韓國水資源學會誌 論文
第29卷 第2號·1996年 4月
pp. 191~198

고정케이블에 작용하는 Icing 하중: II. 적절한 특성길이의 결정
Icing Loads on Fixed Cables: II. Determination of Proper Length Scale

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Abstract

Attempts were made to determine a proper length scale representing characteristics of icing geometry. It was difficult to determine a single length scale especially for glaze icings because of their shape complexity. However, use of icing length, which is defined as the length of icing normal to the wind, as a characteristic length is suggested rather than the cylinder or cable diameter.

요 지

본 논문에서는 icing의 모양을 대표적으로 나타낼 수 있는 적절한 특성길이의 선정에 대해 서술하였다. 실험 자료를 분석한 결과, 어떤 하나의 길이 단위로 특성길이를 정의하기는 곤란하였다. 특히, glaze icing의 경우에는 그 형상이 매우 복잡하여 특성길이를 결정하기가 매우 어려웠다. 그러나, 바람의 방향에 수직한 단면의 길이로 정의되는 icing 길이가 icing으로 인한 하중을 나타내기에는 실린더 혹은 전선의 지름 보다는 더 적절한 특성길이라 판단된다.

1. Introduction

The literature in icings contains fairly extensive information on loads associated with icing formation, but is sparse with regard to the selection of a representative length parameter for characterizing Reynolds numbers of airflow around icings, and thereby appropriately characterizing drag and lift coefficients associated with wind loads. The study reported herein was aimed to provide quantitative insights into this aspect.

A problem with past research is that no standard exists for the characteristic length of an icing shape. McComber and Bouchard (1986) defined an icing characteristic length as the maximum length of an iced conductor's cross–

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section intersecting the center of a cable or circular cylinder. Koutselos and Tunstall (1986) simply used the bare cable diameter. Jones and Govoni (1990) used the average diameter of an iced cable as the characteristic length. McComber et al. (1983) defined characteristic length as the equivalent diameter of radial ice. Govoni and Ackley (1983) defined characteristic length as the cross-section of the accretion normal to the wind.

Each choice, on its own, is based on sound logic, but the problem arises that data become hard to compare between different research programs because the characteristic length chosen, and resulting values of Reynolds number, drag, and lift coefficients, are different. The dimensional values of wind speed, drag, and lift force can be calculated only if consistent dimensions are given. Moreover, for large amounts of data this task becomes tedious and is not suitable for general design purposes.

In this study, attempts were made to determine the proper length scale which represents the characterisrics of icing geometry, based on the data obtained from the laboratory experiments described in the previous paper of this issue.

2. Variation of Loads with Characteristic Length

Results of the companion paper (Yoon and Ettema, 1996) revealed that icing loads are not significantly dependent on the cylinder or cable diameter for glaze icings. Another possible, and probably more reasonable length scale is 'icing length' of icing normal to the wind. For glaze icings, icing length takes into account the added projected length due to the vertical formation of icicles (see Fig. 1a). For rime icings, though, icing length may be just as well be defined as the cable diameter (see Fig. 1b), because the icing accretes in the windward face and does not substantially alter the frontal width of the cable. Selection of an appropriate characteristic length for describing icings, especially the wind loads exerted against them, is described subsequently.

2.1 Icing Weight

Figs. 2 and 3 present values of icing weight per unit length, $\overline{W}$, after 30 minutes of icing accretion, plotted versus cable or cylinder diameter, D and icing length, respectively. Air temperature is a third parameter in Figs. 2 and 3.

As shown in Fig. 2, it is very difficult to determine a simple relation between icing weight and D for the glaze icings, while for rime icings (data points shown as "+"), icing weight varied more or less linearly with D. On the other hand, icing weight generally increases with increasing icing length, as Fig. 3 shows. The data

(a) Glaze Icing (b) Rime Icing

Fig. 1. Definition of Icing Length

still exhibit wide scatter, though less so than in Fig. 2, because icing weight depends on icing thickness (Fig. 1a) as well as on icing length. In fact, although icing thickness is a function of freezing fraction, which is in turn a function of air temperature, icing length is less clearly dependent on air temperature, as indicated in Fig. 2. Therefore, values of icing weight show wide scatter depending on air temperature, even for the same icing length.

It is evident that the data in Figs. 2 and 3 are scattered quite widely. The scatter is attributable primarily to randomness of icicle dimensions, which is considered to be caused, in part, by unsteadiness and uncertainties of environmental conditions such as air temperature, moisture-flow rate, water temperature, spray-nozzle condition and wind speed.

There seems to be a more pronounced trend in Fig. 3, where icing weight is plotted versus icing length. The data in Fig. 2 shows no significant trend because for glaze icings, icicles radically alter the frontal projection of the cable, thereby affecting the growth. Given that icicle growth is quite random, using D, cable or cylinder diameter, as a characteristic length will not produce a reliable relationship. Therefore, it seems feasible that a relation can be more easily developed between icing weight and icing length.

2.2 Lift

Figs. 4 and 5 present values of lift per unit length, after 30-minutes accretion, versus cylinder or cable diameter and icing length, respectively, with air temperature as a third parameter. It is seen in Fig. 5 that lift increases linearly with icing length for glaze icings, although the data are mildly scattered. For rime icings, lift forces are negligible, in keeping with

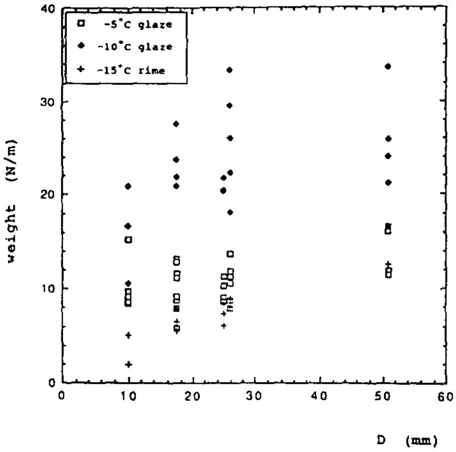

Fig. 2. Icing Weight versus Collector Diameter

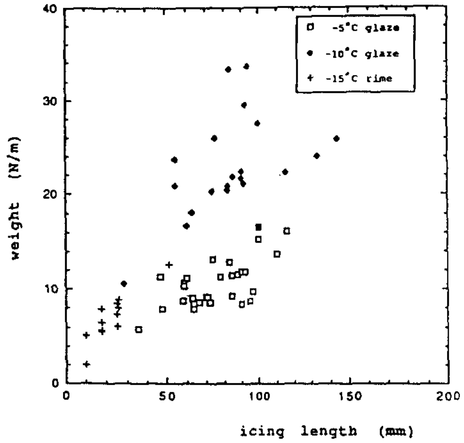

Fig. 3. Icing Weight versus Icing Length

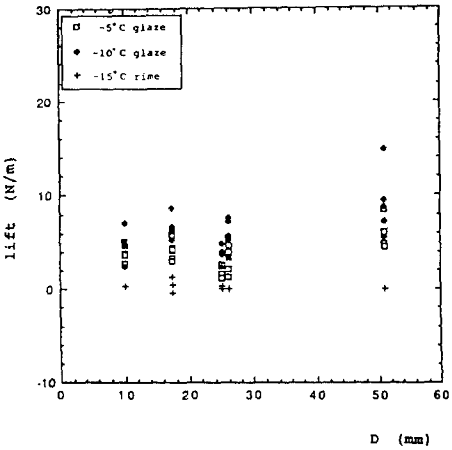

Fig. 4. Lift versus Collector Diameter

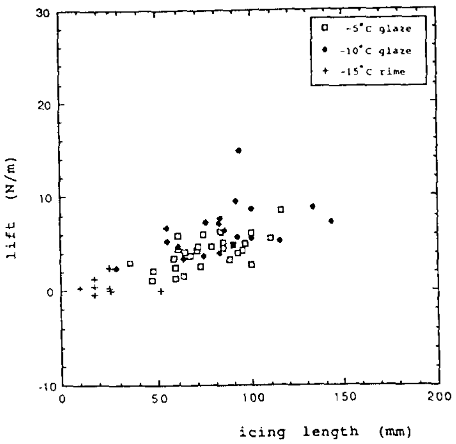

Fig. 5. Lift versus Icing Length

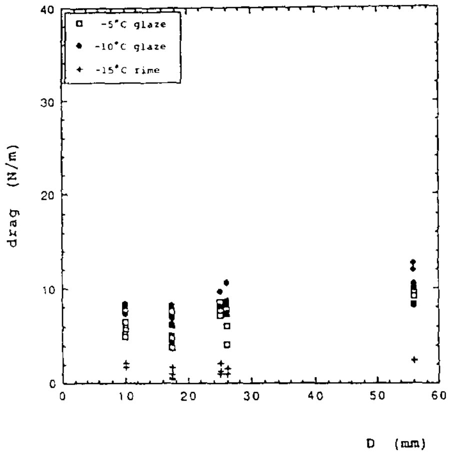

Fig. 6. Drag versus Collector Diameter

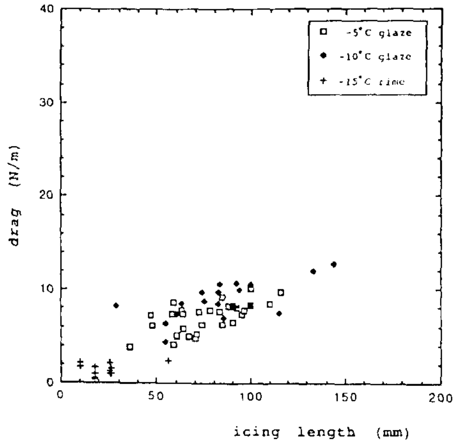

Fig. 7. Drag versus Icing Length

their virtually symmetric shapes.

In determining a characteristic length for an icing, icing length appears a better parameter for determining lift than cable diameter. Since lift is generated from an asymmetric body, the icing length would take into account the asymmetry, while cable diameter, by definition, could not. As seen in a comparison of Figs. 4 and 5, there seems to be a linear relationship in Fig. 5 while there is no relationship between cable diameter and lift forces.

2.3 Drag

Figs. 6 and 7 present values of drag force exerted against icing formed after 30 minutes of formation plotted versus cylinder or cable diameter and icing length, respectively. Drag force exerted against glaze icings is greater than that exerted against rime icings, which demonstrates that icicles significantly increase drag. As shown in Fig. 6, for icings formed at all temperatures, it is very difficult to find a simple relation between drag and D, although drag force increases, in general, with increasing cylinder or cable diameter. Especially, for glaze icings formed at -5℃ and -10℃, drag force exerted against the smallest cable (D = 10 mm) is, on average, about same as those exerted against icings formed on the 17.5 mm cable.

The results described above indicate that drag against glaze icings is not markedly dependent on cylinder or cable diameter. Because icicle for mation completely dominated icing form for glaze icings, it is anticipated that drag for glaze icings is stongly dependent on icing length. Fig. 7 shows, as anticipated, that drag force increases more-or-less linearly with icing length, as did lift (see Fig. 5). Drag, however, is more sensitive to icing length than is lift. Like the scatter in lift data (see Fig. 5), data scatter in

Fig. 7 is attributable to differences in values of freezing fraction for the three air temperatures considered and difficulties in maintaining steady experimental conditions.

As shown in Figs. 6 and 7, drag force correlates well with icing length, more so than cable diameter. This correlation exists because drag is dependent on the projected area normal to the wind. Icing length, by definition, is the projected length normal to the wind. Icing length, therefore, is the better candidate for characteristic length.

2.4 Influences of Wind Speed on Icing Wind Loads

The data used in this part of the study were obtained from the experiments carried out in the non-refrigerated laboratory. The experiments were aimed to determine how drag and lift forces exerted against preformed icings vary with wind speed or Reynolds number (Re) of flow around icings.

In this study, two different length scales, cylinder or cable diameter and icing length, were used to define drag and lift coefficients, and Reynolds number, as indicated in Eqs. (1), (2) and (3).

$$C_D=\frac{\bar{F}_D}{\frac{1}{2}\rho_a V_0^2 L_c} \tag{1}$$

$$C_L=\frac{\bar{F}_L}{\frac{1}{2}\rho_a V_0^2 L_c} \tag{2}$$

$$Re=\frac{V_0 L_c}{v_a} \tag{3}$$

in which L_c = a characteristic length of the body, and v_a = kinematic viscosity of air. Either cylinder or cable diameter, D, or icing length, L_i,

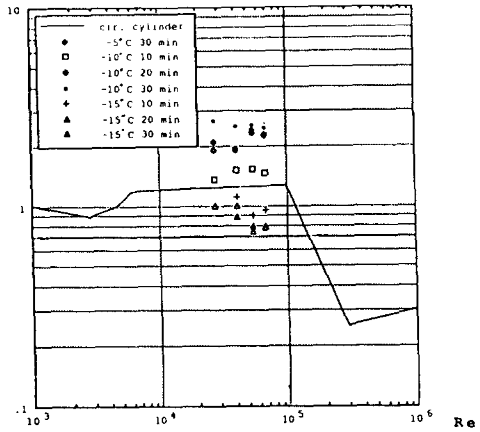

Fig. 8. Drag Coefficient. C_D, in terms of Re, with D Used as Characteristic Length

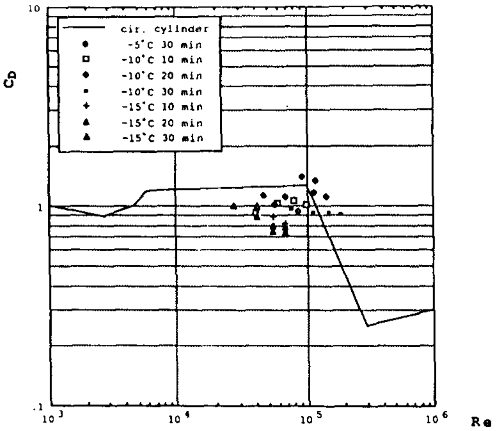

Fig. 9. Drag Coefficient. C_D, in terms of Re, with L_i Used as Characteristic Length

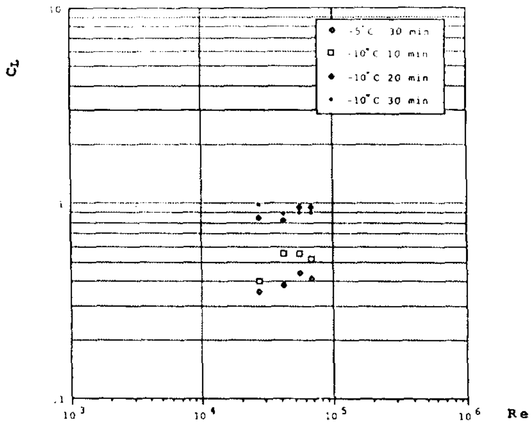

Fig. 10. Lift Coefficient. C_D, in terms of Re, with D Used as Characteristic Length

could be selected as L_c.

As discussed in the companion paper (Yoon and Ettema, 1996), Fig. 8 shows that the value of C_D is constant and of a higher magnitude than the circular cylinder for the Re range of 5×10^3 to 10^5. Fig. 8 also shows that C_D increases with stage of glaze–icing formation. For rime icings, however, C_D was reduced as rime icing formed from the value for a circular cylinder. Fig. 8 also shows that values of C_D associated with rime icings decrease with Re because the data of this Re range (between 2×10^4 and 7×10^4) are probably in what is commonly known as the drag–crisis zone.

Fig. 9 presents the values of C_D versus Re based on icing length as a characteristic length. Values of C_D for rime icings are equal to those in Fig. 8, because the icing length and cylinder or cable diameter are the same for rime icings.

For glaze icings, values of C_D in Fig. 9 are more closely distributed than those in Fig. 8, and average about 1.1. However, it is very difficult to express those data points with a single curve, mainly because glaze–icing geometry is so complex and variable that it cannot be characterized in terms of icing length alone.

As lift forces exerted against rime–icing forms were found to be negligible, they were measured only for the glaze–icing models. Figs. 10 and 11 present values of C_L for four glaze–icing forms in terms of Re, in which C_L and Re are based on D, and icing length, L_i, respectively.

Fig. 10, in which C_L is based on D, indicates that values of C_L range from about 0.3 to about 1.0, and shows clearly the difference between the values of lift exerted against each icing form used in the experiment. Fig. 11, in which C_L is based on icing length, L_i, shows that values of C_L range from 0.2 to 0.5, and that data points of different icing forms are mixed together with an approximate average of 0.4. It is, however, very difficult to determine a unique relation between C_L and Re in Fig. 11, because the local flow field around, and through, an icicle–fringed icing is variable in accordance with the rather random and quite complex geometry of icicle fringes formed along the lower side of glaze icings.

3. On Standardizing Characteristic Length

As mentioned above, there are many ways to define characteristic length. Difficulty arises when researchers, who use different definitions of characteristic length, attempt to compare results, because different usages of characteristic length result in different values of Reynolds number, lift and drag coefficients. Therefore, direct comparison is not possible. In the preceeding section, attempts were made to determine a characteristic length between the choices of bare cable diameter and length normal to the wind, icing length. This study is by no means exhaustive of the possibilties for characteristic length, but possibly a catalyst for further research.

Some desirable properties for a standardized characteristic length would be the strong correlation with design quantities, notably weight, lift and drag. An appropriate characteristic length should also be known or at least be easily determined from other known properties.

In terms of this study, relationships between the dimensional values of weight, lifts, and drag and icing length, L_i, are clearly evident in Figs. 3, 5, and 7, respectively. Relationships between the dimensional values and cable diameter, D, are not as obvious, as shown in Figs. 2, 4, and 6. Examining the non–refrigerated laboratory results of drag (see Figs. 8 and 9) and lift (see Figs. 10 and 11), data points are more closely

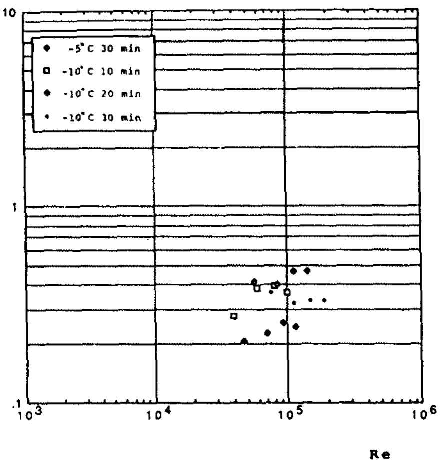

Fig. 11. Lift Coefficient. C_D, in terms of Re, with L_i Used as Characteristic Length

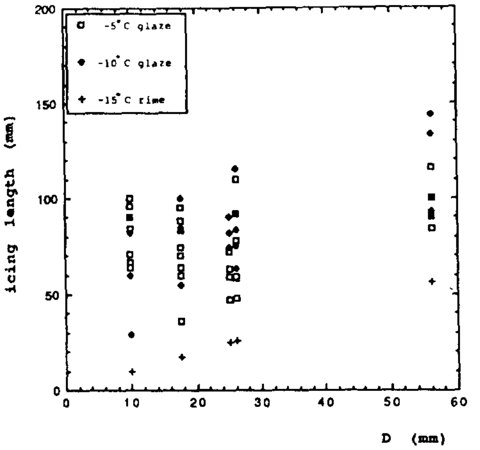

Fig. 12. Icing Length versus Collector Diameter

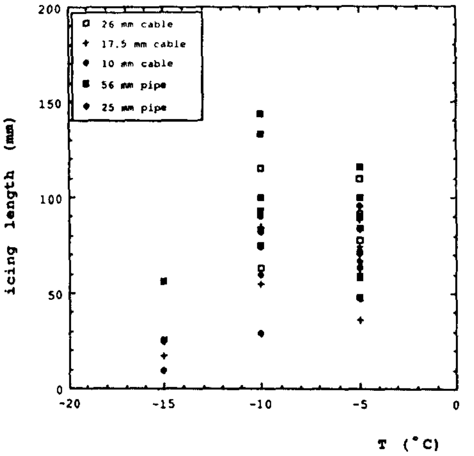

Fig. 13. Icing versus Air Temperature

distributed when icing length is used as a characteristic length. These results indicate that icing length is the better characteristic length in determining the weight and wind loads.

There are, however, many difficulties, particularly for growing glaze icings, in using this result for design purposes because icing length is a dependent variable. Some more efforts are, therefore, needed to correlate icing length with some basic parameters such as air temperature, moisture-flow rate, wind speed, cylinder or cable diameter, etc. In this study, attempts were made to correlate icing length with cylinder diameter or air temerature but no simple relation was found between icing length and cylinder diameter or temperature, as shown in Figs. 12 and 13.

4. Conclusions and Recommendations

A difficulty in comparing wind load data from prior studies is the lack of consensus on use of a standard characteristic length for describing icings. Attempts were made herein to determine a standardized length scale which would have a good correlation with icing loads. For glaze icings, the icing loads were not simply dependent on D, because development of icicles substantially increased cylinder or cable frontal area. To include the effect of icicles, icing length, L_i, was defined and used to describe icing loads. The load data proved better correlated with L_i than D, especially for drag and lift. For rime icings, icing length and cylinder or cable diameter are the same and, therefore, either can be used as a characteristic length.

However, a remaining difficulty for design purposes is that L_i is a dependent variable, varying with the prevailing icing conditions. No simple correlation was found between glaze icing loads and independent variables available in this study such as D and air temperature. It is, therefore, recommended to make more efforts in collecting data under various environmental conditions for representing icing length in terms of dependent variables.

Acknowledgment

This study was supported by funds provided by the U. S. National Science Foundation under grant No. CES-861185, and by funds provided by Myong Ji University.

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〈접수 : 1995년 10월 12일〉