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INTENSITY OF ICING OF BODIES WITH DIFFERENT SHAPES (DIE VEREISU--ETC(U)
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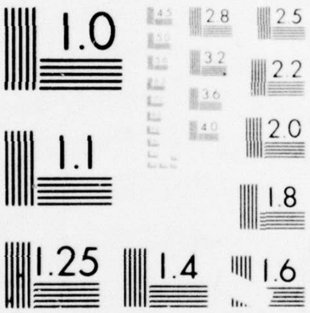

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Draft Translation 619
April 1977

(12)

INTENSITY OF ICING OF BODIES WITH DIFFERENT SHAPES

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HANOVER, NEW HAMPSHIRE

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Draft Translation 619	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) INTENSITY OF ICING OF BODIES WITH DIFFERENT SHAPES		5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) V.G. Gluchov		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Cold Regions Research and Engineering Laboratory Hanover, New Hampshire		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE April 1977 13. NUMBER OF PAGES 8
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

ICING RATE

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Correction factors are obtained for converting the weight of ice deposited on a linear meter of 5 mm diameter wire into that deposited on one square meter of surface of different, simply shaped bodies (circular cylinder, sphere, circular disk, and flat plate), using present concepts of the physical processes that cause the icing of bodies of different shapes and sizes. The magnitudes of the correction factors increase significantly with increase in wind speed and decrease in the characteristic dimensions of the body. The values

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DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE calculated for circular cylinders with a cross section of up to 200 cm are in good agreement with data from observations.

⑭ CRREL-TL-619

DRAFT TRANSLATION 619

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ENGLISH TITLE: INTENSITY OF ICING OF BODIES WITH DIFFERENT SHAPES

FOREIGN TITLE: (DIE VEREISUNGSINTENSITAT VON KORPERN MIT UNTERSCHIEDLICHER FORM),

⑪ Apr 77

⑫ 12 p.

⑩

AUTHOR: V.G./Gluchov

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Trans of ~~SOURCE~~: Zeitschrift fur Meteorologie, 1976, Vol. 26, No. 2, p.94-97.

v26 n2 p94-97 1976

CRREL BIBLIOGRAPHY
ACCESSIONING NO.: 31-592

Translated by Office of the Assistant Chief of Staff for Intelligence for U.S. Army Cold Regions Research and Engineering Laboratory, 1977, 8p.

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INTENSITY OF ICING OF BODIES WITH DIFFERENT SHAPES

V. G. Gluchov

Summary. Correction factors are obtained for converting the weight of ice deposited on a linear meter of 5 mm diameter wire into that deposited on one square meter of surface of different, simply shaped bodies (circular cylinder, sphere, circular disk, and flat plate), using present concepts of the physical processes that cause the icing of bodies of different shapes and sizes. The magnitudes of the correction factors increase significantly with increase in wind speed and decrease in the characteristic dimensions of the body. The values calculated for circular cylinders with a cross section of up to 200 cm are in good agreement with data from observations.

Ice loads that act on structural members are taken into consideration in structural design. These loads are calculated for all structural members other than circular and cylindrical members with a small cross section (wires, cables, lines) in accordance with USSR standards [12] using the equation

$$P_N = k\gamma b_N \frac{kg}{m^2} \qquad (1)$$

where k is the deposit coefficient that expresses the relationship between the surface of the body being covered with ice and the total surface;

$$\gamma = 0.9 \frac{g}{cm^3} \text{ is glaze ice density;}$$

b_N (mm) is the standard ice cover thickness with a density of $\gamma = 0.9$ g/cm^3 probable once in a given number of years.

The deposit coefficient is determined experimentally, primarily for circular and cylindrical members [1, 7, 8].

Initial data from observations of ice deposits on the television tower in Ostankino shows that the extent to which these members are covered with deposits decreases with increase in diameter.

It is of practical importance to define precisely the deposit coefficient, and to determine the relationship between the weight of a deposit on an object with a specific shape and the weight of ice deposit on a standard wire, or a standard rod.

The GGO* has, in recent years, worked on determining the intensity of ice formation on different members using theoretical considerations [3, 4, 5].

It is known that glaze ice and rime deposits on various objects are formed by the settling of supercooled cloud or fog droplets, the result of inertia, by the settling of wet snow, or of rain particles, the result of gravitation, by the settling of minute particles, the result of diffusion, and by the sublimation of water vapor on a cooled surface.

References [7, 10, 13 and 15] have shown that diffusion phenomena are of no practical significance because the percentage of very minute droplets in the water content of a cloud, or fog, is negligibly small.

Nor is the role of the sublimation processes of any great moment because these processes are only responsible for the formation of ice deposits when there is a slight wind, and even then the deposits are small.

Experimental observations of ice deposits on high masts (1, 7, 8], and under conditions that prevail in mountain areas [11], have shown that in many areas of the USSR hoarfrost, and a mixture, are the major forms of deposits that form in clouds and fog, settling out as a result of inertia, followed by freezing of the water droplets on the surface of the body concerned. These deposits thus represent very heavy loads on structures.

This is why the calculations made at the GGO were based on a simplified model of a deposit that is solely the result of inertia and on the assumption that all other factors in the formation of ice deposits were negligible.

The model ice load was calculated in kg per 1 m^2 using

$$P = \tilde{E} \beta u w \tau \frac{s'}{s} \tag{2}$$

where

$\tilde{E}$ is the completely integral deposit coefficient representing the extent of the settling, the result of inertia. of droplets of various sizes on the surface of the body, and is numerically equal to the ratio of the magnitude of the moisture that settles to the magnitude of the moisture transported;

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*GGO - The Soviet Union's A. I. Voyeykov Main Geophysical Observatory.

β is the freezing coefficient, indicating that percentage of the droplets that settle on the surface of the body, freeze, and form the ice deposit;

τ is the growth rate (sec);

u is the wind speed (m/sec);

w is the water content in the cloud, or fog (kg/m^3);

s' is the surface of a projection of the body on a surface normal to the flow (m^2);

s is the total surface of the body (m^2).

Eq. (2) becomes the following when calculating the ice load on a unit length, l (*1 linear meter*), of a wire, cable, or line

$$P_d = \tilde{E}_d \beta_d u w' \tau d \tag{3}$$

The method used to calculate $\tilde{E}$ and β is dealt with in detail in reference [10]. References [3, 4] suggest that $\beta \approx \beta_d \approx 1$ can be assumed for the values of wind speed and air temperature that predominate when high structures ice up. $\tilde{E}$ depends on wind speed, dimensions of the body, and mean droplet radius (r_m).

Eqs. (2) and (3) yield a relationship between the ice load per square meter of surface of the body under consideration and the weight of the ice deposited on one linear meter of a standard wire

$$K_s = \frac{P}{P_d} = \frac{\tilde{E}s'}{\tilde{E}_d s d} \tag{4}$$

K is the correction factor used to convert the ice load on a wire of diameter d to that on bodies of different shapes.

The conversion factors used to convert the ice load on the wire of standard ice deposit measuring equipment (d = 5 mm) to that on wire of other dimensions can be calculated by using the equation

$$K_d = \frac{P_d}{P_5} = \frac{\tilde{E}_d d}{5\tilde{E}_5} \tag{5}$$

where d and 5 are the diameters of the wires, mm.

Eqs. (4) and (5) are valid for use when the bodies are located at the same height above ground and are comparable.

If this is not the case, change in wind speed (v), water content in the cloud (fog) (w), and the longer time of the ice deposit formation (τ) with height all must be taken into consideration when calculating K_s and K_d.

References [3, 4, 5] have shown that correction factors K_d, calculated using Eq. (5), are in good agreement with the experimental values for circular and cylindrical members with a cross section of 10 to 200 mm. Calculations using this formula yield extraordinarily low values for larger diameter bodies.

The explanation for this is primarily based on the fact that when the characteristic dimension of a body (and by characteristic dimension is meant the width of a flat plate or the diameter of a cylinder, sphere, or disk) is sufficiently large, what is observed is definitely greater accretion of deposits on individual sections of the surface, or in the area of the front critical point of a circular cylinder, or sphere, or along the edges of a plate, or disk, for example [2, 10, 14, 16].

The greater the characteristic dimensions of a body, the smaller the width of the area of greater accretion.

It makes sense, therefore, to replace the completely integral deposit coefficient $\tilde{E}$ (characterizing the mean area on which deposits have settled over the entire surface) in Eqs. (4) and (5) with a local deposit coefficient, $\tilde{E}_l$, characterizing the maximum area on which deposits have settled over sections with greater accretion of deposits, when calculating K_s and K_d, in order to obtain a more precise determination of the intensity with which ice deposits form on bodies larger than 200 mm.

Eq. (5) then takes the form

$$K_s' = \frac{F_l d}{E_d d} \tag{6}$$

Eq. (6) is used to find the conversion factor, K_s', for a circular cylinder, a flat plate, a sphere, and a round disk.

$\tilde{E}_l$ and $\tilde{E}_d$ for the cylinder and sphere were taken from nomograms in the studies by I. P. Mazin [10] and V. M. Voloscuk [2]. $\tilde{E}$ for a flat plate and a round disk was found by using the values supplied by L. M. Levin [9].

The mean radius of cloud droplets (r_m) was taken as 5 μ for the $\tilde{E}$ calculations. This was in accordance with references [10, 13, 15].

Table 1 lists the values obtained for K_s' for bodies with characteristic dimensions (d) 25, 50, 100, and 200 cm.

This table now can be used to suggest the following major behavior patterns in the formation of ice deposits on the bodies under consideration.

Table 1

K_s' Values as a Function of Wind Speed (u) and Characteristic Dimensions (w) of the Body, $r_m = 5\mu$

D	Wind speed (m/sec)		
(cm)	<8	8 to 16	>16
Circular cylinder			
25	1,02	1,78	4,25
50	0,18	0,37	1,28
100	0,14	0,32	1,03
200	0,08	0,26	0,80
Flat plate			
25	1,82	5,88	16,00
50	0,95	2,80	6,70
100	0.28	0,67	1,20
200	0,06	0,12	0,18
Round disk			
25	1.28	6,52	12.46
50	0,24	1.87	6.60
100	0,09	0,53	3.00
200	0,05	0,31	1,65
Sphere			
25	0,43	1,45	2,65
50	0,08	0,33	0,82
100	0,05	0,22	0,58
200	0,03	0,12	0,30

1. The intensity of the formation of ice deposits on all the bodies *under consideration decreases significantly with increase in size, and* with reduction in wind speed, because accretion attributable to inertia decreases substantially in such cases.

2. Accretion is most intensive on a flat plate, and on a round disk.

3. The ice load on 1 m^2 of surface is considerably less for bodies *larger than 25 cm, and when wind speed is less than 8 m/sec,* than is the load on a linear meter of wire with a cross section of 10 mm.

K_s' values calculated for a circular cylinder using Eq. (6) were compared with the corresponding experimental values obtained from data processed from observations made at the television tower in Ostankino [1, 8]. The empirical values are for a height of 500 m above the terrestrial surface, so the mean radius of the cloud droplets was taken to be 7 μ at this height in accordance with references [10, 13, 15].

Table 2

K_s' Values, Calculated (Numerator), and Experimental (Denominator), for a Circular Cylinder, $r_m = 7\ \mu$

D	Wind speed (m/sec)				
(cm)	8	10	12	14	15
10	$\frac{2,40}{2,68}$	$\frac{3,47}{2,92}$	$\frac{5,48}{5,70}$	$\frac{7,20}{6,40}$	$\frac{7,32}{6,80}$
20	$\frac{3.06}{2,80}$	$\frac{3,32}{3,65}$	$\frac{3,66}{4,45}$	$\frac{4.03}{4,90}$	–

As will be seen from this table, the K_s' values calculated for circular cylinders with cross sections of 10 and 20 cm are in satisfactory agreement with the empirical values.

Unfortunately, the K' values for a plate, a disk, and a sphere could not be compared with the experimental data because there are no systematic measurements of the weight and scope of ice deposits on bodies with the different shapes listed in Table 1.

A precise elucidation of Eq. (1), which is used in construction standards, very definitely requires that systematic measurements be made of the weight and scope of deposits on bodies with different shapes.

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