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INFLUENCE OF AIRFLOW-RIVULET INTERACTION ON CIRCULAR CYLINDER IN UNIFORM FLOW

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Abstract: *Vibrations of cables subjected to rain-wind interaction was several times observed on existing structures. This paper deals with numerical simulation of airflow-rivulet interaction using fluid-structure interaction (FSI). Computational fluid dynamics (CFD) model involves uniform flow which represents air with constant speed at inlet. An incompressible fluid flow with Navier-Stokes equations has been applied. Computational structure dynamics (CSD) model involves cylinder and rigid water rivulet which is allowed to move on cylinder's surface. Periodic movement of rivulet has been observed which vibration frequency has been lower than vortex shedding frequency. The frequency of periodically moving rivulet also has appeared in estimated cylinder aerodynamic characteristics.*

Keywords: **Aerodynamic characteristics, Flow past cylinder, Fluid-structure interaction, Water rivulet.**

1. Introduction

Significat part of cable-stayed bridges are inclined cables which are sensible to dynamic loading due to their low structural damping. In special weather conditions cables may vibrate with large amplitudes as was observed on several bridges (Meikonishi Bridge, Hikami and Shiraishi, 1988; Fred Hartman Bridge, Zuo et al., 2007). This aeroelastic phenomenom is known as rain-wind induced vibration (RWIV). During last decades numerous wind-tunnel experiments have been realized focused on formation of rivulets and aerodynamic influence on vibration of cables (Matsumoto et al., 2003; Zhang et al., 2008). Fluid mechanical interpretation has been deduced on mechanical models (Yamaguchi, 1990; Peil and Nahrath, 2003; Seidel and Dinkler, 2006) and analytical solutions of airflow-rivulet has also been presented (Seidel and Dinkler, 2006). Using numerical simulations two different approaches has been presented. First, rivulet has been considered as a rigid protuberance and the flow (Li and Gu, 2006). In second approach, the thin-film model has been used to investigates formation of rivulets which modifies effective shape of the body.

According to the complexity and three-dimensionality of the RWIV problem fluid-structure interaction (FSI) approach has been used for investigation airflow-induced rivulet movement, related influence on the airflow and changes of cylinder aerodynamic characteristics.

2. Applied Physical and Boundary Conditions to Numerical Model

Conditions in which the rivulets can be formed have been investigated by several studies (Lemaitre et al., 2010; Consentino et al. 2003). Such as wind velocity when cable vibrations occurs *(5 – 17 m/s)*, cable diameter *(0.1 – 0.25 m)*, Reynolds number $(0.5\ .10^5 - 1.5.10^5)$, cable orientation considering wind direction and angle of inclination.

In this study horizontally positioned circular cylinder with diameter $d = 0.12\ m$ using two-dimensional coupled airflow-rivulet interaction model using fluid-structure interaction (FSI) has been investigated. Air with uniform speed of $u = 13\ m/s$ has been considered with corresponding Reynolds number $Re = 10^5$ and the air has been represented by incompressible viscous fluid flow in Computational fluid dynamics

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(CFD) model with applied Navier-Stokes equations in turbulent regime with Spalart-Allmaras Detached Eddy Simulation model (SA-DES). Dimensions of rivulet has been adopted according to Matsumoto et al. (2003) as shown in Fig. 1. Initial position of rivulet has been considered at the bottom of the horizontally mounted cylinder with angle related to flow direction of $\theta = 270^{\circ}$. It has been considered, the initial position of rivulet has been affected by gravitational force. Mesh of coupled computational model and applied boundary conditions are shown in Fig. 2. Cutting-out circularly-shaped water rivulet has been considered with density of *1000 kg/m*^{3} and nearly infinitesimally rigid, therefore, no surface tension forces have been applied. Rivulet mesh has been fixed to cylinder mesh via shared nodes. In cylinder model nearly infinitesimally small mass and infinitesimal rigidity has been considered. As FSI interaction has been applied and cylinder mesh has been fixed rigidly through its center node, the aerodynamic characteristics have been effectively calculated from resulting forces in this node. Flow model mesh density has been decreasing as the distance from cylinder surface has been increasing. Therefore, high mesh density has been achieved in boundary layer and less time consuming model has been acquired, observing sufficient accuracy (according to experimental measurements) as can be seen in Tab. 1.

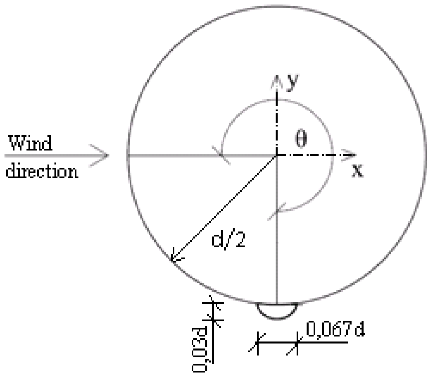

Fig. 1: Cylinder and rivulet relative position and dimensions.

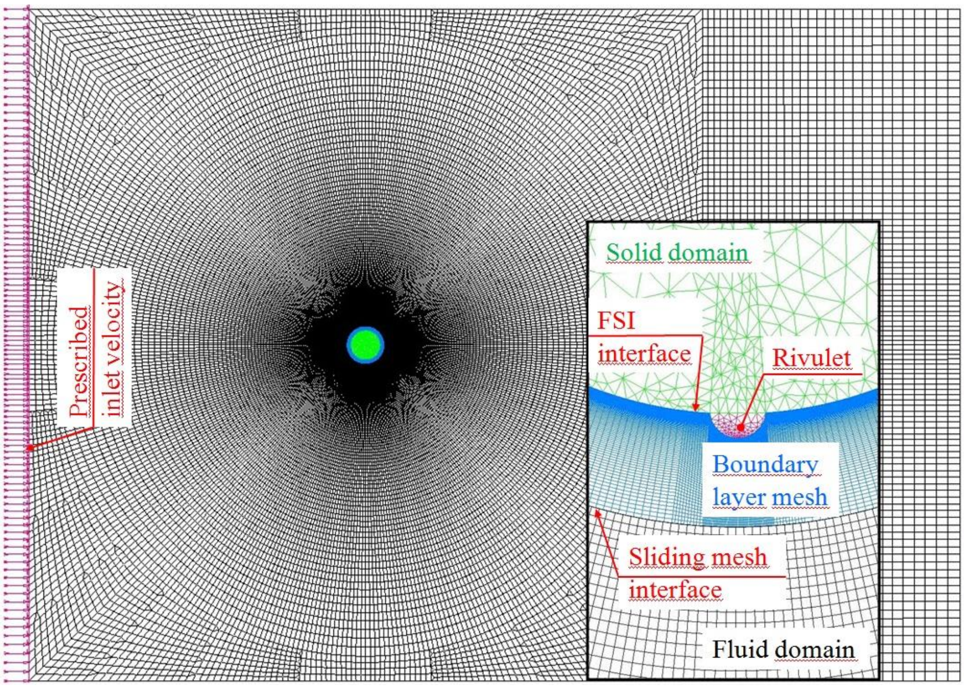

Fig. 2: CFD, CSD and rivulet model meshes and applied boundary conditions.

Tab. 1 summarizes computed aerodynamic characteristics (c_d is drag coefficient, S_t is Strouhal number and f_{sh} is vortex shedding frequency), compared with numerically and experimentally obtained results by Breuer (2000), Wieselsberger (1921) and Roshko (1961). Boundary layer mesh has been fixed to rivulet mesh, therefore the movements have been coupled and sliding mesh interface between two fluid meshes was necessary.

Tab. 1: Aerodynamic characteristics of flow past circular cylinder with and without rivulet.

Method (Re = 10^5)	Mesh size	c_d (-)	S_t (-)	f_{sh} (Hz)
Without rivulet, simulation - SA-DES	200 x 400	1.224	0.201	21.74
With rivulet, simulation - SA-DES	200 x 400	1.385	0.203	22.0
Breuer (2000), LES turbulent model, 3D, (Re = $1.4.10^5$)	165 x 165	1.218	0.217	-
	325 x 325	1.286	0.203	-
Wieselsberger (1921), experiment	-	$\doteq 1.2$	$\doteq 0.2$	-
Roshko (1961), experiment	-	-	$\doteq 0.19$	-

3. Equation of Motion for Rivulet

Rivulet motion can be described according to Seider and Dinker (2006) in polar coordinates using equations of motion

$$m\left(\ddot{\theta}d + \ddot{x}\sin\theta + \ddot{y}\cos\theta\right) = T\,, \tag{1}$$

$$m\left(-\dot{\theta}^2 d - \ddot{x}\cos\theta + \ddot{y}\sin\theta\right) = N\,, \tag{2}$$

where *m, T, N* are rivulet mass, tangential and normal force.

4. Results

Fig. 3 displays the temporal evolution of rivulet position on cylinder surface and corresponding power spectral density. As can be seen, the rivulet hasn't shifted in downwind location, but it has been moving periodically with frequency 3 Hz at the bottom region of the cylinder. It has been assumed, this periodical movement has been particularly coordinated by gravitational force.

Time course of drag and lift coefficients is shown in Fig. 4, also power spectral density of drag coefficient has been calculated. Periodicity with frequency 3 Hz in drag coefficient has been observed which is in coincidence with periodical movement of rivulet. Consequently, the rivulet occurrence directly influences aerodynamic behavior of cylinder. Therefore, aerodynamic force direction and intensity is changing time-dependently.

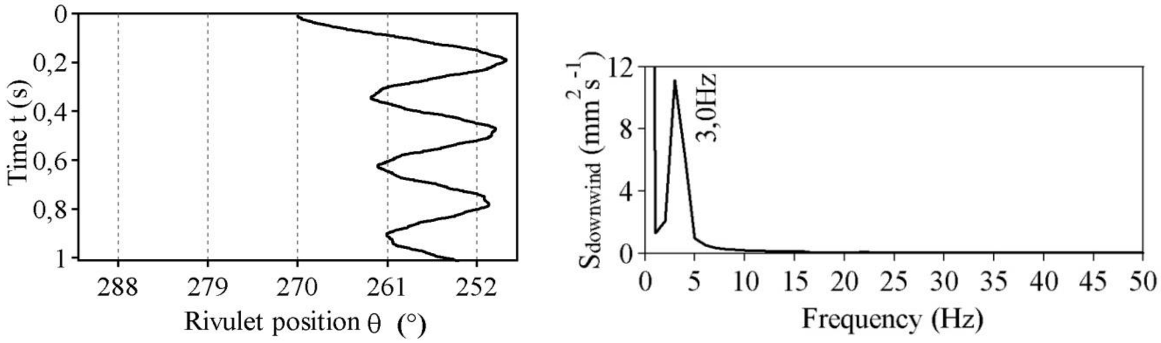

Fig. 3: Rivulet position in time domain (left) and power spectral density (right).

When comparing the values of drag coefficients when rivulet occurred and without rivulet (Tab. 1), significantly increased value has been observed, despite of very small rivulet dimensions. Rivulet occurrence hasn't changed the vortex shedding frequency significantly.

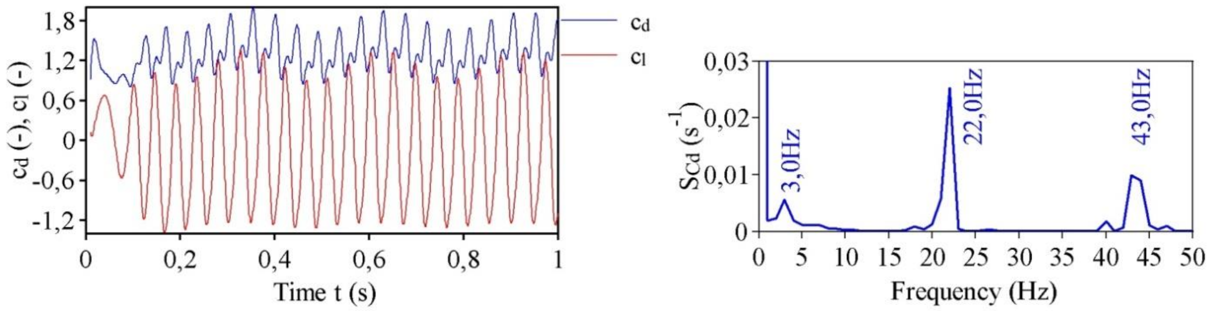

Fig. 4: Drag and lift coefficients (left) and drag coefficient power spectral density (right).

5. Conclusions

Numerical simulation based on coupled model of airflow-rivulet interaction, using commercial software Adina 8.7, has been created. Simulations without and with water rivulet occurrence on circular cylinder surface has been investigated. As the horizontally mounted cylinder has been considered, the gravitational force has been included. It has been assumed, the gravitational force has the influence on periodical rivulet movement. Periodicity of the occurred movement has been 1/7 of vortex shedding frequency. As the frequency of aerodynamic forces on cylinder with formatted rivulet are smaller than vortex shedding frequency and if this phenomenon occurred on cables, resonance of galloping could be arisen. If rivulet was formatted an cylinder section of cable which eigenfrequency was nearby the rivulet-motion frequency, resonance may occur. This resonant effect is called galloping.

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