EFFECT OF WIND SPEED, WIND DIRECTION, RAINFALL INTENSITY, DAMPING AND CABLE DIAMETER ON VIBRATION AMPLITUDE OF THE CABLE

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ABSTRACT

Stay cables of the cable-stayed bridge exhibit a large amplitude vibration under the action of wind and rain and which may have a greater effect on the fatigue life of the stays. These large amplitude vibrations were strongly influenced by a variety of factors concerning the positioning of the cable (inclination angle), meteorological parameters (rain, wind speed and wind direction) and the structural parameters like damping and frequency. This paper explains the effects of wind speed, rainfall, damping, cable diameter, cable inclination angles, wind yaw angles on the vibration amplitude of the stay cables with diameters 0.155 m and 0.128 m. The observations show’s large amplitude vibrations when the cable is inclined at 25° and 30° and wind yaw angles are from 30° and 35° under 10 mm/hr rainfall condition.

Keywords: Rain-wind induced cable vibrations, Cable aerodynamics, Cable stayed bridges

Introduction

Rain-wind induced stay cable vibration was widely studied by the researchers for the past 2 decades. In certain conditions of rain and wind, the stay cables of the cable stayed bridges showed a large amplitude of vibrations which is of the order of twice the diameter of the cable [Shirashi, 1988]. These vibrations was first observed by Hikami [Shirashi, 1988] in Meikonishi Bridge and carried out several tests and coined that the upper rivulet on the cable is more responsible for such vibrations. Since, then there were lots of field investigations reported by Shirashi (1988), Y.Q.Ni (2007) and J.A.Main (2008) and many more conducted experiments [Shirashi (1988), Shirashi (1990), Flamand (1995), Olivari (1996), Xiaoqin Du (2005), and Zhan et al. (2008)] to understand the mechanism behind these vibrationsIn the due course of the study a large number of bridge cables were also subjected to rain-wind induced vibrations. And this paper is mainly concerned with the experimental facility developed to test the effects of wind speed, wind yaw angle, rainfall intensity, diameter, damping ratio and cable inclination angles on vibration amplitude of the cable.

Experimental setup

The experiment tests were conducted at the closed/open circuit type wind tunnel [Liu et al. (2011)] at Shijiazhuang Tiedao University, which was built especially to deal with wind and rain-wind induced studies. And figure 1 shows the schematic view of the cable hanged on to the rain-vibration setup with rainfall system installed. The wind at the exit of the wind tunnel and at the center of the cable was also obtained and plotted in figure 2, which shows a
linear relation between them and is shown in equation (1). Figure 2 (b) shows Setup, approaching flow, inclination and yaw angles.

\[
U_{\text{cable}} = 1.058 \, U_{\text{exit}} + 0.932
\]  

(1)

There were two cable models used in the experiment with two different diameters. The first one is of 0.155 m and the other is 0.128 m. The model I is of diameter 0.155 m was tested for cable with inclination angles from 25° to 40° and wind yaw angles from 25° to 50° as shown in table 1. And the model II was tested for critical cases and is shown in table 2.

Cable model and testing conditions

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Table 1. Details of the tests for the cable model I: Diameter 155 mm

<table>
<thead>
<tr>
<th>$\beta$</th>
<th>$\alpha$</th>
<th>25°</th>
<th>30°</th>
<th>35°</th>
<th>40°</th>
</tr>
</thead>
<tbody>
<tr>
<td>25°</td>
<td>-</td>
<td>-</td>
<td>R0, R10, R40, R70</td>
<td>-</td>
<td></td>
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<tr>
<td>30°</td>
<td>R10, R20, R40, R70</td>
<td>R0, R10, R40, R70</td>
<td>R10, R40, R70</td>
<td>-</td>
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<tr>
<td>35°</td>
<td>R0, R10, R40, R50, R70</td>
<td>R10, R40, R70</td>
<td>R0, R10, R40, R70</td>
<td>-</td>
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</tr>
<tr>
<td>40°</td>
<td>R0, R10, R20, R40, R70</td>
<td>R10, R40, R70</td>
<td>R0, R10, R20, R40, R70</td>
<td>-</td>
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<tr>
<td>45°</td>
<td>-</td>
<td>-</td>
<td>R10</td>
<td>R10</td>
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</tr>
<tr>
<td>50°</td>
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<td>R10, R20, R40, R70</td>
<td>R0, R10, R20, R40, R70</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Frequency, $f_n=1.02$ Hz  
Frequency, $f_n=1.07$ Hz

Note: R0: without rain; R10-80: Represents the amount of Rainfall from 10 to 80 mm/hr.

Table 2. Details of the tests for the cable model II: Diameter 128 mm

<table>
<thead>
<tr>
<th>$\beta$</th>
<th>$\alpha$</th>
<th>25</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>R10, R40, R70</td>
<td>R10, R40, R70</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>R10, R20, R30, R40, R50, R60, R70, R80</td>
<td>R10, R40, R70</td>
<td></td>
</tr>
</tbody>
</table>

Note: R-Represents Rainfall Intensity, whereas the number followed by R represents the intensity of rain in mm/hr.

Characteristics of Rain-wind induced stay cable vibration

Figure 3, shows a basic case for the comparison of vibration amplitudes of the cable with and without rain conditions when the cable is inclined at 25° and wind yaw angle is 35°. It can be seen that the amplitude of cable vibration is much larger during rainfall condition when compared without rainfall condition.

Effect of wind speed and Rainfall Intensity on cable vibration

Figure 4 shows the vibration amplitude of cable model I. Figure 4(a) shows the effect of rainfall intensity on stay cable vibration ($\alpha=30°$, $\beta=35°$) for the first test. The increase in
rainfall intensity shows a decrease tendency of vibration amplitude. Figure 4(b) shows the second test carried out for three rainfall conditions namely 10 mm/hr, 40 mm/hr and 70 mm/hr

**Fig. 4** Effect of rainfall intensity and wind speed on vibration amplitude of the Stay cable (α=30°, β=35°) - Cable model I

**Effect of damping ratio on rain-wind induced cable vibration**

Figure 5 shows the comparison of damping ratio’s and Scruton number for the cable positioned to α=25°, 30° and β=30°, 35.

**Fig. 5** Effect of damping ratio and Scruton number on stay cable vibration (α=30°, β=30°)

**Effect of cable diameter on rain-wind induced cable vibration**
Figure 6 shows the effect of vibration amplitude of the cable ($\alpha=30^\circ, \beta=35^\circ$) of diameters 0.155m and 0.128m for different rainfall intensities i.e., 10 and 40 mm/hr.

**Effect of cable inclination and wind yaw angle on peak amplitude of rain-wind induced cable vibration**

Figure 7 shows the effect of cable inclination and wind yaw angle on maximum vibration amplitude at 10 mm/hr rainfall condition.

Conclusion

The rain-wind induced stay cable experiment setup was made to test the cable for a large number of parameters such as inclination angles from 25-40, wind yaw angles from 25-45, rainfall conditions from 10-80 mm/hr for two kinds of damping. The main observations are listed below.

1) The observations showed that the low-rainfall condition used in this experiment i.e., 10 mm/hr causes very large amplitude for several combination of inclination and wind yaw angles.

2) The effect of damping, Scruton number, and diameter were studied. And the cable with diameter 0.128m causes vibrations for a short range of wind speeds whereas the increase in diameter (0.155m) cause vibrations for a longer range of wind speeds. The larger diameter cable is more susceptible to large amplitude vibrations.

3) The cable is tested for several combination of inclination and wind yaw angles i.e., $\alpha=25^\circ$ to $40^\circ$ and $\beta=25^\circ$ to $50^\circ$, and the amplitude of vibration is very large for the combination of cable inclination and wind yaw angles i.e., $\alpha=25^\circ,30^\circ$ and $\beta=30^\circ,35^\circ$ under 10 mm/hr of rainfall.

References


