ARTICLE IN PRESS

Journal of Wind Engineering & Industrial Aerodynamics xxx (2017) 1–16

Contents lists available at ScienceDirect

Journal of Wind Engineering & Industrial Aerodynamics

journal homepage: www.elsevier.com/locate/jweia

Aerodynamics of a stay cable with helical fillets - Part I: Stability and load characteristics

H. Christiansen [a,*], J.B. Jakobsen [a], J.H.G. Macdonald [b], G.L. Larose [c,1], H.R. Bosch [d]

[a] Department of Mechanical and Structural Engineering and Material Science, University of Stavanger, Norway
[b] Department of Civil Engineering, University of Bristol, UK
[c] National Research Council Canada, 1200 Montreal Road, Ottawa, Ontario, Canada
[d] Aerodynamics Laboratory, Federal Highway Administration, McLean, Virginia, USA

ARTICLE INFO

Keywords:
Bridge stay cable
Helical fillets
Inclined circular cylinder
Cable instability
Surface pressures
Sectional loads
Quasi-steady theory
Reynolds number

ABSTRACT

The aerodynamic behaviour of a bridge stay cable with helical fillets in smooth flow at high Reynolds numbers is presented in this paper. The cable response and related sectional load characteristics were studied experimentally on a 1:1 scale cable section model. The studies showed that a cable with helical fillets inclined 60° to the flow could experience large amplitude wind induced vibrations and that the occurrence of vibrations were highly dependent on cable surface irregularities. The ambition is not to explain fully the excitation mechanism, but to present global and local influences of the helical fillets on the flow field. It was revealed that the flow field around the cable shifted between semi-stable transition states which took place when the transition from laminar to turbulent flow propagated from the free shear layers to the boundary layer. The transitions would form locally and spread along the cable axis. The helical fillet appeared to dominate the local flow structures when located at an angular position between 40° and 130° from the stagnation region. In the stagnation and base regions, the surface irregularities appeared to dominate. Furthermore, the helical fillets displaced the mean stagnation line. The application of quasi-steady theory with the measurement data available appeared not to be able to explain the vibrations.

1. Introduction

The first application of helical fillets to bridge stay cables were on the Normandy Bridge in France. The purpose of the helical fillets was to mitigate rain-wind induced vibrations (RWIV) which most likely compose 95 % of all inclined bridge cable vibrations according to Gimsing and Georgakis (2012). The efficiency of different fillet designs was examined in precipitation conditions at the Centre Scientifique et Technique du Bâtiment (CSTB) in Nantes by Flamand (1995) before the final design was selected for the bridge. Further wind tunnel tests of cables with helical fillets were undertaken in connection with the construction of the Øresund Bridge by Larose and Smitt (1999). However, the efficiency of helical fillets to also mitigate dry inclined cable vibrations has not been verified. There is no compelling evidence that cables with helical fillets installed on cable stayed bridges have experienced large amplitude vibrations, but dry inclined cable vibrations have been observed on cable stayed bridges with smooth cable surfaces, see e.g. Zuo and Jones (2010). This has lead to concerns regarding the aerodynamics of inclined stay cables with helical fillets, and in order to fill this gap in knowledge, wind tunnel experiments were carried out at the National Research Council Canada (NRC) in 2011. Based on those experiments, this paper examines the aerodynamic stability of a dry inclined bridge cable with helical fillets at high Reynolds numbers in smooth flow and the underlying load characteristics.

Helical fillets (also called ribs in the literature) are widely used on bridges in both Europe and the Americas. However, no guidelines to the geometry of the fillet exist which has led to different designs promoted by the cable manufacturers. Examples of various helical fillet designs in use are presented in Table 1 together with the design that was selected for the present study, estimated to be a good representation of actual designs. The cross-section of helical fillets is normally either rectangular or near-circular, with a slightly larger width than height due to the manufacturing process. Should the cross-section of the helical application be round, it is referred to in the literature as a helical wire. Larger

* Corresponding author. Now at: Svend Ole Hansen Aps, Sankt Jørgens Allé 5C, 1615 Copenhagen V, Denmark.
E-mail address: hch@sohansen.dk (H. Christiansen).
[1] Now at: RWDI, 75 Albert Street, Suite 209, Ottawa, ON, K1P 5E7, Canada.

https://doi.org/10.1016/j.jweia.2018.01.045
Received 23 July 2017; Received in revised form 28 January 2018; Accepted 28 January 2018
Available online xxxx

Please cite this article in press as: Christiansen, H., et al., Aerodynamics of a stay cable with helical fillets - Part I: Stability and load characteristics, Journal of Wind Engineering & Industrial Aerodynamics (2017), https://doi.org/10.1016/j.jweia.2018.01.045

Table 1
Typical helical fillet geometries (all double helix). The elliptical shapes were formed by a semi-circular shape squeezed to the cylinder surface.

Bridge	Cable diameter [mm]	Pitch [mm]	Helix angle [degrees]	Pitch to diameter ratio	Helical fillet [mm]	Cross-section helical fillet
Normandie	170	600	41.7	3.5	1.3 high × 2 wide	rectang.
Øresund	250	550	55.0	2.2	2.1 high × 3.0 wide	rectang.
Charles River	178	610	42.5	3.4	1.5 high × 3.3 wide	rectang.
Generic 1	200	600	46.3	3.0	2.0 dia.	round
Generic 2	160	490	45.7	3.1	4.0 dia.	round
Generic 3	200	620	45.4	3.1	2.0 dia x 4.0 wide	elliptical
Generic 4	200	630	45.0	3.1	2.0 dia x 4.0 wide	elliptical
Present study	162	520	44.5	3.2	2.3 high × 2.4 wide	rectang.

helical protrusions of rectangular cross-section known as helical strakes or fins also exist, but have so far not been installed on bridge cables. With a significant height of 10–12% of the cylinder diameter they suppress vortex-induced vibrations and are found on e.g. marine risers and chimneys. Over the years, numerous studies have been undertaken to investigate the influence of various types of helical applications, concerning parameters as the angular position of the protrusion, the shape of the protrusion, the size relative to the cylinder diameter, the pitch length and the number of helical protrusions. A detailed review of the development of the helical applications can be found in Kleissl (2013).

2. Experimental setup and measurements

A short introduction to the experimental setup is given here. For in-depth explanations see Jakobsen et al. (2012) or Larose and D'Auteuil (2014).

2.1. Wind tunnel and model arrangement

The tests were conducted in the 3 m × 6.1 m x 12.2 m Propulsion and Icing Wind Tunnel at NRC which is an open-circuit wind tunnel, completely open to the atmospheric conditions, drawing outdoor air, pushing it through the test section and ejecting the flow outdoor. The experiments were performed on a 1:1 scale cable model with a mean diameter of 161.7 mm and a length of 6.7 m, see Fig. 1.

At an inclination of 60°, 6.1 m of the cable was exposed to the flow. The cable section model was composed of a central steel core covered with a high density polyethylene (HDPE) tube obtained from a bridge construction site. The mass per unit exposed length of the cable model was equivalent to 66.7 kg/m. It was determined as the mass of the steel core, the HDPE tube, the instrumentation, the mass of the moving parts of the rig and a third of the mass of the active part of the springs, divided by the length of the model that is actually exposed to the flow. The fillet itself had a rectangular cross-section with sharp edges, 2.3 mm thick and

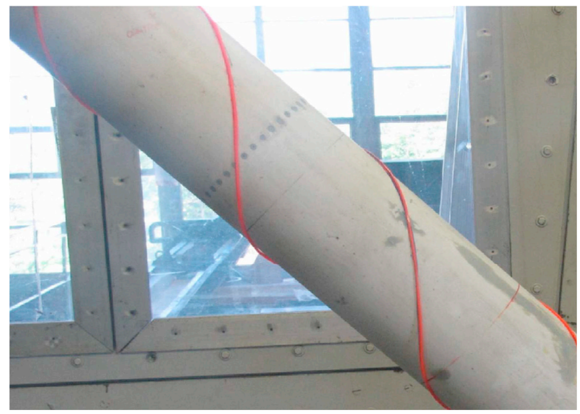

Fig. 2. The side of the cable with the helical fillets normal to the oncoming flow near ring 2 for a cable inclination of 45° and a cable rotation of -25°.

2.4 mm wide and was fixed to the surface of the model with double sided tape. The fillet material was stiff plastic. The helical fillet thickness (width) to outer cable diameter ratio was 0.014 (0.015). The helical fillet was installed as a double parallel helix, as done by the manufacturers, with a pitch of 520 mm and a helix angle of 44.5°. The cable diameter, relative size of the helical fillets and the cable weight were representative of common designs for cables in service. Each end of the cable was supported on four springs allowing the cable to move in two principal orthogonal planes normal to the cable axis; along-wind motion described as heave and across-wind motion described as sway. The model was fixed against torsion by the suspension rig. The model aspect ratio was approximately 38 and the turbulence intensity $I_u = 0.5\%$. The largest difference in turbulence intensity along the model span was about 0.1%, i.e. the flow conditions were quite uniform. A more complete description of the flow characteristics in the open-circuit wind tunnel is presented in

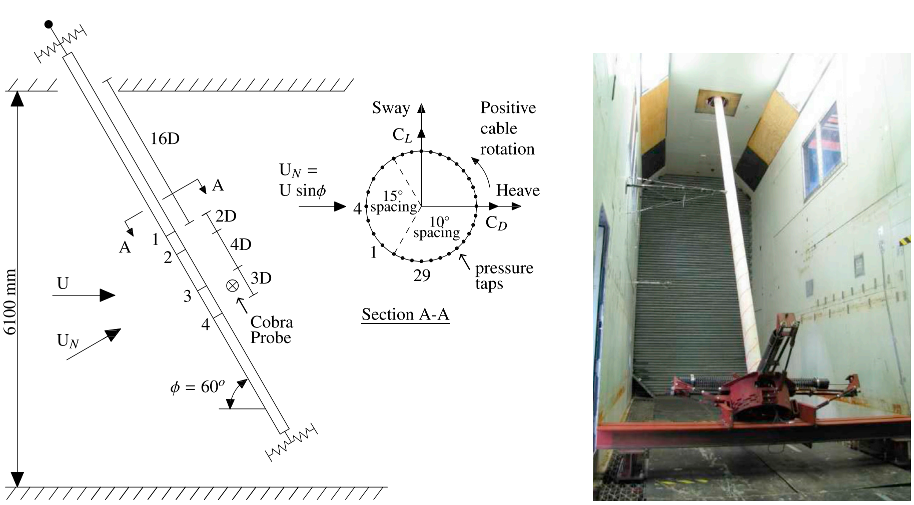

Fig. 1. Cable geometry and model setup. Photo taken downwind.