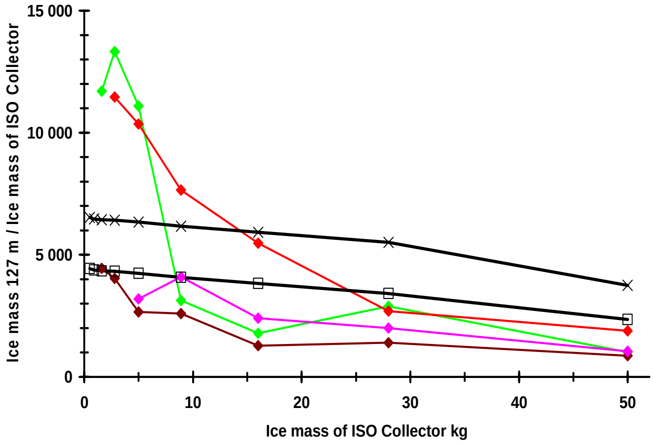

Figure 5. Ratio of ice masses on the 127 m guyed tower and the ISO collector in different Ice Classes in four icing cases. The upper black curve connects results obtained by calculation using the ISO 12494 method and including the guy wires, and the lower black curve the same calculation but excluding the guy wires.

IV. CONCLUSIONS

The results of the comparisons of the ice masses in Figs. 4 and 5 show a large scatter between the icing cases, particularly in the cases of the 127 m tower and small Ice Classes. The accuracy of our measurements was insufficient for making firm conclusions about comparisons in the smallest Ice Classes. Since the measurement accuracy is determined by the maximum capacity of the weighing system, several sensors with a different maximum capacity should be used at sites prone to high ice loads.

From our ice load data in general, we conclude that the correlation between the icing rates on the ISO collector and the two full-scale structures is strong. Ice shedding, however, makes the instantaneous ice loads more weakly correlated. This is particularly evident in the case of the 127 m tower and is probably mainly related to ice shedding from the guy wires and the effect of height from the ground.

The ratio between the ice mass on the 7.5 m tower and that on the ISO collector is almost the same in all Ice Classes, except for the smallest ones. The ISO Ice Classes determined by the ISO collector, thus, seem to be reasonably well transferable to a complex full-scale structure at the same height. This is not quite so in regard to the 127 m tower, however. The ratio between the ice mass on the structure and that on the ISO collector clearly decreases with increasing Ice Class and there is an overall over-prediction when calculating the 127 m tower ice mass by the ISO method, especially when the guy wires are included.

Overall, our results demonstrate the relevance of the ISO 12494 Ice Classes to tower structures. They also support the ISO calculation method, but emphasize the need for further research on its accuracy and on icing of complex structures in general. Ice shedding should also be studied further, in order to better understand the long-term cumulative growth of ice loads for purposes of structural design.

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REFERENCES

[1] E. Sundin and L. Makkonen, “Ice loads on a lattice tower estimated by weather data,” J. Appl. Meteor., vol. 37, 523-529, 1998.

[2] L. Makkonen, “Models for the growth of rime, glaze, icicles and wet snow on structures,” Phil. Trans. Roy. Soc. London, vol. A358, pp. 2913–2939, 2000.

[3] L. Makkonen and E.P. Lozowski, “Numerical Modelling of Icing on Power Network Equipment,” in Atmospheric Icing of Power Networks, M. Farzaneh, Ed.), Springer, pp. 83-118, 2008

[4] G. Thompson, B-E. Nygaard and L. Makkonen, “Using the weather research and forecasting (WRF) model to simulate ground/structural icing events,” XIII International Workshop on Atmospheric Icing of Structures (IWAIS2009), 8-11 September 2009, Andermatt, Switzerland, Proceedings.

[5] S. M. Fikke, G. Ronsten, A. Heimo, S Kunz, M. Ostrozlik, P-E. Persson, J. Sabata, B. Wareing, B. Wichura, J. Chum, T. Laakso, K. Säntti and L. Makkonen, “COST727: Atmospheric icing on structures - Measurements and data collection on icing: State-of-the-art,” Veröffentlichung MeteoSchweiz Vol. 75, 110 pp. ISSN 1422-1381, 2007.

[6] N. I. Popov and V. U. Holodov, “Accuracy of icing observations,” Trudy GGO, vol. 408, pp. 44-48, 1978 (in Russian).

[7] L. Makkonen, ”Can ice load measurements be standardized?,” International Seminar on Iceload Measurements, 18 - 20 May 1992, Kristiansand, 9 p.

[8] M. N. Mytarev, “Considering ice loads in the design of tall structures,” Trudy GGO, vol. 515, pp. 58-65, 1987 (in Russian).

[9] L. Makkonen and K. Ahti, “Climatic mapping of ice loads based on airport weather observations,” Atmospheric Research, vol. 36, pp. 185 – 193, 1995.

[10] International Standardization Organization ISO International Standard 12494 “Atmospheric Icing of Structures,” 56 pp, 2001.

[11] L. Makkonen, “Modeling of ice accretion on wires,” J. Climate Appl. Meteor, vol. 23, pp. 929-939, 1984. Also in: Guizhou Qixiang, vol. 4, pp. 22-29, 1990 (in Chinese).

[12] L. Makkonen and J. R. Stallabrass, “Experiments of the cloud droplet collision effiiency on cylinders,” J. Climate Appl. Meteor, vol. 26, pp. 1406-1411, 1987.

[13] V. U. Holodov and N. I. Popov, “The effect of structural parameters on ice accretions on power line cables,” Trudy GGO, vol. 379, pp. 30-36, 1976.

[14] L. Makkonen and P. Lehtonen, “Ice observations on the Kivenlahti TV-tower” unpublished.

[15] L. E. Lomilina, ”The effect of relief on glaze-ice and rime deposition,” Soviet Meteor. Hydrol., vol. 2, pp, 49-55, 1977.

[16] P. Lehtonen, K. Ahti and L. Makkonen, ”The growth and disappearance of ice loads on a tall mast,” 3rd International Workshop on Atmospheric Icing of structures, IWAIS1986, Canada, Proceedings, pp. 363-368, 1991.