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Dynamic Analysis of Suspension Bridge using Matlab Simulation

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Abstract: ***This paper presents a full-scale analysis of wind and traffic-induced vibrations of a long-span suspension bridge in complex terrain. Several wind and acceleration sensors have been installed along the main span on Lysefjord Bridge in Norway whose data has been available for study purpose. In the present study, three days of continuous records are analysed. Traffic-induced vibrations are dominant at low and moderated wind speed, with non-negligible effects on the overall bridge response for heavy vehicles only. Traffic and wind-induced vibrations are compared in terms of root mean square of the acceleration response, and three simples approaches are proposed to isolate records dominated by wind-induced vibration. The first one relies on the separation of nocturnal and diurnal samples. The second one is based on the evaluation of the time-varying root mean square of the acceleration response. The last one evaluates the relative importance of the high frequency domain of the acceleration bridge response. It appears that traffic-induced vibrations may have to be taken into account for the buffeting analysis of longspan bridge under moderated wind***

Keywords: Dynamic load, suspension bridge , eigen value, seismic loads ,cable layout

1. Introduction

Relatively few analyses of wind and traffic-induced vibrations of full-scale suspension bridges in complex terrain have been done. Hui [1, 2] did a detailed analysis of the wind conditions near the Stonecutter Bridge, which is subjected to both a sea and mountain wind, by using a wind mast. Macdonald [3] studied the response to wind and traf- fic load of the Clifton Bridge, which is a relatively shortspan suspension bridge crossing a narrow gorge. Cai [4] proposed a detailed analytical model to study both wind and traffic induced vibrations of a long span bridge, but no detailed measurement campaign of such phenomenon has been found, apart from Macdonald [3]. In Norway, the coastal highway E39 project requires a detailed description of the wind conditions and bridge response in complex topography such as fjords. Long span bridges already in service are ideal study cases for such purpose, but traffic induced vibrations may perturb the buffeting analysis. Heavy trucks crossing the bridge are likely to produce non-negligible vibrations, but they are often ignored. This assumption is likely to be justified for strong winds only. The present paper investigates the influence of traf- fic on wind-induced vibrations of the Lysefjord Bridge in Norway. First the topography and the wind conditions observed at Lysefjord are described. Then the influence of traffic-induced vibrations is highlighted using the peak and standard deviation of the acceleration response. Finally, three strategies are proposed to separate records dominated by traffic-induced vibrations from those affected by wind turbulence only.

2. Bridge Site and Instrumentation

The Lysefjord Bridge (figure 1) crosses the narrow inlet of a fjord in the South-West of Norway, at an altitude of 55 m. Its main span is 446 m long and is oriented from NorthWest to South-East. Steep hills and high cliffs surround its extremities. Its East side is oriented toward the inside of the fjord while its West side faces a more open area. The proximity of the mountains and small islands is likely to be responsible for a very high turbulence intensity. The channelling effect of the fjord produces local wind conditions that requires the installation of wind sensors directly on the bridge. At the beginning of October 2014, seven sonic anemometers and four couples of tri-axial accelerometers were operational along the bridge deck (figure 2). The accelerometers are installed near Hangers 09, 18, 24 and 30 on both side of the deck so that lateral, vertical and torsional accelerations can be recorded. The anemometers located on hangers 10, 16, 18, 20, 24 and 30 are placed about 6 m above the West side of the deck. Two additional anemometers are installed on hanger 08. They are noted H-08b and H-08t and are located 6 and 10 m above the bridge deck respectively. The anemometer on H-10 is a Waisala weather transmitter WXT520 while the other ones are 3D WindMaster Pro sonic anemometers. Acceleration and wind data are synchronized using GPS timing and down-sampled to 20 Hz. The recording is continuous over every 10 minutes and the files are transferred using a mobile net.

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Figure 1: View to the North-East (top), the bridge (middle) and view to the South-West (bottom) from the bridge.

The wind components normal and along the bridge deck refer to the "bridge-based" coordinate system and are denoted Vx+vx and Vy+vy respectively. These components are split into a mean part (Vx and Vy) and a fluctuating one (vx and vy). The along and across-wind components, noted U + u and v, are recovered by projecting the wind components in the bridge-based coordinate system onto the mean wind direction, at the yaw angle β, and normal to it. Similarly, u and v denote the fluctuating components, and U denotes the mean components. Two main wind conditions are usually observed at Lysefjord Bridge. On one hand, the wind from N-NE comes from the inside of the fjord, with a high turbulence intensity. On the other, the wind from S-SW "hits" the bridge before entering into the fjord, with usually a higher wind speed than the wind from N-NE. In the present study, three days of wind and acceleration data from the 01/10/2014 to the 03/10/2014 are selected. The usual wind conditions are not fully verified here, because of the low wind speed recorded (figure 3), which allows nevertheless the investigation of the influence of traffic-induced vibrations. It has been observed that the two main wind direction lead to two distinct wind conditions, with different spatial and temporal characteristics. Consequently, the buffeting response of the bridge is studied by using a case by case approach, i.e. by separating the wind from SSW and N-NE. When the wind direction changes, a nonstationary wind field is usually recorded. However, the wind induced non-stationary response is generally easily distinguished from traffic-induced vibrations, that occur at a much smaller time scale.

3. Separation of Wind and Traffic-Induced Vibrations

The buffeting response of Lysefjord Bridge can be studied by separating samples recorded during the night and the day, by assuming that no heavy vehicles cross the bridge at night-time. The definition of day-time and night-time is arbitrary. It can be done by comparing the periodicity of the bridge vibration during several days that are characterized by a very low wind speed. The day-time is started on the morning when the bridge response start increasing while the mean wind speed remains unchanged. The night-time is started when the response of the bridge dramatically decrease at the end of the day. One drawback of the method is the reduction of the number of available samples, which is already lowered by using a case by case approach to separate wind from N-NE and from S-SW. However, this is the most simple and straightforward method to reduce the number of samples affected by traffic. Another method is to consider only samples with a high mean wind speed. Macdonald [3] noted that an appropriate threshold wind speed for the Clifton suspension bridge may be 8 m/s. For the Lysefjord Bridge that limit is likely to be different. One of the purpose of this paper is to look at the bridge acceleration response with a low wind speed, and therefore this method is not applied here. Another possibility to eliminate records dominated by traffic-induced vibrations is to study the non-stationarity of the bridge response. The goal is to find an exclusion criterion that dismisses acceleration records influenced by heavy vehicles. This criterion relies on the time varying standard deviation of the vertical bridge acceleration response. Every single 10-minutes record is divided into 300 segments of 2 seconds, which mean that the slowest frequency recorded in each segment is above the first vertical symmetric and asymmetric eigen-frequency of the bridge deck that are equal to 0.29 and 0.21 Hz respectively. For every 2-seconds segment, the time varying standard deviation σAz (t) of the bridge acceleration response at mid-span is calculated. However, variations of σAz (t) can be due to traffic or wind gusts. The time derivative of the turbulent wind component w is defined as :

$$\dot{w} = \frac{\partial w}{\partial t}$$

The variation rate τ of the vertical bridge acceleration is used as exclusion criteria and defined using the standard deviation of ˙w written σw˙:

$$\tau = \frac{\sigma_{A_z}(t)}{\sigma_{\dot{w}}(t)}$$

A sudden variation of the wind speed is likely to lead to a high value for σw˙, and therefore a lower value for τ. Consequently, high values of τ are reached only when strong traffic-induced vibrations are recorded. One limitation is that if a strong wind gust occurs while a heavy vehicle is crossing the bridge, then τ is likely to be abnormally low. If the lateral bridge response is studied, the turbulent component u should be used instead of w. As underlined by Macdonald [3], traffic-induced vibrations affect mainly the high frequency content of the bridge response. It should be possible to detect any nonnegligible traffic-induced response by comparing the low and high frequency part of the power spectral density (PSD) of the vertical bridge acceleration response, written S Az . In the following, the separation between the high and low frequency content is arbitrary set to 4 Hz, while the Nyquist frequency is fixed to 10 Hz. The relative contribution of the frequency interval [f1, f2] to the RMS of the acceleration response is written σf1−f2 , and defined as :

$$\sigma_{f_1-f_2} = \sqrt{\int_{f_1}^{f_2} S_{A_z}(f)\,df}$$

Therefore, another criteria λ can be defined as the ratio between the high and low frequency contribution to the RMS of the bridge response:

$$\lambda = \frac{\sigma_{4-10}}{\sigma_{0-4}}$$

If the criteria λ is higher than 1, then the bridge acceleration response is assumed to be dominated by traffic induced vibration.

4. Results

We are loading acceleration data made of 288 time series assumed to be acceleration histories of a suspension bridge, recorded at mid-span. Only the natural frequency for the vertical DOF of the bridge is considered here. Traffic induced vibration has been introduced every 25 samples, i.e. sample 25,50,...,275 near t = 300 sec. Time series are supposed to be recorded between the 01/01/2016 at 00:00:00 and the 02/01/2016 at 23:50:00. The top below shows wind induced vibrations only, whereas the bottom one shows a sudden peak indicating dominating traffic induced vibrations.

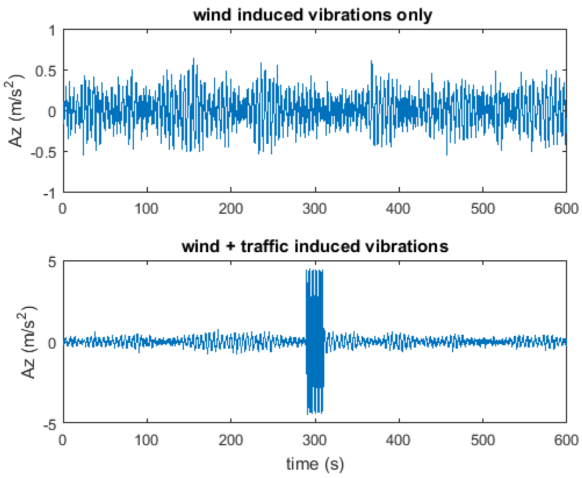

Figure 2: Wind and traffic induced vibrations

To separate data dominated by wind from those dominated by traffic, we can separate diurnal and nocturnal data, by assuming that traffic-induced vibrations only occur at day time. Here day time is taken between 5 a.m. and 6 p.m This method is fast and efficient but too many samples are detected as "dominated by traffic".

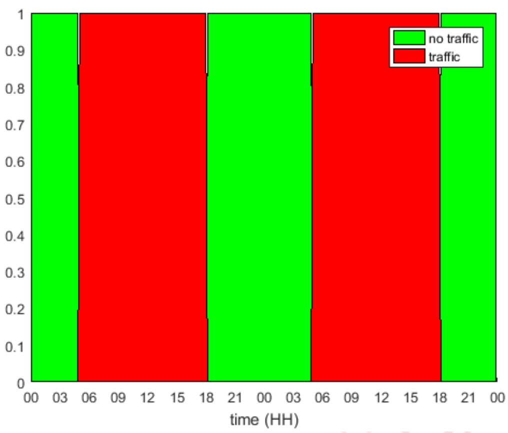

Figure 3: Graph for categorizing traffic and wind response seperately

In the next stage the variation rate tau is evaluated, and broadly corresponds to the flucutating RMS of the bridge acceleration weighted by the wind velocity fluctuations. This method works pretty well, but depends on the initial threshold that has to be fixed. this threshold sepcifies the limit over which traffic is detected as non-negligible.

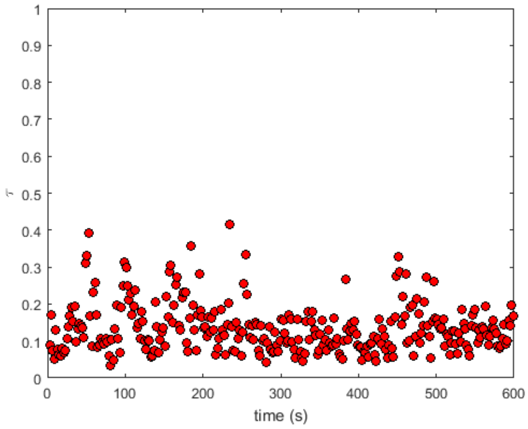

Figure 4: Determining response type based on tau

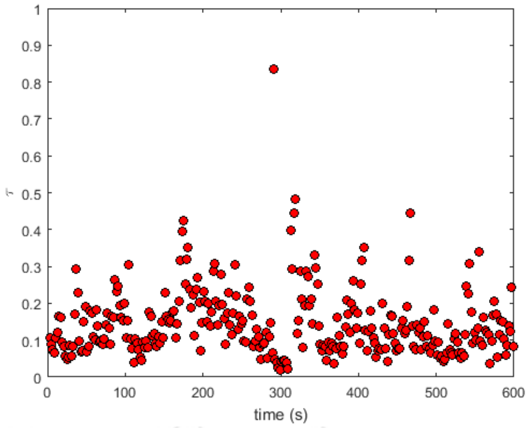

Figure 5: Determining response type based on tau

As clearly seen in the above figures that a sudden change in tau is seen in the fig 5 is observed at around t=300s this sudden jump of tau indicates traffic whereas fig 4 indicates wind.

Next step focuuses on the idea that traffic induced vibrations affects generally more the high frequency part of the response spectrum than the low frequency part. On the contrary, wind-induced vibrations are mainly concentrated on the low frequency part of the response spectrum. In the present exemple, the frequency threshold is taken as equal to 1Hz, i.e. below 1Hz we have the "low frequency domain" and over 1 Hz we have the "high frequency domain".

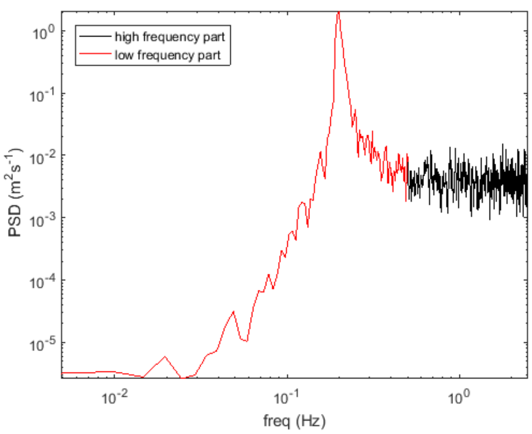

Figure 6: Graph showing frequency response for wind induced vibrations

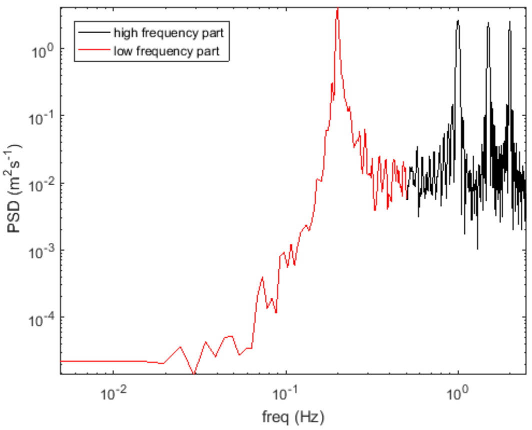

Figure 7: Graph showing both wind and traffic induced vibrations

In addition to the above several static analysis has also been carried out that are reflected below for ready reference :-

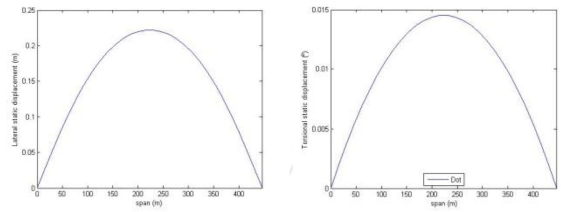

Figure 8: Lateral and torsional static displacement vs span graph

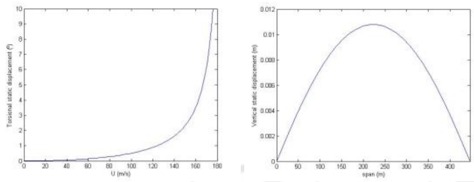

Figure 9: Graph showing torsional displacement vs wind velocity graph and other showing vertical displacement vs span graph

5. Conclusion

This research paper in short summarizes and calculates various dynamic and static properties of a cable suspension based bridge structure. It has been shown through simulations that the majority of displacement in a cable suspension bridge arises due to heavy traffic rather than wind pressure. Thus our study clearly indicates that traffic monitoring on a cable suspension bridge must be taken carefully. Also we have produced results for static analysis also which obviously ignores traffic but is worth while to give a more holistic picture of the entire effort.

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