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Rain/Wind Induced Vibrations of Parallel Stay Cables

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Abstract

1. Introduction

The Öresund High Bridge is a cable-stayed bridge with a main span of 490 m flanked by side spans of 301 m each. The two-level truss-girder bridge deck will carry vehicles and train traffic and will be supported by two vertical cable planes anchored to two 204 m high H-shaped pylons. The cable system has a harp configuration, each cable forming an angle of 30° with the bridge deck. The bridge has 40 stays per cable plane, each stay being composed of two parallel cables placed one on top of the other with a 670 mm centre-to-centre spacing. The steel strands of the stay cables are covered with a polyethylene high-density (PEHD) tube, 250 mm in diameter. Fundamental natural frequencies of the stay cables will range from 0.5 Hz to 2.5 Hz.

The combination of cable angle, polyethylene surface, low natural frequencies and high probability of occurrence of light rain with moderate winds at the bridge site set the stage for possible rain/wind-induced vibrations of the stay cables. Based on experience, it was decided at an early stage in the detailed design of the superstructure to fit the PEHD tube with an aerodynamic countermeasure to prevent rain/wind-induced vibrations, namely a double helical fillet, 2.1 mm thick, similar to the fillet used for the stay cables of Pont de Normandie in France. To verify the effectiveness of the proposed *countermeasure* for 250 mm diameter cables in a tandem configuration, a series of wind-tunnel tests was initiated by Sundlink Contractors and carried out by the Danish Maritime Institute (DMI).

2. Scope of Wind-Tunnel Tests

A 6 m long section model of a stay was built at a geometric scale of 1:1 and was mounted in a purposely designed test rig fitted with suspension springs. The rig was designed such that only one of the cables of a pair could oscillate while the other, when present, was kept fixed and only acted as a dummy to simulate adequately the surrounding flow field. All wind-tunnel tests were carried out in the Velux Wind Tunnel in Østbirk, Denmark, that has a 4 m x 4 m open jet cross-section, a 30 m/s maximum wind speed and a rain facility. A view of the test rig in the wind tunnel is shown in Figure 1.

The parameters investigated during the rain/wind vibration tests were:

- the influence of the tandem cable configuration on the vibrations;
- the influence of wind incidence, ±40° in the horizontal plane;
- the influence of wind speed and rain intensity; and,
- the influence of structural damping.

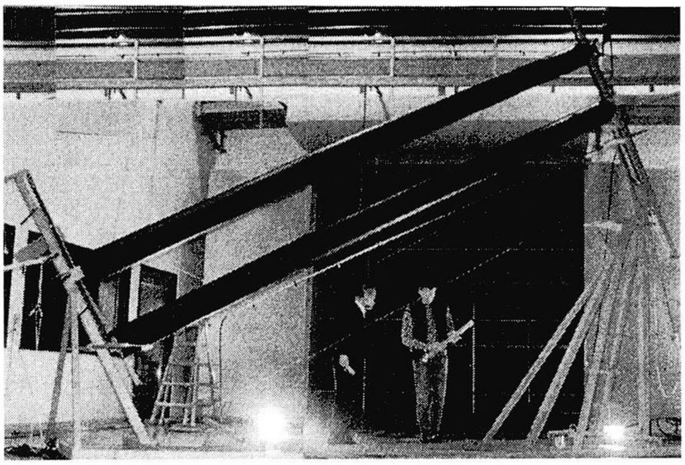

Figure 1 Test rig in A/S Velux Wind Tunnel

Initially, the test programme focused on the reproduction of rain/wind-induced vibrations observed elsewhere for an isolated smooth PEHD tube forming an angle of 30° with the horizontal plane in yawed winds and light rain. This was followed by a series of tests aimed at defining a systematic test procedure including surface treatment of the PEHD tube. The test procedure was applied for a series of exploratory tests where the worst case conditions were sought for the cable fitted with the helical fillet. Finally tests aimed at comparing the level of aerodynamic damping between a dry and a wet cable with rivulet were performed for various cable configurations and various levels of structural damping.

3. Main findings

Rain/wind-induced vibrations of a smooth PEHD tube, 250 mm in diameter were observed for an angle of wind incidence of +30° and wind speeds varying between 9 and 12 m/s. The vibrations developed rapidly, within a few cycles, up to ±250 mm, after the formation a small coherent rivulet on the upper and lower surfaces of the tube.

Large rain/wind vibrations (up to ±250 mm) were also observed for smooth cables in a tandem configuration (670 mm cable spacing). The damping level was adjusted so that the amount of energy dissipated per cycle for the experiments was equivalent to the prototype conditions, assuming a prototype structural damping of 0.16% of critical. An increase of structural damping up to an equivalent prototype damping of 0.58% of critical was not sufficient to damp out completely the rain/wind-induced vibrations for smooth cables in a tandem configuration.

The tests conducted with the PEHD tube with a double helical fillet, 2.1 mm thick showed a strong reduction of the rain/wind induced vibrations observed with the smooth tube. The helical fillet disrupted the formation of a coherent upper rivulet, therefore mitigating the excitation at its source. These observations are in accordance with the results of the wind tunnel investigations made for the stay cables of the Pont de Normandie. The helical fillet proved to be effective in reducing the large rain/wind induced oscillations even for the cases where the structural damping of the model was as low as 0.025% of critical. For some conditions, the rain/wind-induced excitation persisted even with the cable fitted with the helical fillets. The amplitude of vibrations were limited, however, when compared to the results of the smooth PEHD tube tests. This paper presents the main findings of the experiments and puts forward a description of the excitation mechanism.