GPS DEFLECTION MONITORING OF THE WEST GATE BRIDGE

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Abstract: The use of GPS for monitoring long-term deformation and short-term high frequency movements has been investigated by many researchers. While static GPS positions have been available with millimetre level precision by post-processing techniques for many years, centimetre level epoch-by-epoch kinematic positions are also available, in real time or by post processing as a result of ongoing GPS software and hardware advancements. Moreover, kinematic positions are becoming available at high sampling rates of 20 Hz or more, without sacrificing the precision of the final results. The achievable precision and relatively high sampling rates of currently available GPS receivers are well suited for monitoring the movements of long-span engineering structures where the amplitude of movements is often more than a few centimetres and the frequency of vibrations is low (below 10 Hz).

However, engineering structures often offer non-ideal environments for GPS data collection due to high multipath interference and obstructions causing cycle slips in the GPS observations. These environmental impacts can seriously degrade the accuracy of positioning results. At the same time, for many engineering structures such as bridges, vertical movements are more pronounced and more structurally critical than horizontal movements. This poses a further challenge to structural monitoring by GPS since the accuracy of positions determined with GPS in the vertical direction are typically two to three times poorer than in the horizontal component.

The frequency and magnitude of movements derived from GPS provide useful information to validate Finite Element Models. Such models are typically conservative, in as much as certain structural members that add structural stiffness are often ignored. GPS movement data provides a validation tool for the testing and refinement of Finite Element Models. Such data can also serve as a valuable structural health monitoring tool in its own right. Any abnormal change in structural frequency or movement beyond expected limits can provide early warning of potential structural health issues.

This paper describes the results of a GPS deflection monitoring trial on the West Gate Bridge in Melbourne, Australia. The results are compared to the estimated frequencies and movements from the design of the bridge and previous accelerometer campaigns. The frequency information derived from the GPS results is also compared to frequency data extracted from an accelerometer installed close to a GPS receiver.

1. INTRODUCTION

Many studies have been completed on the use of GPS for monitoring deflections of structures such as cable stayed bridges [1, 2], suspension bridges [3-5], high rise buildings [6, 7] and towers [8, 9]. Among these structures, bridges often present the most challenging environment for GPS data collection due to the presence of multipath signals from towers, cables and traffic. Multipath from reflected signals from stationary and near stationary objects like towers and cables repeats on a daily basis as the geometry between GPS receiver, reflectors and GPS satellites repeats. Its effect can thus be reduced by applying post-reception techniques like adaptive filtering [10]. Multipath arising from traffic, however, is nearly impossible to reject before signal reception or correct after reception. It is this *dynamic* multipath that often gives rise to high frequency noise in GPS positions in structural monitoring applications.

When monitoring large bridges, it is usually the vertical deflection of the deck that is the most critical element. Unfortunately this requirement does not sit well with the capabilities of GPS. The geometrical and physical limitations of using a satellite based measurement system mean that height is the weakest component of position, often being two or three times poorer than the horizontal component. Researchers have demonstrated that vertical accuracy can be improved by using Pseudolites [PSEUDO(-GPS-Satel)LITES] [11] but practical problems associated with their application to deformation monitoring exist and are under investigation [12].

Despite the limitations mentioned above, experimental results have shown that GPS can be used to measure structural movements on large bridges, allowing the dynamic properties to be detected and the modal frequencies to be identified [4, 13]. This paper discusses the results of one such trial to validate the modal frequencies of West Gate Bridge in Melbourne, Australia using GPS.

The West Gate Bridge is a cable stayed bridge where the amplitude of deck deflections is in the order of a few centimetres under ambient traffic and wind loading. In terms of monitoring this structure practical considerations severely limit the choice of suitable locations for GPS antennas. The West Gate Bridge is therefore a challenging site for trialling GPS deflection monitoring.

In this paper, after a brief introduction to the bridge, an instrumentation scheme is described which provides details of the different sensors used in the trial, their locations and configuration. The results from the different sensors are then graphed in both the time domain, in the form of displacements, and the frequency domain, in the form of Power Spectral Density (PSD) functions. As a result of this analysis, a number of modal frequencies have been observed in the PSD functions at different points on the bridge. Some of these frequencies were found to match or closely match results from earlier accelerometer investigations, model studies and FEM analyses. Some other frequencies were observed for the first time. These findings are discussed in detail in this paper.

1.1. West Gate Bridge

The West Gate Bridge is a cable stayed box girder bridge constructed across Melbourne's Yarra River in the mid 1970s. The bridge was first opened to traffic in 1978. As well as being a prominent landscape feature, the bridge provides the primary vehicular link between the western suburbs and city's central business district. Estimated traffic volume is currently about 160,000 vehicles per day [14]. The West Gate Bridge consists of a number of steel spans with concrete approaches making a total length of 2590 m. The central steel section of the bridge, as shown in Figure 1, consists of five spans of lengths 112 m, 144 m, 336 m, 144 m, and 112 m respectively. These spans are supported by a combination of cables and concrete piers. The two sets of cables are supported on steel towers, each rising to a height of 45.75 m above the deck of the bridge. The steel bridge deck is 58.61 m above the Yarra River and has a width of about 37.34 m. This deck width is achieved by welded cantilever beams on both sides of a trapezoidal box girder sections.

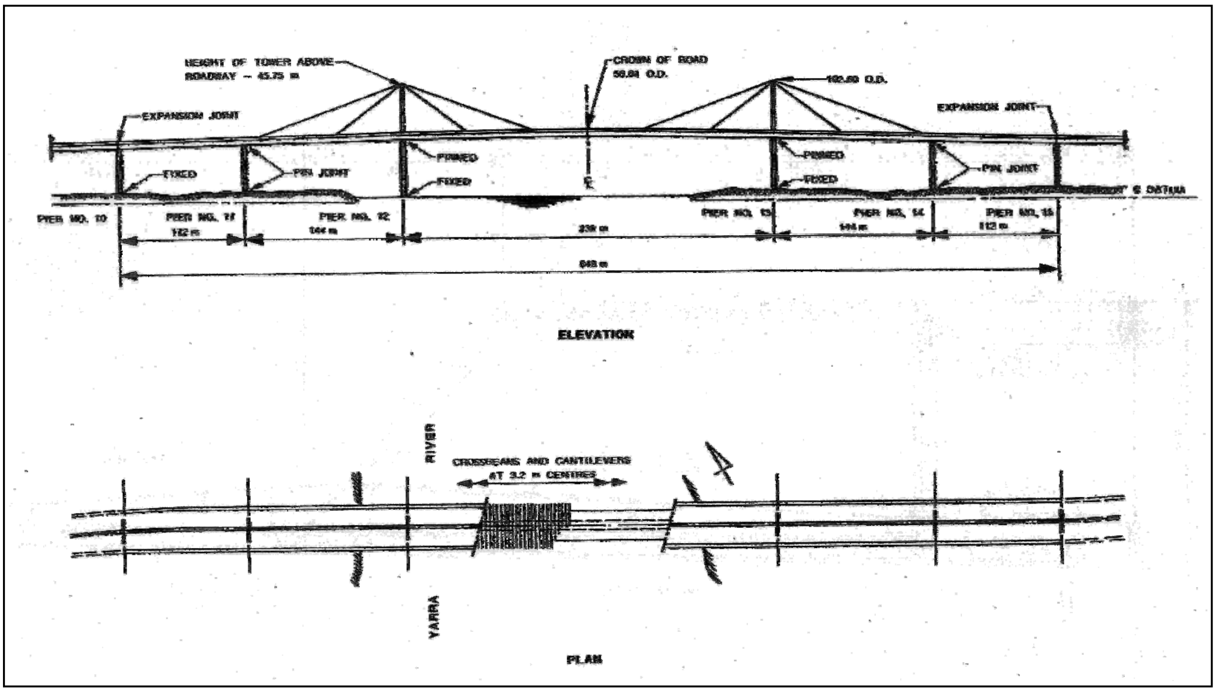

Figure 1: General layout of West Gate Bridge (from [15])

2. INSTRUMENTATION

Four Leica System 500, dual frequency GPS receivers were used for the purposes of the trial reported here. Three of these receivers were coupled with Leica AT504 Choke Ring antennas, with a Leica AT502 antenna being used in conjunction with the fourth receiver. Ideally choke ring antennas would have been used with all receivers because of the potential for high multipath interference, but only three such antennas were available for the project. In addition to the GPS receivers, Four DYTRAN model 3191A uni-axial accelerometers were used for comparison and evaluation of the GPS results. These accelerometers have a sensitivity of 5 V/g and work in a frequency range of 0.1 – 1000 Hz.

One GPS receiver with an AT504 antenna was installed close to the crown of the bridge in the median. The location of this receiver is labelled “CENTRE” Figure 2 (photograph from [16]). A second receiver with AT504 antenna was installed in the median near the quarter point of the central span and is labelled “EAST” in Figure 2. AT504 choke ring antennas were used with the receivers on the bridge deck to minimize the effect of multipath interference from different components of the bridge structure and from the high volume of passing traffic. A third GPS receiver with an AT502 antenna was installed on top of the eastern tower of the bridge and is labelled “TOWER” in Figure 2. The AT502 antenna was used for station TOWER because it was presumed that this highly elevated position would not be subject to significant multipath interference. The fourth GPS receiver and the final AT504 antenna were used as a base station, installed at a stable site on the roof of the nearby ScienceWorks Museum, some 500 m from the bridge.

The antennas on the bridge deck at stations CENTRE and EAST were installed on purpose-built steel posts attached to the guard rail using timber spacers and bolts [see Figure 3 (a)]. The GPS receivers and controllers were stored in weather-proof boxes that were likewise secured to the guard rails. The antenna on the station TOWER was installed on a specially made magnetic base [see Figure 3 (b)]. The magnetic base was secured to the tower using cables to ensure it did not move or blow off in high wind conditions. The AT504 antenna for the base station receiver at Science Works was installed on a bracket that was permanently mounted on a concrete wall [see Figure 3 (c)].

Figure 2: Location of GPS receivers on West Gate Bridge

(a) Station CENTRE & EAST (b) Station TOWER (c) Base station at Science Works

Figure 3: Installation of GPS antennas

Four accelerometers were used as part of the trial. Three of these accelerometers were installed inside the bridge deck immediately below station CENTRE [see Figure 4(a)]. One of