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ICE RISK LEVELS - A PRACTICAL APPROACH TO DESIGN

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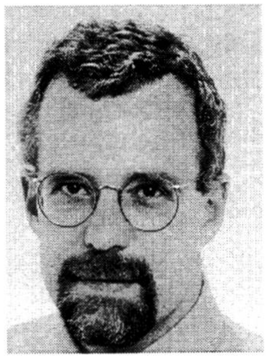

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Summary

The work with the elaboration of a new international standard for atmospheric iceloads on structures under the ISO have come up with a new term to be used world-wide for definition of atmospheric iceload on structure, namely "Ice Risk Level".
The ice risk levels are intendend to be used for instance for national mapping giving the ice load in various areas of a country.
The present paper briefly introduce the philosophy of the ISO Standard for Atmospheric Icing on Structures, the ice risk levels, examples of the ice accretion (shape and dimension) on various members and objects, wind drag coefficients for iced members, combination factors for wind and ice, etc.

1. Introduction

Atmospheric icing may have a great impact on the overall design and safety of various structures. The decisive load may be the increased vertical load due to the weight of accreted ice but quite often it is a combination of ice and wind, as the ice may increase the wind drag considerably. This is now commonly known and accepted in many national standards, but the big question is how much ice and how is it deposited onto various kind of structures and structural elements.
The work with elaboration of a new international standard for atmospheric iceloads on structures under the ISO (International Standardisation Organisation) have come up with a new term to be used for definition of atmospheric iceload on structure, namely "Ice Risk Level".
Two different categories of ice risk levels are defined, one for glaze and one for rime.
The ice risk levels are intended to be used for instance for national mapping giving the ice load in various areas of a country. A major problem faced by the ISO Working Group for Atmospheric Icing of Structures was primarily connected to rime ice accretion on non-circular, non-rotating objects and rime accretion on various shaped objects with large dimensions. After quite some reflection combined with full scale observations the Group have come up with a proposal for rime accretion on such members and objects.

The new ISO Standard will besides the ice risk levels and the models for ice accretion on various kind and shapes of objects also give rules for the ice accretion dependent on height above terrain, the shapes of ice vanes on fixed objects for the different ice risk levels, drag coefficients for wind drag on iced members, combination factors for combination of wind and ice, etc. necessary for the engineering design of structures exposed to atmospheric icing.
The present paper briefly introduce the philosophy of the ISO Standard for Atmospheric Icing on Structures, the ice risk levels, examples of the ice accretion (shape and dimension) on various members and objects, wind drag coefficients for iced members, combination factors for wind and ice, etc.

2. Types of Icing

Atmospheric icing is traditionally classified according to two different formation processes, "in-cloud icing" and "precipitation icing". Often is in-cloud ice called "rime" while precipitation ice often is devided into "glaze" and "wet snow". The physical properties and the appearance of the accreted ice will vary widely according to the variations of the meteorological conditions during the icing procedure. In Table 1 is given typical properties of atmospheric ice.

Type of ice	Density (kg/m^3)	Adhesion Cohesion	General Appearance	
			Colour	Shape
Glaze	900	Strong	Transept-rant	Evenly distributed/ icicles
Wet snow	300-600	Weak (forming) Strong (frozen)	White	Evenly distributed/ eccentric
Hard rime	600-900	Strong	Opaque	Eccentric, pointing windward
Soft rime	200-600	Low to Medium	White	Eccentric pointing windward

Table 1: Typical properties of accreted atmospheric ice.

Besides the properties mentioned in Table 1, other parameters such as compression strength, shear strength, etc. may be used to describe the nature of the accreted ice. For an engineering point of view it has been chosen to operate with two types of ice and simplified into "glaze" and "rime", and in the ISO Standard the practical application rules will be devided into rules for glaze and for rime.

3. Ice Risk Levels (IRL)

To be able to have a precise expression of the design ice load on structures at a certain location it is suggested to introduce the term "Ice Risk Level". Having the specific Ice Risk Level for a location the designer should have very valuable and important information for the assessment of the design atmospheric ice load on structures and combination of wind and ice. Ice Risk Levels are defined for glaze and for rime.
For glaze is the ice risk levels (IRL G) defined as the 50 years thickness of ice on a reference collector. In total is defined 5 levels, G1 to G5, starting with a thickness of 10 mm for level G1 and up to 40 mm for level G4. Ice risk level G5 is to be used for extreme glaze accretions, where the specific information should be given by a specialist.

IRL	Thick ness [mm]	Masses for Glaze on an object with diameters			
		10 mm	30 mm	100 mm	300 mm
G1	10	0,6 kg/m	1,1 kg/m	3,1kg/m	8,8kg/m
G2	20	1,7 kg/m	2,8 kg/m	6,8kg/m	18,1kg/m
G3	30	3,4 kg/m	5,1 kg/m	11,0kg/m	28,0kg/m
G4	40	5,7 kg/m	7,9 kg/m	15,8kg/m	38,5kg/m
G5	to be used for extreme ice accretions				

Table 2: Ice Risk Levels for Glaze (IRL G)

In Table 2 is given the definition of the five ice risk levels for glaze together with the weight of the glaze on a circular member with different diameter (density of the glaze: 900 kg/m^3).

IRL	Ice-mass [kg/m]	Ice diameter on an Ø30 mm collector Density of ice			
		300 kg/m^3	500 kg/m^3	700 kg/m^3	900 kg/m^3
R1	0,5	47 mm	7 mm	32 mm	28 mm
R2	0,9	63 mm	49 mm	42 mm	37 mm
R3	1,6	83 mm	65 mm	55 mm	49 mm
R4	2,8	109 mm	85 mm	72 mm	64 mm
R5	5,0	146 mm	113mm	96 mm	85 mm
R6	8,9	195 mm	151 mm	128 mm	113 mm
R7	16,0	261 mm	202 mm	171 mm	151 mm
R8	28,0	345 mm	267 mm	226 mm	199 mm
R9	50,0	461 mm	357 mm	302 mm	266 mm
R10	to be used for extreme ice accretions				

Table 3: Ice Risk Levels for Rime (IRL R)

The ice risk levels for rime (IRL R) are defined as the 50-years mass of ice per meter accreted on a standard collector. For rime is defined 10 levels starting with 0.5 kg/m for level R1 up to 50 kg/m for ice risk level R9. For extreme ice accretions to be treated individually by specialist level R10 should be used.

The standard collector is for both rime and glaze a 30 mm diameter cylinder rotating around its axis, and orientated perpendicular to the wind direction and 10 m above ground level. In Table 3 is given the defined 50 years ice masses for the ice risk levels for rime, as well as the outer diameter of the ice on a 30 mm cylinder for various densities of the rime.

4. Variation of Icing with Height above Terrain

The amount of atmospheric icing on a structure may vary with height above terrain, normally resulting in an increased ice load with increased height. If no site specific data are available the mass of rime dependent on the height above terrain may be found as

$m_H = (H/10)^{0.25}\, m_{10}$, where

m_H is the mass at H meters above terrain
m_{10} is the mass at 10 meters above terrain

For glaze is normally assumed that the amount of accreted ice is independent of the height above terrain.

5. Icing on Members and Objects

The meteorological parameters together with the physical properties are influencing the sizes, shapes and weights of accreted ice on a given object.
The shape the size and the orientation of an object has especially a big influence on the accreted ice when it concerns rime, while glaze normally will have the same thickness independently on the shape of the member/object, see Figure 1.

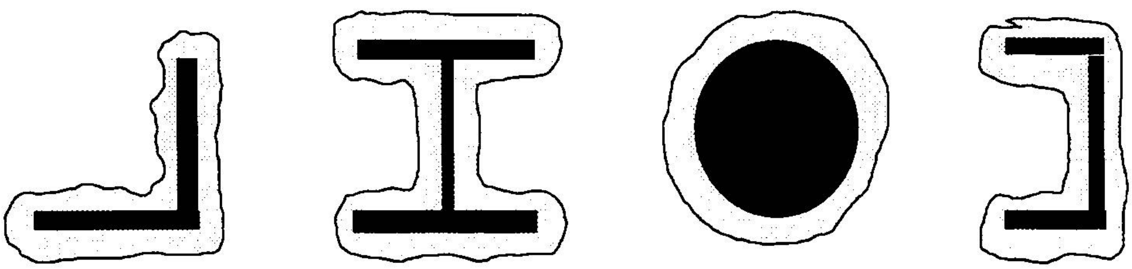

Fig. 1: Glaze on different members

The ISO Working Group for Atmospheric Icing on Structures has after quite some reflection combined with full scale observations come up with a proposal for rime accretion on various shaped members and objects.
For a fixed wind direction rime will accrete forming vaneshapes on profiles with a relatively small width perpendicular to the wind. On objects with larger widths the shapes will be more complex. Cylindrical accreted rime is normally only valid on slender elements with low

torrional stiffness and not sloping more than about 45° degrees to horizontal e.g. cables, mast guys - or on fixed nearly vertical members when the icing wind direction varies.
It is in the ISO Standard assumed that the mass of rime (50-years values) on objects with a width up to 300 mm is the same as defined by the ice risk level, i.e. independent on shape and width of the actual element, but the shape of the ice varies.
Besides theoretical reflections this has also been seen at full scale observations where vertical members of different shape and size has been observed during heavy icing periods. It was then seen that the amount of ice was nearly the same on all members independent on their shape and size.
When it comes to larger objects the constant mass is no longer valid. In the ISO Standard is given simple application rules for estimating the shape of the rime ice on various members and objects dependent on the ice risk levels.

Cross section shape of bars:		H		[		L ↕ W			
Wind direction: →		L		L		L			
Object width [mm]		10		30		100		300	
IRL	Icemass	ICE VANES DIMENSIONS [mm]							
	G [kg/m]	L	W	L	W	L	W	L	W
R1	0,5	101	102	179	37	13	100	4	300
R2	0,9	124	104	197	42	23	100	8	300
R3	1,6	155	108	223	48	41	100	14	300
R4	2,8	196	113	260	57	102	113	24	300
R5	5,0	252	122	313	71	137	122	42	300
R6	8,9	327	135	385	89	191	135	76	300
R7	16,0	430	156	486	114	275	156	136	300
R8	28,0	560	185	614	146	390	185	321	343
R9	50,0	739	227	793	191	556	227	435	371
R10	*to be used for extreme ice accretions*								

Table 4: Ice dimensions for vane shaped rime on bars

In Table 4 is for typical cross sections of bars given the dimensions of the ice vanes for the various ice risk levels. The dimensions in the table are based on a density of the ice of 500 kg/m^3.
For larger objects the mass of ice per meter will be bigger than that on the standard collector. In figures 2 and 3 is shown the principles for estimating the shape and the mass of rime on large objects.

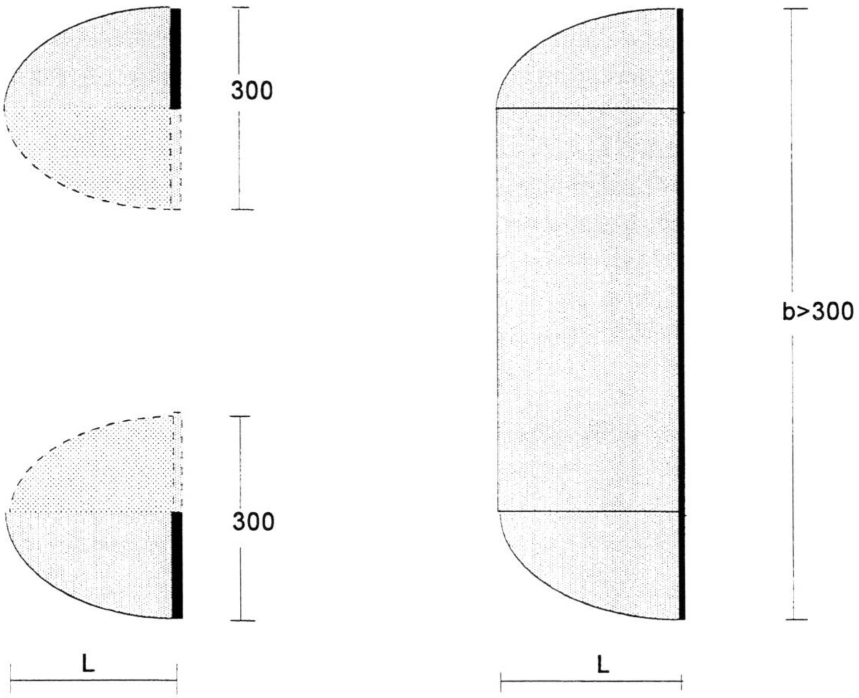

Fig. 2: Principle for estimation of ice on large flat objects

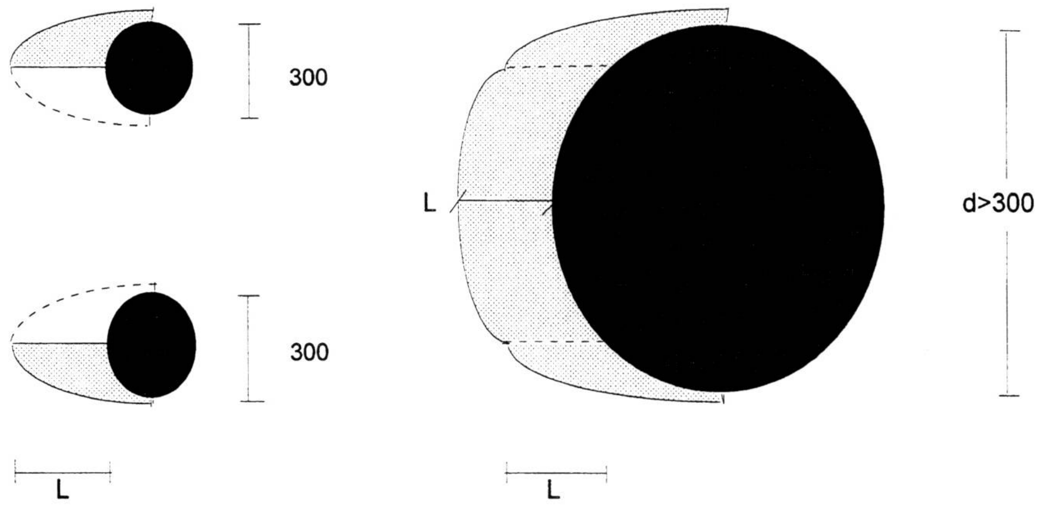

Fig. 3: Principle for estimation of ice on large round objects.

6. Wind and Ice

Besides the extra vertical loads due to the weight of the ice on the structure the icing will also increase the wind drag of the structure, and a combination of ice and wind may then govern the design. This is the case for instance for telecommunication masts and towers and for overhead transmission line towers in areas with reasonable ice loading.
In the ISO Standard is given recommendations for the estimation of wind drag coefficients for iced members and objects. The principle is based on factors to be used on the drag coefficient of the uniced members for the different ice risk levels. In Table 6 is as an example shown the factors for uniced members for rime.

IRL	Ice-mass [kg/m]	FACTOR ON THE DRAG COEFFICIENT Drag coefficient without ice 1	1,2	1,4	1,6	1,8	2
R1	0,5	1,07	1,04	1,02	1,00	0,99	0,98
R2	0,9	1,13	1,07	1,03	1,00	0,98	0,96
R3	1,6	1,20	1,11	1,05	1,00	0,96	0,93
R4	2,8	1,27	1,15	1,06	1,00	0,95	0,91
R5	5,0	1,33	1,19	1,08	1,00	0,94	0,89
R6	8,9	1,40	1,22	1,10	1,00	0,93	0,87
R7	16,0	1,47	1,26	1,11	1,00	0,91	0,84
R8	28,0	1,53	1,30	1,13	1,00	0,90	0,82
R9	50,0	1,60	1,33	1,14	1,00	0,89	0,80
R10	to be used for extreme ice accretions						

Table 6: Drag coefficients for rime on bars.

When combining atmospheric iceload and wind load is normally combined the 50 year value of one load with a reduced value of the other load - for instance the one year value. Further the 50 year wind load is taken as the 50 year value of windload that may occur during icing periods. The reduction factor on the wind pressure to give the wind pressure in icing periods may be taken from Table 7 if no better information is available.

IRL G	Φ	IRL R	Φ
G 1	0,6	R 1	0,60
G 2	0,6	R 2	0,65
G 3	0,6	R 3	0,70
G 4	0,6	R 4	0,75
		R 5	0,80
		R 6	0,85
		R 7	0,90
		R 8	0,95
		R 9	1,00

Table 7: Reduction factor Φ on wind pressure to give the values in icing periods.

7. Concluding Remarks

The ISO Working Group for Atmospheric Icing on Structures plan to conclude the final draft for the standard in the Autumn 1996 so it will be ready for a voting by the Technical Committee TC 98 in the end of 1996.
Having hopefully finished the ISO Standard there still need to be undertaken a great job to implement the philosophy of the standard nationally as well as internationally. One of the most comprehensive tasks will be the creation of ice maps giving the actual Ice Risk Level for the various parts of the contries, in a similar way as for basic wind speeds and snow loads.
The members of the ISO Working Group contributes to the elabration of the standard without any financial support from ISO, and it is not realistic to include the elaboration of icemaps in the scope of the Working Group. The members of the Working Group may of course to a certain aspect assist national, European or other international organizations in the future implementation of the ISO Standard for Atmospheric Icing on Structures.