Monitoring the Deflections of the Suspension Cables of the Severn Suspension Bridge by GNSS

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ABSTRACT:

Some 106 bridges and tunnels exist to cross the River Severn in the UK. There are two large bridges that cross the Severn towards the estuary's entrance, linking Bristol and South Wales. These are the M48 Severn Bridge and the M4 Second Severn Crossing. The Severn Bridge is a 1,600m long suspension bridge, with a main span length of 988m, and the M4 Second Severn Crossing has a total length of 5km, with the longest span being a 482.8m section of a cable stayed bridge.

A series of field surveys were carried out in 2010, to monitor the magnitude and frequencies of the M48 Severn Bridge's movements. This was carried out through attaching 9 dual frequency survey grade GNSS receivers on the bridge itself, being positioned relative to two reference stations located adjacent to the structure. The bridge's GNSS receivers were attached to the tops of the four towers, as well as directly onto the suspension cables. Traditionally, this type of work has been carried out by attaching the receivers to the bridge deck or parapet, but this is thought to be a novel data gathering exercise.

Overall, some 3 days of raw code and carrier phase GNSS data were gathered, at rates of 10Hz and 20Hz. Initial processing has been conducted, as well as an outline analysis of the results. This paper describes the survey, and presents a selection of the key results.

1. INTRODUCTION

The use of GPS and GNSS to monitor the movements and deflections of bridges has been an ongoing area of research by the authors for over 15 years [Ashkenazi et al, 1996; Ashkenazi et al, 1997; Brown et al, 1999; Roberts et al, 2000]. The authors' work started on the Humber Bridge, and then moved onto the Millennium Bridge in London, the Wilford Bridge in Nottingham, the Forth Road Bridge, the Avonmouth M5 crossing and now the M48 Severn Suspension Bridge [Roberts et al, 2010]. Historically the authors have clamped the antennas onto the parapet on the side of the bridge, and on the parapets at the tops of the tower [Roberts et al, 2004]. However this latest piece of work saw the GNSS antennas attached directly to the suspension cables, in addition to the tops of the towers.

The following paper outlines some field work carried out on the M48 Severn Bridge, in March 2010. The bridge is a 1,600m long suspension bridge, with a main span length of 988m long. This is thought to be the first time GNSS antennas have been attached to the suspension cables of such bridges to conduct this type of monitoring.

2. GNSS LOCATIONS

The data gathering trials were conducted on two separate occasions, during the 10-12th March and again on 18th March 2010. Each session had the GNSS antennas located at 8 of the 9 survey points, along with up to 2 reference receivers. Figures 1 and 2 illustrate the locations of the GNSS antennas for the various sessions. The main reference GNSS receiver was located upon a survey point on top of the adjacent toll building, Figure 3. A second backup reference GNSS receiver was placed on top of the port cabin on the cliff compound. Both of these locations are on the land adjacent to the bridge, and within 2km of the furthest GNSS antenna.

The survey points upon the bridge and cable were carefully fixed by staff from Severn River Crossing Plc. (SRC), and the authors would like to take the opportunity to thank them for their kind efforts and care taken with the task. The GNSS receivers used were Leica 530 dual frequency geodetic receivers, Leica 1200 dual frequency geodetic GNSS receivers, Leica SR510 single frequency receivers and a Leica Viva receiver, and the antennas used were Leica choke ring antennas. The various sessions saw the antennas located at different survey points for some of the sessions. In particular, the focus for most of the survey was the upstream cable, where 4 antennas were placed (A, B, C, D). However, for a prescribed period, an antenna was placed on the downstream cable E – opposite position C (see Figures 1,2) to enable checks of the synchronous nature of cable movement to be carried out. SRC attached the 4 choke ring antennas to the very top of the towers, Figure 4, and carefully trailed the 50m antenna cables into the enclosed crossway. This meant that it was a safer and sheltered environment for the authors to be able to download the data,

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under the supervision of SRC staff. It also meant that an uninterrupted power supply was available. In addition to this, SRC attached the antennas directly to the suspension cables, Figure 5, and 50m cables were carefully placed so that the authors could attach the GNSS receivers to the cables at bridge deck level. This allowed easy battery changeover as well as data downloading. Data was downloaded on a periodic basis in order to prevent large data loss in case of any issues with the receiver. Luckily there were none.

The raw GNSS data was gathered at a rate of 20 Hz for the 1200 and Viva receivers, and 10Hz for the SR510 and SR530 receivers. Due to the high resolution of the GNSS carrier phase data used, in addition to using the choke ring antennas, the precision of the results are millimetre in level. Once gathered, the GNSS data was then post processed through a technique known as On-The-Fly (OTF) kinematic processing, resulting in data files that consist of 3D coordinates in WGS84 coordinate system with corresponding times at either 0.05 or 0.1 second intervals. Due to the large data files, the sessions were split for processing purposes. Subsequently the resulting coordinates were transformed into the bridge coordinates and filtered. The orientation of the bridge was calculated through using the known average coordinates of the cable GNSS receivers, and calculating the bearing between them which resulted as a bearing of 120°.

Location	10.03.10 AM	10.03.10 PM	11.03.10 AM	11.03.10 PM	12.03.10 AM	12.03.10 PM	18.03.10
A	1200	1200	1200	1200	1200	1200	SR510
B	1200	1200	1200	1200	1200	1200	1200
C	1200	1200	1200	1200	1200	1200	1200
D	1200	1200	1200		1200	1200	1200
E				1200			1200
T1	SR530	SR530	SR530	SR530	SR530	SR530	SR530
T2	SR530	SR530	SR530	SR530	SR530	SR530	SR530
T3	SR530	SR530	SR530	SR530	SR530	SR530	SR530
T4	SR530	SR530	SR530	SR530	SR530	SR530	SR530

Figure 1. Session times, locations, dates and corresponding GNSS receiver types.

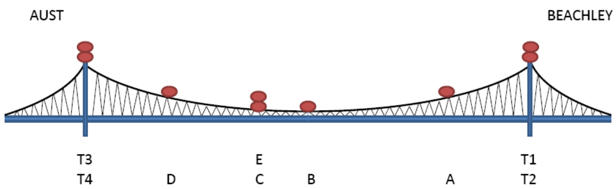

Figure 2. Survey points upon the bridge.


Figure 3. The principal reference GNSS antenna located upon an adjacent building to the bridge.

Figure 4 illustrates one of the choke ring antennas located on top of the four towers. The antenna cables from these were fed through the manhole into the tower, where SR530 GNSS receivers were located and gathered the data. This meant that the GNSS receivers could be accessed even in windy conditions (access would not otherwise have been permitted if wind speeds exceeded 20mph). The SRC engineers placed the antennas in position as well as the cables.

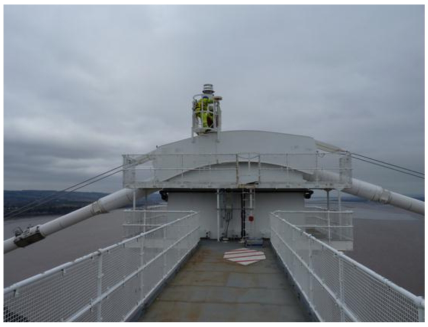
Figure 4. The GNSS antennas located at survey point T2 on the bridge. The illustration shows the GNSS antenna being installed.


Figure 5. GNSS choke ring antenna located on the suspension cable.

Figure 5 illustrates one of the choke ring antennas located on the cable. This is, as far as the authors can deduce, the first time that such an elaborate measurement of this type has been carried out, on both the towers and cables at the same time. The results are direct movements of the suspension cable. The research also investigated the relationship between the movements detected on the cables with those of the towers. This will be the focus of a future paper.

3. RESULTS

Due to the vast amount of data gathered, the results and number of data-points are phenomenal. This section illustrates a small subset of the results, and various processing techniques have been used.

Figure 6 illustrates the 3D movements in bridge coordinates of the GNSS antenna located at point A, over approximately a 50 minute period of time. The deflections in the vertical direction can be seen to reach over 0.3m in magnitude at times. All these deflections are predominately due to the mass of traffic travelling over the structure. In addition to the vertical movements, the lateral deflections show a relationship with some of the vertical.

Figures 7 and 8 illustrate smaller periods of time, 10 minutes and 1 minute respectively. From these figures, and in particular figure 8, the sinusoidal nature of the deflections is evident. Further to this, the noise of the GNSS results can be seen in these figures. The values for the noise have not been quantified as yet, but the noise and actual movements are clearly distinguishable from each other in the figures.

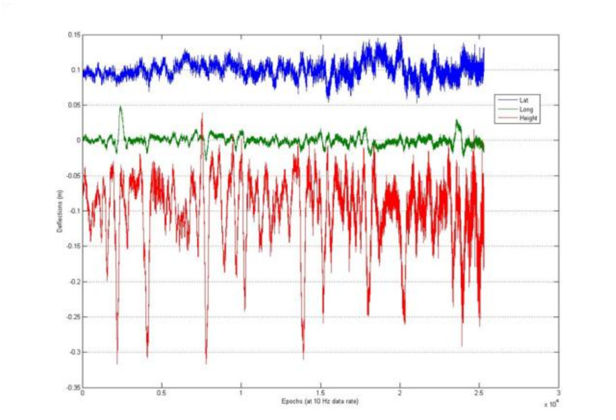

Figure 6. Deflections at point A from 13:09:45 to 13:51:55.

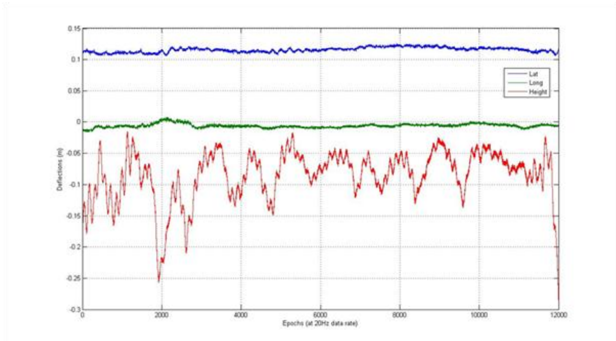

Figure 7. Deflections at point B over a 10 minute period.

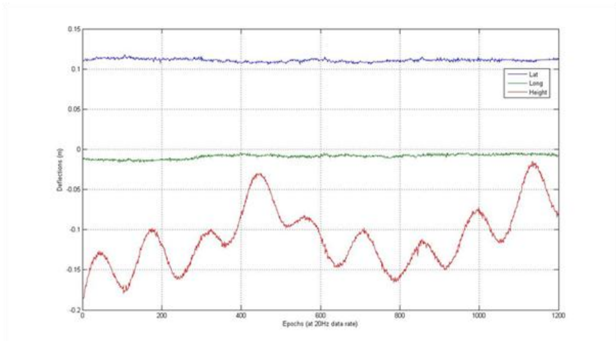

Figure 8. Deflections at point B over a 1 minute period.

Frequency response analysis was carried out on the data. Figure 9 illustrates the results for point B. It is clear that at least two vertical frequencies are present in this data at 0.146 Hz and 0.2265 Hz. Full analysis of the results is currently being conducted, as well as how these frequencies vary due to changing external factors, in particular the temperature and mass of traffic loading. Previous work on the Forth Road Bridge illustrated that the mass of traffic does in fact alter the natural frequencies of the bridge, as the traffic mass becomes a significant part of the bridge mass [Brown et al, 2007]. This data will also be analysed for similar phenomena.

Figures 10 and 11 illustrate the height deflections of all 4 locations on the bridge over a 40 minute and 10 minute period, respectively. It is evident from figure 11 in particular that some of the deflections are slightly offset from each other. This is due to the mass of the vehicles travelling over the bridge. Due to the varying nature of traffic movements over the bridge, from both directions and over all the lanes, the movements are also variable in nature. Figure 11, for example, shows a lot of movement in particular just after the 4,000 epoch mark, but then shows little movement at approximately the 8,000 to 11,000 epoch mark; apart from the sinusoidal movement of the bridge.

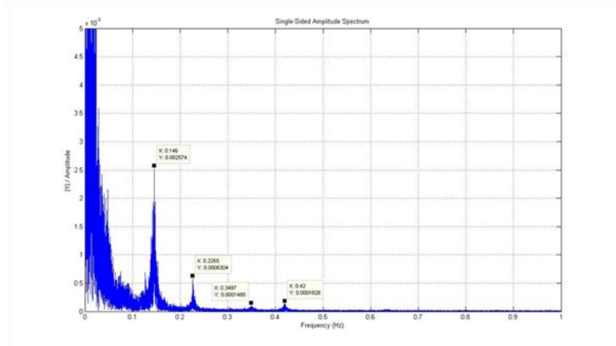

Figure 9. Frequency response in the vertical direction at point B.

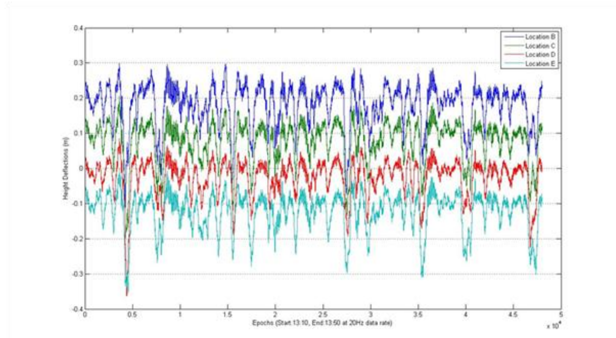

Figure 10. Vertical Deflections for 4 locations over a 40 minute period.

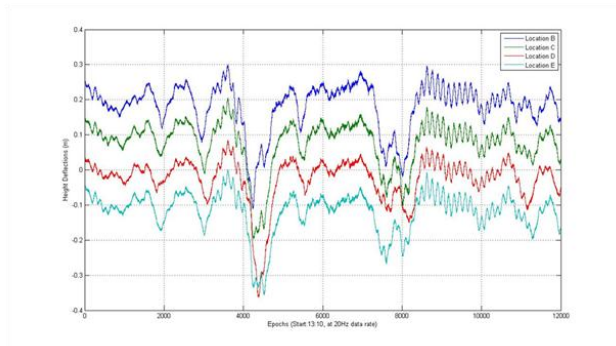

Figure 11. Vertical Deflections for 4 locations over a 10 minute period.

4. CONCLUSIONS

The results from this piece of field work are under constant analysis. The dataset itself is an invaluable piece of data that will allow the authors to pursue the research into this type of monitoring and analysis.

5. ACKNOWLEDGEMENTS

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