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MODE SWITCHING OF RAIN-WIND INDUCED VIBRATIONS

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Summary Rain-wind induced vibrations exist in the range of low wind speed as well as in the range of higher wind speed. The transition from the low speed range to the high speed range results in a mode switching as cable oscillations are regarded. This paper presents a description as well as experimental and numerical investigations concerning this vibration phenomena.

PHENOMENA

Rain-wind induced vibrations are a vibration phenomena that occurs when rain and wind act simultaneously on cables, hangars and ropes. The vibration phenomena may induce oscillations with large amplitudes, thus the fatigue of construction elements is possible. This kind of vibrations are mainly observed at stay cables of cable stayed bridges and hangars of arch bridges. Oscillations could also occur at overhead lines, ropes of pylons and cables of suspension bridges. In the literature, i.e. [1,2], rain-wind induced vibrations are generally described in the range of low wind speeds (8-20 m/s). Continuative experiments in the wind tunnel [3] show that rain-wind induced vibrations exist in the range of higher wind speeds (20-30 m/s), too. These observations indicate that rain-wind induced vibrations are composed of two phenomena. The first phenomena of vibrations is present in the range of low wind speeds and the second phenomena of vibrations is present in the range of higher wind speeds.

Typical for both vibration phenomena is a critical onset velocity and an upper limit of critical velocity. Thus, both kinds of vibrations exist for a special range of wind speed. At first rain-wind induced vibration can be observed in the range of low wind speeds. The vibration in the range of higher wind speeds can only occur when this vibration has finished.

In the majority of cases the vibrations in the range of low wind speeds and also the vibrations in the range of higher wind speeds exhibit dominant but different direction of oscillations. Characteristical vibrations are oscillations perpendicular or parallel to the wind direction. Significant for rain-wind induced vibrations is the mode switching between the vibrations in the range of low wind speeds and the vibrations in the range of higher wind speeds. Therefore, the dominant direction of oscillations may change from parallel to the wind direction in the range of low wind speeds to perpendicular to the wind direction in the range of higher wind speeds or otherwise.

A possible mechanism of excitation of rain-wind induced vibrations is derived in [4]. This mechanism is based on the phenomena of the Prandtl tripwire and considers the rivulets as a movable disturbance. Following this approach the occurrence of the lower and the upper limit of the critical velocity can be explained and all kinds of observable vibrations may be described. Figure 1 shows the effect of the Prandtl trip wire. Herein, a wire, which is attached to a sphere (∅ 300 mm) in the critical point of transition, reduces the drag coefficient significantly. The wire induces a transition from the subcritical to the supercritical flow at considerably lower Reynolds number than for a flow around an undisturbed sphere.

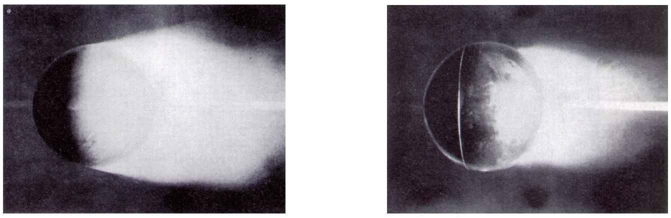

Fig. 1a, b. flow around a sphere with a Prandtl tripwire. a) laminar flow, b) turbulent flow [5]

Similar phenomena can be seen at elongated cylinders. Regarding rain-wind induced vibrations a movable disturbance due to the rivulet exists in contrast to the fixed, immovable disturbance of the Prandtl tripwire. When the oscillations start the rivulets are located near the separation point of the subcritical flow. The Prandtl tripwire is active in the same area. In contrast to the Prandtl tripwire a interaction between the motion of the cable and the rivulets exists in the special case of rain-wind induced vibrations. This interaction is due to the reduction of the drag and stiffness of the cable. For the overall mechanism it is important that rivulets oscillate around the point of transition of the flow with the same frequency as the cable. The result of this motion is a periodical transition of the flow between subcritical and supercritical flow. An energy transfer between the flow around the cable and the elastic structure is induced due to the different pressure distributions of the subcritical and supercritical flow. The interaction between cable, rivulets and flow determines the development of a self-excitation mechanism. This leads to vibrations with large amplitudes parallel or perpendicular to the wind direction depending on the location of rivulets.

MODEL

The equations of motion in two dimensions for cables and rivulets is formulated under consideration of the phenomenology and the assumption that cables are infinitely long cylinders. It is essential to include the influence of the rivulets and its resulting interaction with the structure in the equations of motion of the cable cross-section and in the quasi-stationary theory. Furthermore, the equations of motion of the rivulets are developed. Therefore the effects of the boundary layer based on the Prandtl boundary layer equations and fundamentals of the physics of drops are considered. The equations of motion of the cables are formulated in an inertial system. Neglecting eigenrotations there are 6 non-linear coupled differential equations. These are required to calculate the unknown translations of cable, the unknown angles of rivulets and the reactive forces for both rivulets.

EXPERIMENTS AND RESULTS

Extensive experimental and numerical investigations confirm the correlation between the Reynolds number and rain-wind induced vibrations, see [4]. It is shown that the excitation mechanism in the range of low wind speeds is different from the mechanism in the range of higher wind speeds. Thus, the observed mode switch can be explained.

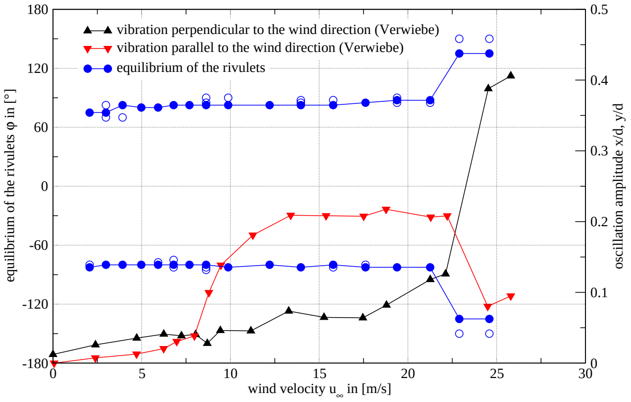

Fig.2. Equilibrium position of rivulets and oscillation amplitudes for a cable (α = 79°, β = -90°, ∅ 110 mm)

Figure 2 shows the response characteristics of the rivulets measured in wind tunnel test. Own experimental investigations illustrate the equilibrium position of the rivulets as function of the wind velocity. Furthermore, the vibration amplitudes measured by Verwiebe are diagrammed in figure 2. When mode switching appears the rivulets move away from the equilibrium position of the subcritical flow to the equilibrium position of the supercritical flow. This phenomena effects a fundamental modification of the drag and lift coefficients. Unless the drag coefficient is dominant in the subcritical flow, the lift coefficient is dominant in the supercritical flow. Due to this effect vibrations parallel to the wind direction decrease when the transition of the flow occurs at a velocity of 21,2 m/s. Then vibrations perpendicular to the wind direction become decisive.

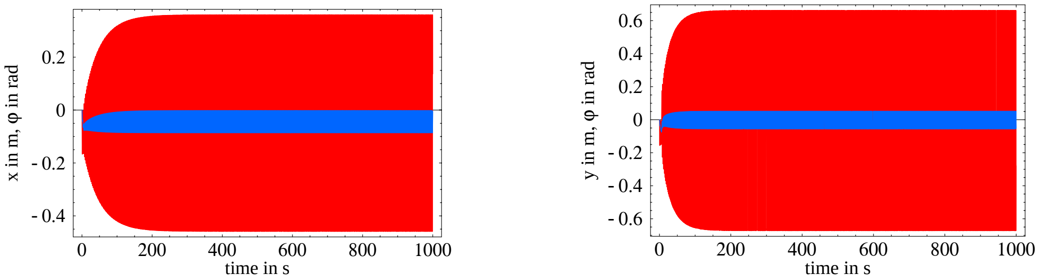

Fig. 3. Vibrations of cable and rivulets parallel (u_∞ = 8 m/s) and perpendicular to the wind direction (u_∞ = 20 m/s)

Numerical investigations based on the mechanical model confirm the experimental results. Figure 3 shows the vibrations of the cable and the rivulets for both cases, the subcritical and supercritical flow. A dominant oscillation exists parallel to the wind direction for a wind speed of 8 m/s (subcritical flow). Though, the wind flow with a speed of 20 m/s leads to a dominant vibration perpendicular to the wind direction.

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