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Variation of Strouhal Number on Iced Cable in Sub-Transitional Range

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Abstract: The influence of ice accretion, angle of attack and Reynolds number on the flow field around iced cables of the cable-supported bridges is not clearly understood. The paper presents results of a wind tunnel investigations of Strouhal number of stationary iced cable model of cable-supported bridges. The investigations were carried out in a Climatic Wind Tunnel Laboratory of ITAM. The methodology leading to the experimental icing of the inclined cable model in the climatic section of the laboratory was prepared. For the aerodynamic investigations the iced cable model in a smaller scale was reproduced with combination of photography and 3-D printing procedure. The Strouhal number (St) was determined within the range of the Reynolds number (Re) between 2.4×10^4 and 16.4×10^4, based on the dominant vortex shedding frequency measured in the flow behind the model. The model was orientated at three principal angles of wind attack for each of the Re. Good agreement with the generally reported value in the sub-critical Re range for a circular cylinder was obtained.

Introduction

The change of the cross-section of the cable due to the ice accretion has a significant influence on the flow field around the cables and its aerodynamic [1]. In this case, an asymmetric airflow around the cable appears, thus, an asymmetric distribution of the wind pressure on its surface exists. For this reason, three aerodynamic coefficients, i.e. drag, lift and moment coefficients depending on the angle of the wind attack should be taken into account. Moreover, in such conditions, an aeroelastic instability of an iced cable known as galloping instability may occur if the specific criteria are met. It is well documented that the amplitude of galloping of ice accreted cables or transmission lines could be very large, [2]. The analysis of the vortex excitation response of the iced cables requires, among others, knowledge of the Strouhal number, which characterizes the vortex shedding frequency and is necessary for determination of critical wind velocity at which the largest amplitudes due to the vortex excitation are observed. This manuscript presents the method and the results of a wind tunnel investigations of St of stationary iced cable model with respect to different angles of wind attack. The methodology leading to the experimental icing of the inclined cable model in the climatic section of the laboratory was prepared. The shape of the ice on the cable was registered by a photographic method with combination of numerical image analysis. St number was determined within the range of the Re between 2.4×10^4 and 16.4×10^4, based on dominant vortex shedding frequency measured in the flow behind the model. The model was oriented at three principal angles of wind attack for selected values of the Re.

Ice accretion on cable

Different types of ice can be rise in different climatic conditions, i.e. in different combinations of temperature, wind velocity, angle of wind attack and droplets of the rain. For the purpose of this research, the most common natural conditions, expected at Central European geographical condition, were selected, causing smooth evenly distributed ice accretion together with frozen rivulets on the cable within a mild rain, relatively low wind velocity (2.8 m/s) and the temperature slightly below 0^oC.

After several preliminary tests, 40 min cooling exposure time was selected as sufficient from the point of view of ice creation. During the experiment, the model was inclined in a horizontal plane to the airflow direction at the angle of 60^o. The angle was found from several preliminary tests as one, at which the ice ribs on the bottom side of the model are distinctive. The final ice shape on the cable model was compared to the reference pictures from real situations. The characteristic ice ribs (frozen rivulets on the bottom side of the model) were created and used for further examination. On the upper part of the model the ice shape was similar to the circular shape. The cross-section of the cable with an ice became strongly non-symmetrical with the dimensions 0.192 m in high and 0.181 m in width. The cooling and icing procedure was carried out on a scale of 1:1, thus, no scaling factors were considered. Surface (roughness, material) effect on the flow around the cable during icing procedure is negligible because of low wind velocity, also relatively big drops were simulated and effect of the flow deflection near the surface of the cable on drop trajectory is negligible. Three configuration were selected with respect to the wind angle attack on the cable, see Fig. 1.

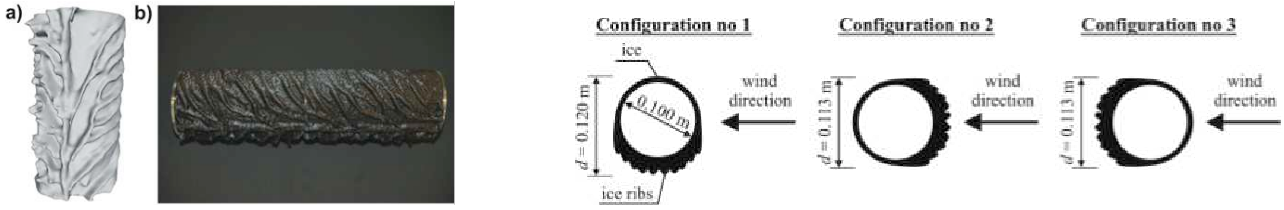

Fig. 1: Left: Ice on the cable segment - a) digital model, - b) printed section; Right: Ice configurations.

Conclusion, results

The experimental creation of the ice on an inclined cable model of cable-supported bridges was carried out in the climatic chamber of the wind tunnel of CET ITAM. The St was investigated for the stationary iced cable model with respect to three principal angles of wind attack. The ice accretion process produced the asymmetrical and irregular iced cross-section of the cable model with rounded edges of the ice ribs accreted on the bottom side of the model (with maximal surface roughness of 18%) and with the quasi-circular shape on its upper part (with minimal surface roughness of 0.73%).

At first configuration initially, in the range of $Re = 2.5 \times 10^4 \div 6.1 \times 10^4$, the St values linearly decrease from $St = 0.199$ to 0.189. In the range of $Re = 6.1 \times 10^4 \div 9.9 \times 10^4$, St suddenly increases to $St = 0.206$ and for $Re > 9.9 \times 10^4$, St again decreases to $St = 0.198$. As for the second configuration the St number is changing in the range of $St = 0.201 \div 0.205$ and seems to be independent of Re. All obtained St values are 12% to 14% higher than $St = 0.18$ used as reference. The variability of the St for this configurations can be incidental and may be caused by the randomness of the vortex excitation. The St number determined for the third configuration strictly depends on Re. Its values were initially in the range of $St = 0.186 \div 0.187$ for $Re = 2.4 \times 10^4 \div 4.6 \times 10^4$, while in the range of $Re = 4.6 \times 10^4 \div 9.5 \times 10^4$, St number suddenly increased to maximum value $St = 0.215$. In the range of $Re = 9.5 \times 10^4 \div 15.8 \times 10^4$, St number remain in the range of $St = 0.205 \div 0.215$. Effect of the change of wind direction on the iced cylinder can thus be attributed to the experimental data by [3] obtained at different surface roughness of the cylinder.

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