Correlation of the movements of the Severn Suspension Bridge derived with GNSS with Temperature Variations.

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Abstract. In March 2010, four days of GNSS data were gathered on the Severn Suspension Bridge. The GNSS antennas were located on the tops of the four support towers, as well as five locations on the suspension cables. The Severn Bridge has a main suspended span of 998m long. The GNSS data were gathered at rates of 10Hz and 20Hz between the 10th to the 12th and on the morning of the 18th March 2010. In addition to the GNSS data, the air and steel temperatures were gathered every 10 minutes. The GNSS data were processed in an On The Fly manner relative to a reference GNSS receiver located on a solid building adjacent to the Bridge.

The resulting OTF data were then analysed, and compared to the temperature data, and variations. Moving average filters were applied in order to extract the short term movements due to wind loading and traffic loading in the vertical direction, resulting in the longer term deflections. The temperature over the three days varied by up to 10°C, and movements of the order of decimetres were seen.

Clear correlation between the changes in temperature and the changes in height are presented.

Keywords. GNSS, Bridge Deflections, Deformation Monitoring.

1 Introduction

GNSS has been used to monitor the deflections of long span bridges for approximately 20 years.

Suspension bridges are prone to movements, by design. These movements can be split into three main components. These being the movements due to the natural frequencies of the bridge, which is usually in the range of a few Hz to 0.1Hz or so and induced typically by the loading due to traffic or wind, the deflections of the bridges due to loading from traffic and wind, which is of the order of up to decimetres, but over a time period of a few seconds, and finally the long term movements of the bridge due to temperature changes. This last type of movement occurs over a much longer time period, typically hours.

Previous work on the Humber Bridge and the Avonmouth M5 crossing have shown results that have this type of long term movement evident. Figure 1 illustrates the results from the Humber Bridge illustrating the vertical movements at a single location during three successive days, using 12 hours of data from each day. The three days' results are overlapped with each other in the figure. The data from the 1 March starts at a slightly later time, due to the setup time at the start of the survey. The deflections at this location are evident in the figure, showing the Bridge dipping down at the order of up to 30cm due to the traffic loading. However, it can also be seen that all three day's results gradually drop down over the 12 hours. This is due to the increase in temperature, and the corresponding expansion of the steelwork on the Bridge. On the 2 March, the temperature at 09:15 was 4°C, and changed down to 1.8°C at 09:40 and finally up to 8°C by 15:00 [Cosser, 2005]. On the 4th March, the temperature started at 14.5°C at 09:00, changed down to 9°C by 10:05 and then up to 15°C by 12:00, then again dropping to 11°C from 12:45 to 14:10, rising again to 13°C at 14:50, then gradually dropping from 15:15 to 10°C at 16:30. It can also be seen that the height of this location on the 4th March started off at a lower location. This is because the temperature at this time was higher.

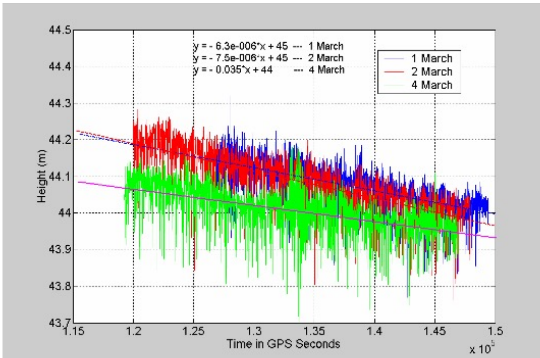

Fig. 1 Three consecutive days' of data from the same location on the Humber Bridge, illustrating the effect of temperature on the overall level of the Bridge deck [Roberts *et al.*, 2005b].

Figure 2 illustrates the lateral, longitudinal and vertical deflections at a location on the M5 Avonmouth viaduct [Ogundipe et al, 2014; Roberts et al, 2014]. Here, again, it can be seen that over an approximately 6 hour period, the bridge moves in a mainly vertical and longitudinal direction. Again, this is thought to be due to the heating effect and expansion of the bridge.

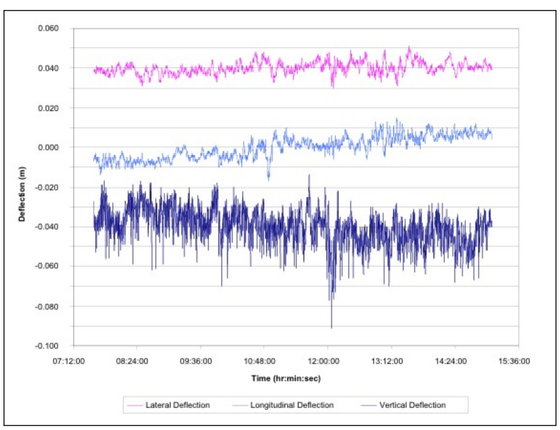

Fig. 2 Lateral, longitudinal and vertical movements of location M on the 30 November 2007, the Avonmouth viaduct [Roberts et al, 2014].

Further work has been carried out on the Severn Suspension Bridge in the UK, and this is the topic of this paper.

2 The Severn Bridge Survey, 2010

An extensive survey was carried out on the Severn Suspension Bridge in the UK in March 2010. This consisted of placing 9 GNSS antennas on the Bridge itself; on the tops of the four towers as well as key locations on the suspension cables. Figure 3 illustrates the locations of the GNSS antennas. 30m long antenna cables were used to connect the GNSS antennas to the receivers. This allowed the surveyors to be located in safe locations whilst operating the receivers. The four receivers attached to the antennas on the tops of the towers were Leica SR530 dual frequency GPS receivers, and the receivers attached to the suspension cables were Leica 1200 dual frequency GPS/GLONASS receivers. The antennas used were Leica AT504 choke ring antennas on the tops of the towers, and Leica AT503 lightweight choke ring antennas on the suspension cables. Two GNSS reference stations were set up, both using Leica 1200 GNSS receivers and AT504 antennas [Roberts et al, 2014].

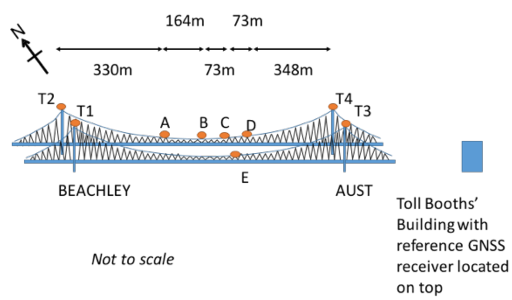

Fig. 3 The locations of the 9 GNSS antennas on the Bridge.

Data were gathered at a rate of 10Hz at the SR530 receivers, and 20Hz at the 1200 receivers. Details about the survey are explained further in Roberts et al [2014]. The data at location A on the 11th March is used in this paper to detail the relationship between the movements at that location and the changes in temperature. Temperature information is available at 10 minute intervals, for both the air and the steel.

3 Data Analysis

The GPS data were processed using RTKLib, and converted into the coordinate system of the Bridge. Figure 4 illustrates typical movements of the Bridge at location A over a 1 hour period on the 11th March, between 11:00 to 12:00. Here it can be seen that there are short term movements due to traffic loading in particular, resulting in movements of the order of up to 250mm in the vertical direction, as well as smaller movements of the order of up to 30mm in the longitudinal direction, and 10mm in the lateral direction. The small lateral movements also imply that the wind during this time was very small.

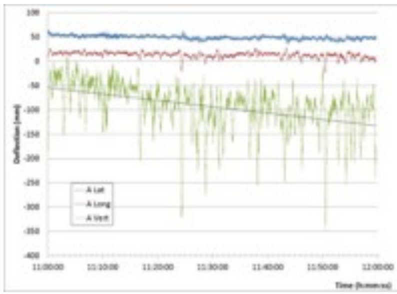

Fig. 4 Lateral, Longitudinal and Vertical GNSS movements at location A over a 1 hour period on the 11th March 2010.

There are also short term 0.146Hz movement data within these data [Roberts et al, 2014]. The movement that is focussed on in this paper is the longer term movement due to the change in temperature. During the 1 hour test period, the air temperature changes from 4.947ºC to 5.672ºC (0.725ºC/h), and the steel temperature changes from 2.781ºC to 3.815ºC (1.034ºC/h). The corresponding change in the average vertical value for location A, Figure 4, is 78mm/h. Further to this, the corresponding change in the lateral direction for A is 8.3mm/h, and the corresponding change in the longitudinal direction is 8.7mm/h.

Figure 5 illustrates the vertical component of the antennas at locations A, B, C and D over a 4 hour period on the 10th March. This time the data was gathered in the evening, when the air and consequently steel temperatures were dropping.

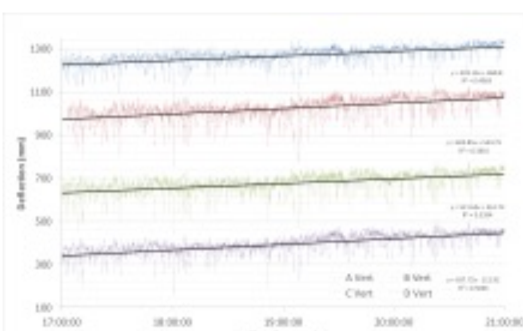

Fig. 5 Vertical movements at locations A, B, C and D over a 4 hour period on the 10th March 2010.

The average vertical cable locations during a period of air cooling in the evening (Figure 5) become more positive in value – that is move upwards. The air temperature changes from 6.124ºC to 2.615ºC (3.509ºC or 0.877ºC/h), and the steel temperature changes from 5.875ºC to 3.765ºC (2.11ºC or 0.528ºC/h) between 17:00 to 21:00. The corresponding change in the average vertical value for location A is 21mm/h. Further to this, the corresponding change in the lateral direction for A is 10.5mm/h, and the corresponding change in the longitudinal direction is 0.1mm/h.

The temperature values for both the air and the steel of the Bridge are recorded at a 10 minute interval. The data for location A was filtered with a moving average to correspond to the same 10 minute interval. Figure 6 illustrates the relationship between the lateral, longitudinal and vertical movements of location A using the moving average filter, as well as the air and steel temperatures.

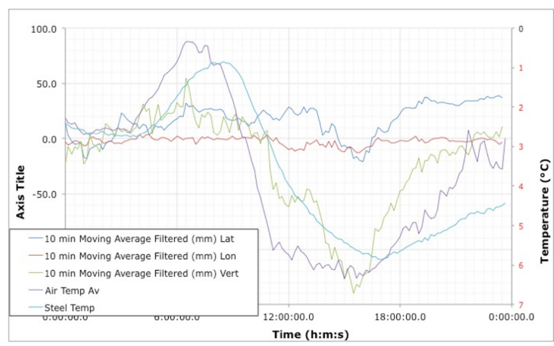

Fig. 6 Lateral, Longitudinal and Vertical movements at location A, as well as the air and steel temperatures over a 24 hour period on the 11 March.

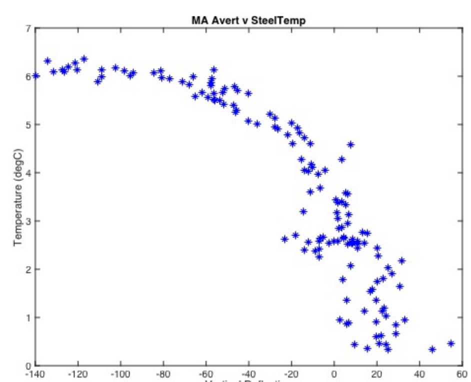

Fig. 7 Relationship between the change in temperature and change in height at location A on the 11th March.

Figure 7 illustrates the relationship between the change in height at location A and temperature during the 10 minute epochs, over the 24 hour period. This again shows that there is a good relationship between these data.

4 Conclusions

The results show a clear relationship between the movements at the GNSS receivers on the Severn Bridge and the temperature of the steel and air. Further work is being carried out to investigate this relationship further for the whole of the survey in 2010. In addition to this, work is underway to look at the relationship between these data as well as data gathered in July 2015. The temperature variation will then go up to 24 °C, rather than only the 6 °C illustrated in this paper. Such understanding of the movements of a structure due to changes in temperature is an important factor when designing and also when monitoring the movements over a period of time. Such knowledge can be used as part of a Structural Health Monitoring (SHM) system

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