Analysis of Traffic Effects on a Dutch Highway Bridge

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Summary

In this paper, we propose a method for reliably extracting modal parameters from concrete bridges, which depends on the proper identification of vehicles passing the bridge. We collect data from a sensor network installed on a large highway bridge in the Netherlands, called the Hollandse Brug. There are three sensor types involved in the network, sensing strain, vibration and temperature. Large traffic events, such as trucks crossing the bridge, can be recognized clearly in the strain signal, so we use it to identify the exact moments of vehicles passing. At the same time, the measured strain is also influenced by other factors, such as traffic jams and temperature changes. We remove these factors, which interfere with the proper identification of traffic events, with an improved threshold-based classification method, and obtain a number of peaks with the *zero-crossing* and *local maximum* method. We then divide these peaks into different categories with a supervised classification method. The signals produced by the vibration sensors when excited by passing trucks is a good source for analysing structural parameters of the bridge, so we extract the free vibration periods of the vibration signals associated with truck events in the strain signals, and subsequently conduct modal analysis.

Keywords: concrete bridge; ambient excitation; baseline drift; traffic identification; modal analysis

1. Introduction

In this paper, we intend to analyse the modes of a highway bridge with data collected within an ambient excitation setting. This bridge is called the Hollandse Brug, and is located between the Flevoland and Noord-Holland provinces in the Netherlands. A sensor network was installed on this bridge during a renovation launched in 2007, to monitor the condition of the bridge. There are three kinds of sensors involved in the sensor network, measuring strain, vibration and temperature. Each sensor type provides a specific perspective on the dynamics of the bridge. Furthermore, there is a weather station and a video-camera to measure the weather and the actual traffic on the bridge.

The obtained raw data from the sensor network cannot be used to conduct modal analysis directly, because it contains a mixture of factors acting on the bridge including temperature wind, and various forms of traffic. All these factors will influence the modal parameters of the bridge in some way. We prefer to analyse very specific periods of the measured data. In this paper, we focus our analysis on the periods of free vibration

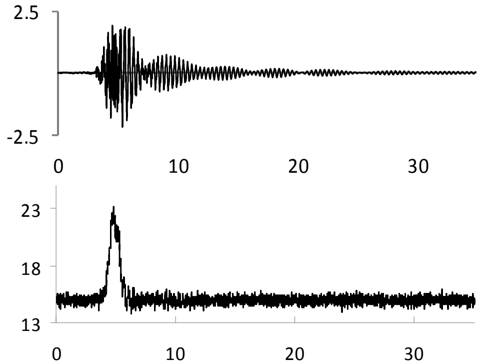

Fig. 1: Vibration and strain signal of a truck.

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of the bridge, which is the period after a truck has passed, and before a next vehicle appears on the bridge. To extract data that meet such requirements, we need to be able to effectively recognise traffic events first. We combine several signal processing and data mining techniques to pre-process the baseline drift and identify traffic events in the strain signal, and then continue to analyze the spectrum with the corresponding free vibration periods in the vibration signal.

2. Methods

In the sensor network, both the strain and vibration signal respond to traffic events. A traffic event in the strain sensor is represented as a peak, which occurs when the vehicle is actually on the measured span, and disappears rapidly when the vehicle passes. The truck event in the vibration sensor produces oscillations, which will last for a long period after the truck has passed, if it is not disturbed by subsequent vehicles. Based on this observation, we first use the strain signal to detect traffic events; then conduct spectral analysis on the corresponding vibration signal. The procedure is illustrated as Fig. 1. Details of each step can be found below.

Step 1: Find baseline. The baseline of the strain signal is influenced a lot by temperature and traffic jams. To measure the amplitudes of peaks correctly, we must find the baseline first.

Step 2: Remove baseline. Baseline removal is quite straightforward. It is obtained by subtracting the baseline from the original strain signal.

Step 3: Find peaks. Using the *zero-crossing* and the *local maximum* methods, we succeed to detect a number of peaks, with *amplitude*, *duration* and *area under peak* as peak descriptive features.

Step 4: Label peaks. Based on the video stream, we hand-label each peak as either of *noise*, *car on lane 1*, *truck on lane 1*, *car on lane 4* or *truck on lane 4*. This will be our training data.

Step 5: Classify peaks. Based on the obtained peak features and labels, we try to find the boundaries between each class, by means of classification techniques from the Data Mining field.

Step 6: Extract single truck events. One whole traffic event is composed of the traffic-free period before the traffic peak, the actual peak and the traffic-free period after the traffic peak.

Step 7: Extract free vibration. Free vibration fragments are extracted from the vibration signal, which corresponds to the traffic-free period directly after a truck-related peak in the strain signal.

Step 8: Modal analysis. The Discrete Fourier Transform is employed to analyze the modes of the free vibration spectrum.

3. Modal analysis of free vibration

We focus on truck events on the bridge, because they can cause obvious oscillations in vibration signal, which is useful to detect free vibration. By selecting truck events with at least 20 seconds of free vibration, we obtained 72 events on lane 1 and 77 events on lane 4.

To obtain all the possible modes of the bridge, we looked into the spectrum of the free vibration period of each selected truck event. After normalizing the 149 spectra, we got the graph in Fig. 2.

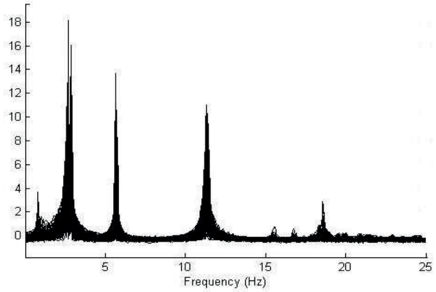

Fig. 2: The vibration modes of the bridge

As illustrated in Fig. 2, modes 2 (2.69 Hz) and 3 (2.88 Hz), are the principal modes of the bridge, which occur in every event. Mode 4 (5.61-5.77 Hz) and mode 5 (11.22-11.43) are also important modes, which have strong amplitude and happen in most events; mode 1 (0.73-0.93 Hz) and mode 8 (18.30-18.70 Hz) have modest occurrence, but their amplitudes are relatively weak. Mode 6 (15.35-15.55 Hz) and mode 7 (16.55-16.90 Hz) is so weak that it can be ignored in most cases.