Temperature Effects on the Vertical Movements of the Severn Suspension Bridge's Suspension Cables Measured by GNSS

Gethin Wyn ROBERTS, Xu TANG, China, Christopher John Brown ,United Kingdom

Key words: GNSS, Kinematic GNSS, Deformation Monitoring, Long span bridges

SUMMARY

The use of GNSS for the deflection monitoring of large bridges has been an ongoing field of research for 20 years. The Severn Suspension Bridge, in the UK, has a main span length of 988metres. Datasets were gathered in both March 2010 and July 2015 by placing GNSS antennas on the tops of the support towers, as well as on the suspension cables. The data were gathered over four days and three days respectively during these surveys. In addition to the GNSS data, weigh in motion data of the traffic loading, the temperature of the bridge's steel work, and the air temperature and wind speed and direction at a number of locations were collected. In 2010, the temperature during the survey varied between 0.335ºC to 13.750ºC for the air temperature, and between 0.886ºC to 12.390ºC for the steel temperature. During the survey in 2015, the temperature for the air varied between 10.800°C to 22.160°C, and the steel temperature varied between 13.820ºC to 20.410ºC.

This paper analyses the vertical movements at the mid-span of the bridge's suspension cable using the data from 2010 and also 2015. The vertical movements are due to a number of reasons. Firstly, the traffic flow will cause rapid changes in the height of the cable, of the order of decimetres due to changes in traffic loading over a time period of seconds or minutes. Secondly, the wind will also cause movements in the cable, but mainly in the horizontal direction. Vertical movements due to the vibrating nature of the cable will also be present, at a rate of 0.1Hz or so. Finally, the cable will expand and contract due to the change in temperature. This will take place over a period of tens of minutes. The relation between the antenna location in 2010 and 2015 are calculated against changes in temperature, and correlation between the movements are shown. The overall movements due to the change in temperature during the survey in 2010 can be shown to be of the order of decimetres, and similarly in 2015.

The change in a bridge's height, due to a change in temperature is an important parameter to be known. A bridge in the UK could experience changes in temperature from almost 30 °C to -10 °C in a period of a year during its lifetime. In other parts of the world, this differential could be even more. This could result in a very significant vertical movement of the bridge, which in turn could affect the clearance space under the bridge for passing ships. This type of movement tied with changing tides could result in large ships colliding with such bridges if the clearance is not fully understood.

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1. INTRODUCTION

The use of GPS and more recently multi-GNSS for measuring the deflections of bridges, and long span bridges in particular, has been an ongoing piece of research for 20 years. The authors have carried out such work on a number of bridges in the UK, as well as Australia and South Korea [Roberts et al, 2014]. During this work, it has been reported that long term movements, over periods of hours, have been measured, caused by changes in temperature. This change in temperature causes the steelwork of the structure to expand and contract, and hence the position, in particular in the vertical direction, changes. Figure 1 illustrates the long term movements on the Humber Bridge during three consecutive days of surveys. Here it can be seen that the bridge drops down gradually by up to the order of 20cm, over 12 hour periods, during which the temperature changed by 13 ºC.

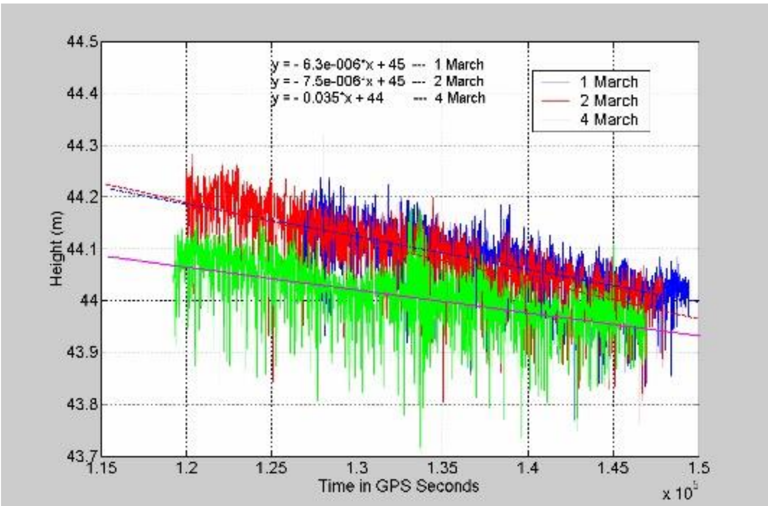

Figure 1, Three consecutive days' of data from the same location on the Humber Bridge, illustrating the effect of temperature on the overall level of the Bridge deck [Roberts et al., 2005b].

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.

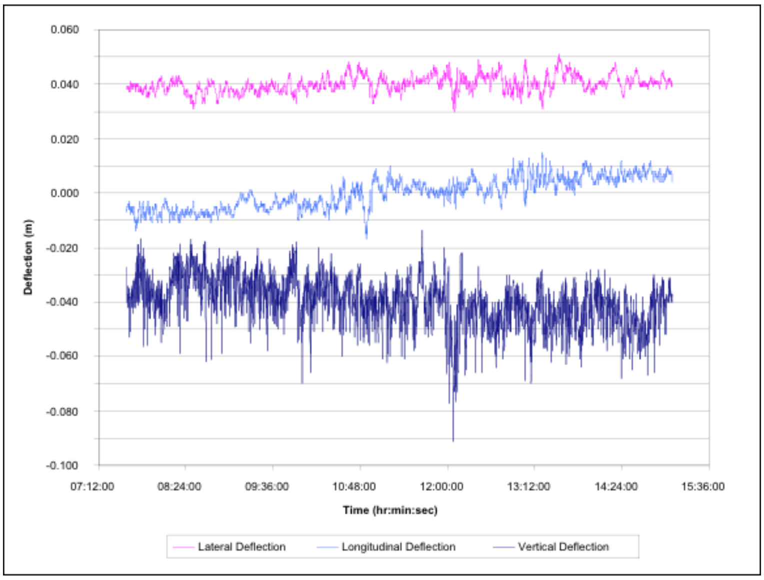

Figure 2, Lateral, longitudinal and vertical movements of location M on the 30 November 2007, the Avonmouth viaduct [Roberts et al, 2014].

Again here it can be seen that there is a long term movement, due to the change in temperature in both the vertical and longitudinal direction of the bridge.

The following paper gives details of movements at the middle of the main span on the Severn Suspension Bridge during surveys conducted in 2010 and 2015.

2. SEVERN BRIDGE SURVEYS

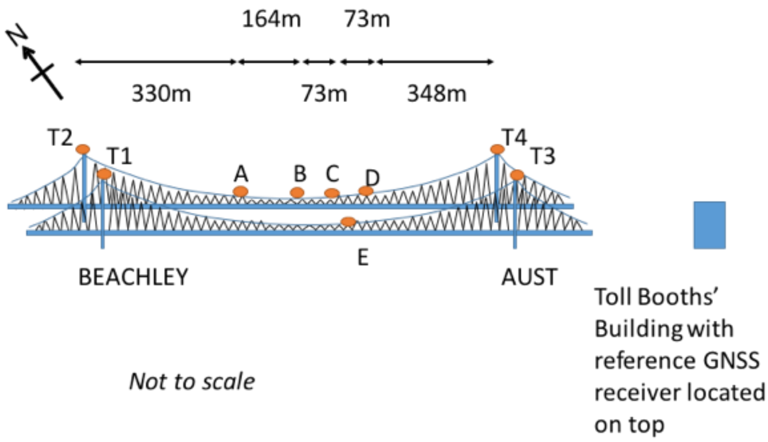

Figure 3, Locations of the GNSS antennas on the Severn Bridge during the 2010 surveys.

Extensive surveys were carried out on the Severn Suspension Bridge on the 10th -12th and 18th March 2010, as well as the 21st – 24th July 2015. During these surveys, 9 and 10 GNSS receivers were placed upon the Bridge, simultaneously gathering data, relative to reference GNSS receivers placed adjacent to the structure. The main reference station for both surveys was located on top of the toll control building, and the same survey marker used both times.

During the 2010 surveys, 9 GPS and GNSS receivers were located on the Bridge, the locations being the tops of the 4 towers, as well as directly on the suspension cables. Figure 1 illustrates a schematic illustrating the locations of the GNSS receivers. Leica SR530 dual frequency GPS receivers were located on the tops of the towers, and Leica 1200 dual frequency GNSS (GPS and GLONASS) receivers were placed on the locations on the suspension cables, as well as at the reference stations [Roberts et al, 2014].

During the 2015 surveys, 4 GNSS receivers were located on the tops of the towers, this time a pair of Trimble receivers, and a pair of Javad receivers. Leica receivers were placed on the suspension cable, and reference station. This time, instead of having two separate reference stations, the survey consisted of one antenna, but gathering data at two receivers using an antenna splitter. This will allow analysis of observable noise, and noise due to the satellite constellation geometry to be carried out in the future. Antennas were located at locations T1, T2, T3 and T4, as well as locations A, B and D, in Figure 3. In addition to this, an antenna was located on the south side suspension cable opposite location B, and a floating GNSS receiver was used at various locations, including the deck at location B, and the deck at the midspan of the Aust side span.

This paper focusses on the data gathered at location B during the two surveys. The locations used in 2010 and 2015 are slightly different. This is because in 2010, the location at the exact centre of the Bridge also had a lamp post close to the cable. It was decided to move location B in 2015 in order to avoid this, and hence possible multipath contamination of the data. The relative locations of the two are known, and this will be the focus of further work in order to correlate the data from 2010 with that of 2015. However, in this paper the results are shown for both 2010 and 2015, but the correlation between 2010 and 2015 is not illustrated.

3. DATA ANALYSIS

The GNSS data were converted into RINEX format using TEQC, and processed using RTKLib. Some of the datafiles were too big to process in one session, therefore, the larger datafiles were split into 1-hour long sessions, and the various results joined up afterwards. The processing used for this paper used only GPS data, and only dual frequency data. However, various GNSS exist in the datafiles, as well as some triple frequency data, and this will be the focus of further research.

Figure 4 illustrates typical movements of the Bridge at location B 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.

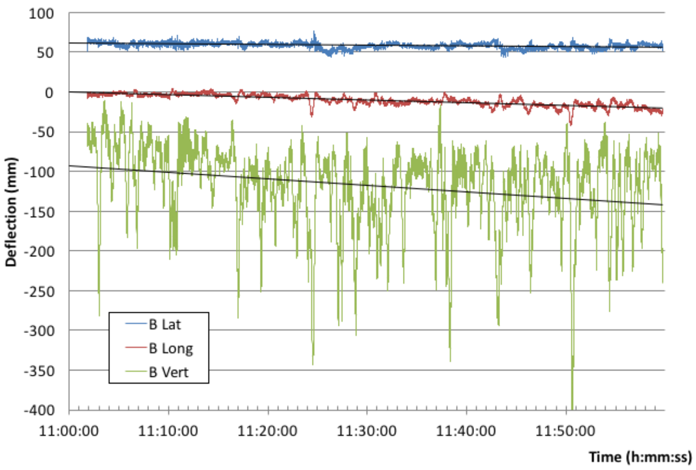

Figure 4, Lateral, Longitudinal and Vertical GNSS movements at location B over a 1 hour period on the 11th March 2010.

There are also short term 0.146Hz movement data within these data [Roberts et al, 2014]. The movement that is focused 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.

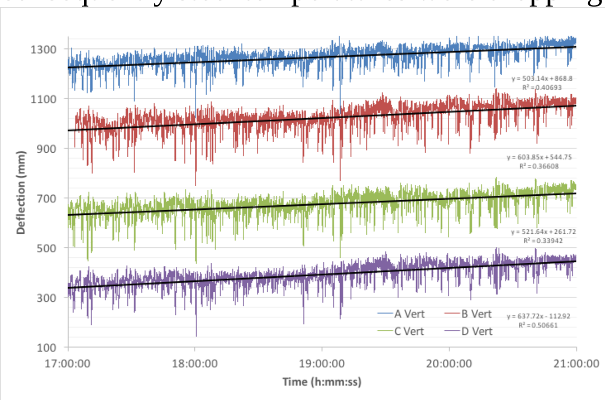

Figure 5, Vertical movements at locations A, B, C and D over a 4 hour period on the 10th March 2010.

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.

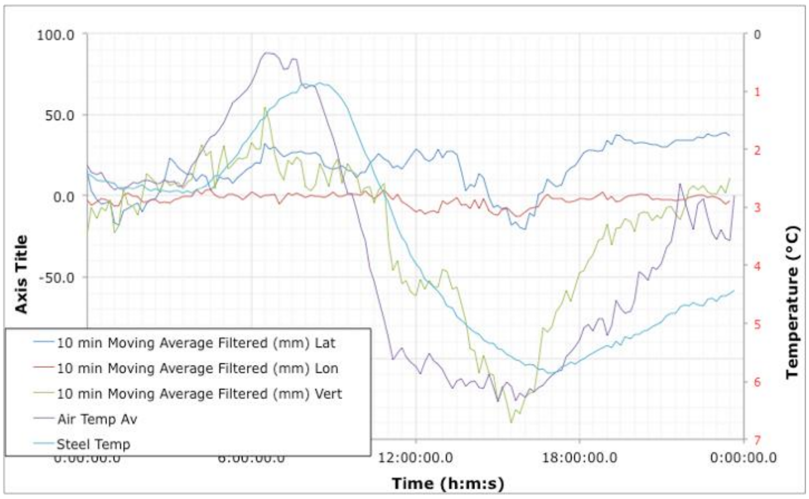

Figure 6, Lateral, Longitudinal and Vertical movements at location A, as well as the air and steel temperatures over a 24 hour period on the 11 March 2010.

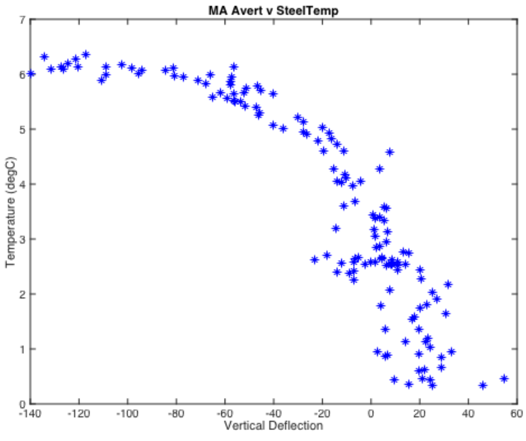

Figure 7, Relationship between the change in temperature and change in height at location A on the 11th March 2010.

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.

Further to these results from 2010, results from 2015 are also presented in this paper. The vertical movements at location B were adjusted using a 10 minute moving average filter, which correspond to the temperature data. Figure 8 illustrates the relationship between the air temperature, the steel temperature as well as the Moving Average filtered vertical movements at location B over a 29-hour period. Here it can be seen that there is a very good visual correlation between these data.

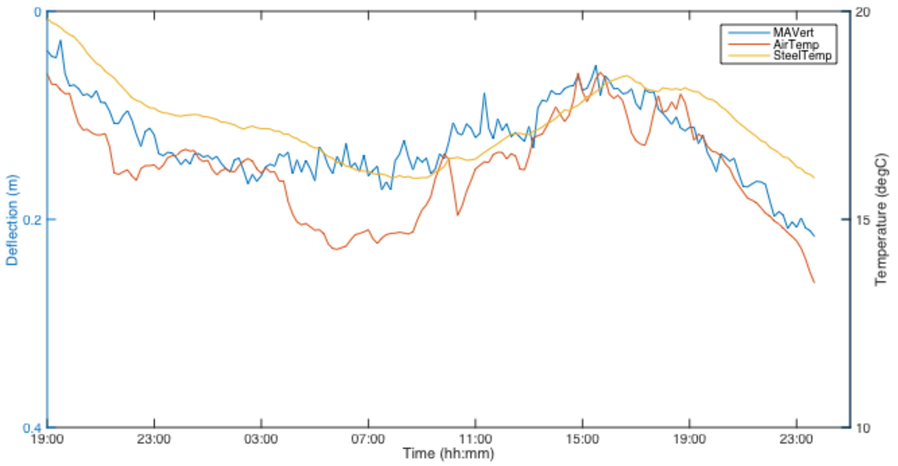

Figure 8, Steel Temperature, Air Temperature and the Moving Average (10 minutes sample) vertical movements at location B, July 2015.

4. CONCLUSIONS

The results illustrate that there is a correlation between the temperature and vertical deformations of the Bridge. The deformations can be of the order of decimeters, with only a handful of degrees in temperature change. Considering that the temperature in this part of the UK could fluctuate by up to 30 ºC in the period of a year, resulting in an overall larger movement. This could be important information for future bridge designs, as well as being used to monitor the ongoing Structural Health of the structure, and to look out for abnormal changes in relation to temperature changes.

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BIOGRAPHICAL NOTES

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