Structural integrity monitoring by global positioning systems

Christopher Furneaux writes about his undergraduate project at University of Nottingham which was awarded commended in the Model Analysis Award 2003

Fig 1. Wilford Suspension Bridge

The large structures that exist throughout the world are subjected to a significant number of changing loads, for example the traffic on our roads increasing and also climate changes resulting in more floods and higher winds. Monitoring the displacements and corresponding frequencies of large structures such as bridges, dams and skyscrapers is of vital importance to safety.

Monitoring the structures closely can provide valuable information on how they react to applied loads, and therefore abnormal movements can be identified. Monitoring structures can be used not only to identify abnormal movements, but also to aid in planning detailed surveys and maintenance work. The ability to monitor structures also allows comparisons to be made with the designs, which will result in more accurate design procedures in the future.

Many of the established techniques[1] are only effective in monitoring the static deformation. This project investigated the use of GPS equipment, able to measure to a few millimetres without any filtering, in monitoring static or dynamic structural movements[2,3,4,5].

Trial methodology

The trials were carried out on the Wilford Suspension Bridge over the River Trent in Nottingham (see Fig 1). The bridge is owned by Severn Trent Water and carries water pipes across the river, and is also used by pedestrians and cyclists. It is approximately 65m long, has a wooden deck that is about 3.5m wide, and lies on a bearing of 12º.

Two different trials were undertaken the first looking at the vibration of the bridge, and the second looking at the deformation. In both sets of trials dual frequency GPS receivers were attached firmly to the structure of the bridge, two at mid-span and one at each quarter span. In the vibration trials a number of different methods were used to try and initiate a vibration; these included groups of people running and jumping on the bridge.

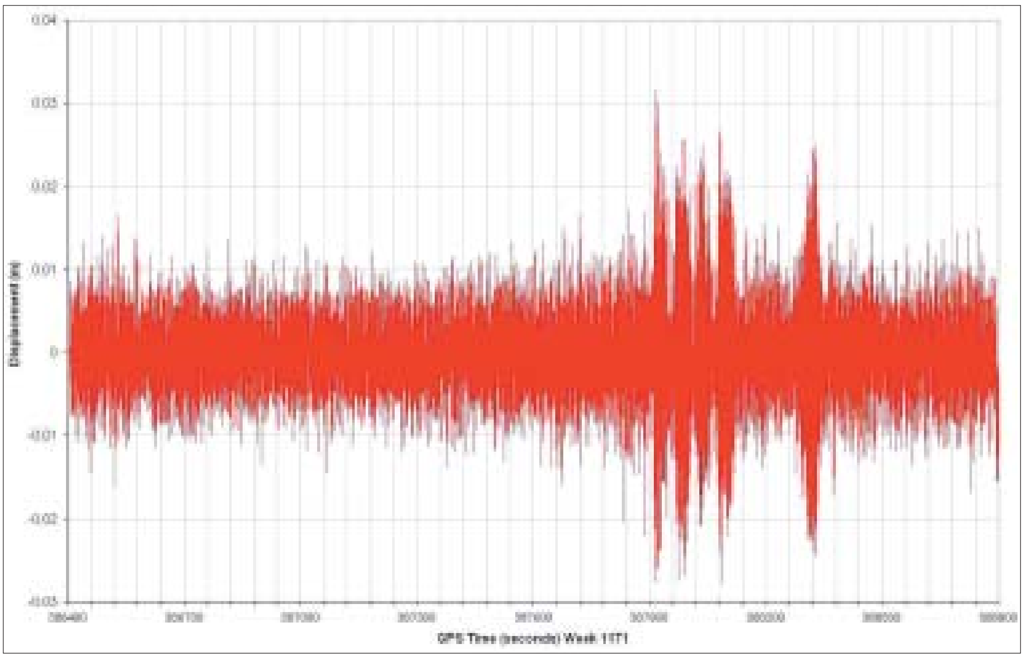
In the deformation trials a known mass was positioned at mid-span. The load applied to the bridge consisted of a number of wheeled boxes with a total mass of 580kg.

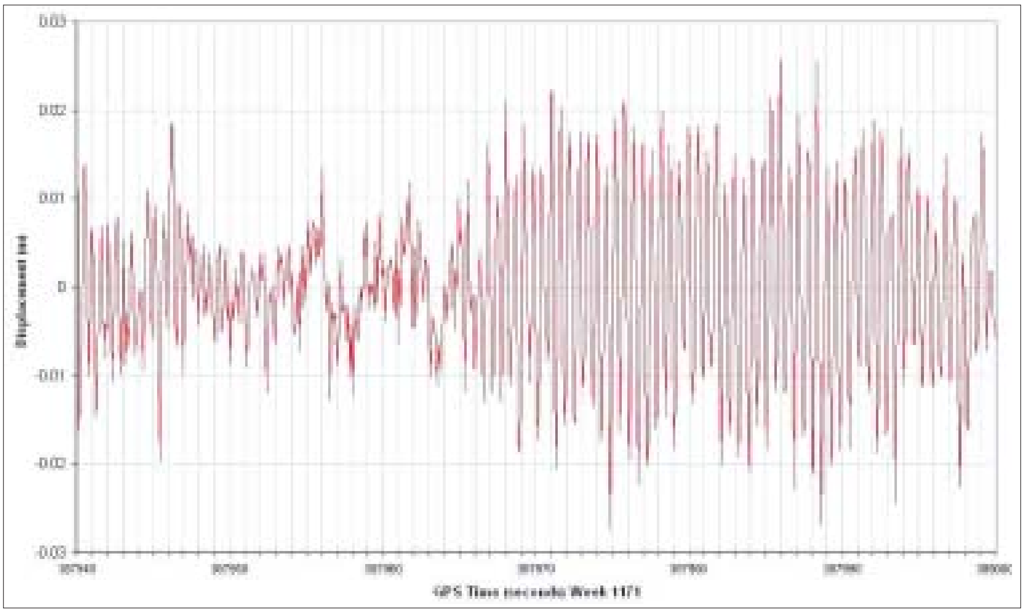
Results

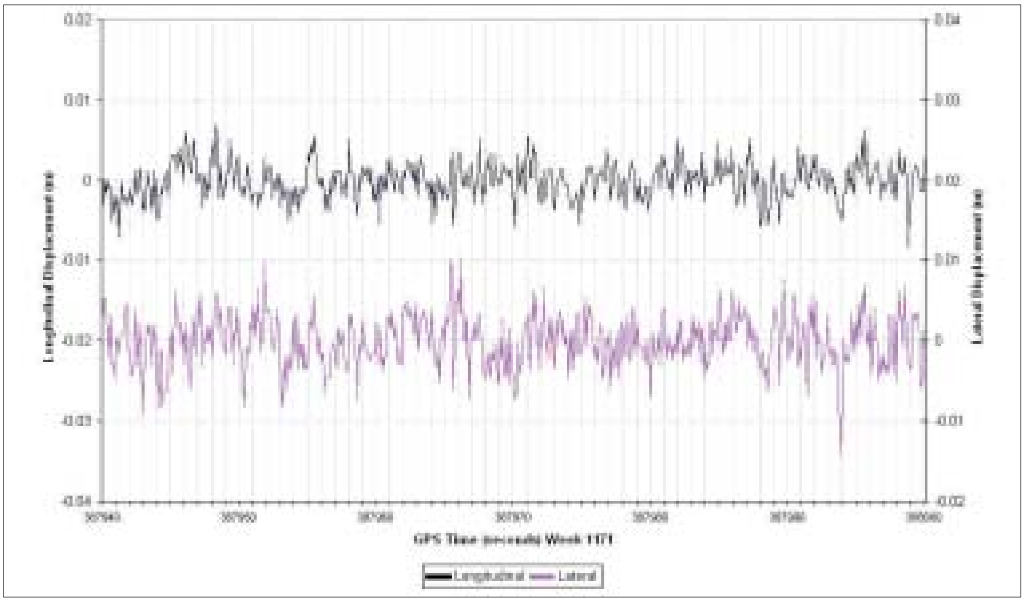
Processing techniques. The data collected during the trials was processed in an 'On the fly' manner reflecting the method that would be used if the information was processed in real-time. The software outputs the coordinates of each station at the rate used in the survey of 10Hz. This information could then be used to study the movement of the bridge. The data was processed and the residual (the difference between the actual and average values) calculated and then plotted against time. The residuals were averaged over a period of 10 seconds.

Vibration trials. The data relating to the height of the stations collected during the vibration trials was studied, and the time periods when a loading had been applied to the bridge studied in greater detail. The information was plotted against time to show the vertical movement of the structure during the time period. The residuals were plotted against time for 40 minute periods, and a clear increase in displacement was visible at several times throughout the results.

Fig 2. Vertical residual displacements (40 minute period)







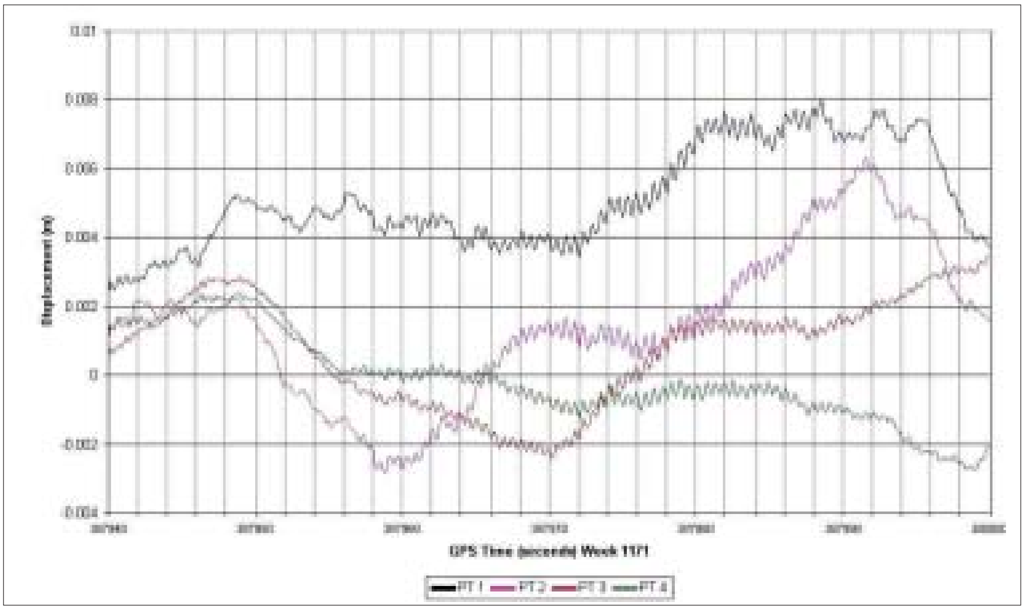


Fig 3. (above) Vertical residual displacements (1 minute period)
Fig 4. (below) Lateral and longitudinal residual displacements (1 minute period)
Fig 5. (bottom) Vertical residual displacements for all the receivers located on the bridge (1 minute period)

Fig 2 shows a number of spikes in the vertical displacement that coincided with the periods of people jumping on the bridge. These spikes were then investigated further, (see Figs 3 and 4) and the vertical residual displacement plotted for time periods of one minute.

The analysis of the data collected showed a very important movement of the structure. The vertical residuals showed a frequency of approximately 1.7Hz in a number of different time periods, and on all the receivers located on the bridge, (see Fig 5). This is likely to be related to the natural frequency of the structure and resonance, and not solely related to the people jumping.

The magnitude of the frequency means it is unlikely to be multipath or other known sources of errors related to GPS. This is because the people jumping are unlikely to cause such an increase in displacement, but more likely to have excited the bridge to vibrate and cause the resonance. The displacements shown in Fig 5 for the different receivers also suggested the bridge was only vibrating in the first mode of vibration; this is as expected for a single forcing load. It is also unlikely to have caused the second mode as the jumping mainly took place in the centre of the bridge, i.e. a single forcing load.

This trial has shown it is possible to identify the frequencies related to the movement of the structure as well as those related to error sources such as multipath. The spikes shown in the residuals illustrated how clearly the technique shows the natural frequency. The natural frequency identified by the trial is comparable to that identified recently by other work related to the bridge (work yet to be published).

Deformation trials. The data relating to height was again used to study the movement of the bridge as the load was applied and then removed from the bridge. The application and removal of the load is shown by the shaded areas (see Fig 6).

The deformation trial results in Figure 6 show a clear deformation to the structure when the load was present and an initial deformation as the load was applied. The difference between the levels suggests the bridge deformed by 7.35mm under loading. The vertical deformation shown prior to the application of the load is the result of a load passing over the bridge. The data does not show the bridge recovering to the level of displacement prior to the load, therefore suggesting a level of damping present in the structure. The apparent damping in the structure is also of interest and shows how the structure reacts to applied loads.

Conclusions

The project has shown the ability of GPS to show structural movements static and dynamic.

The GPS showed the dynamic movement of a structure and by a simple change in techniques would be able to monitor the movement of the structure in real time. The processing techniques

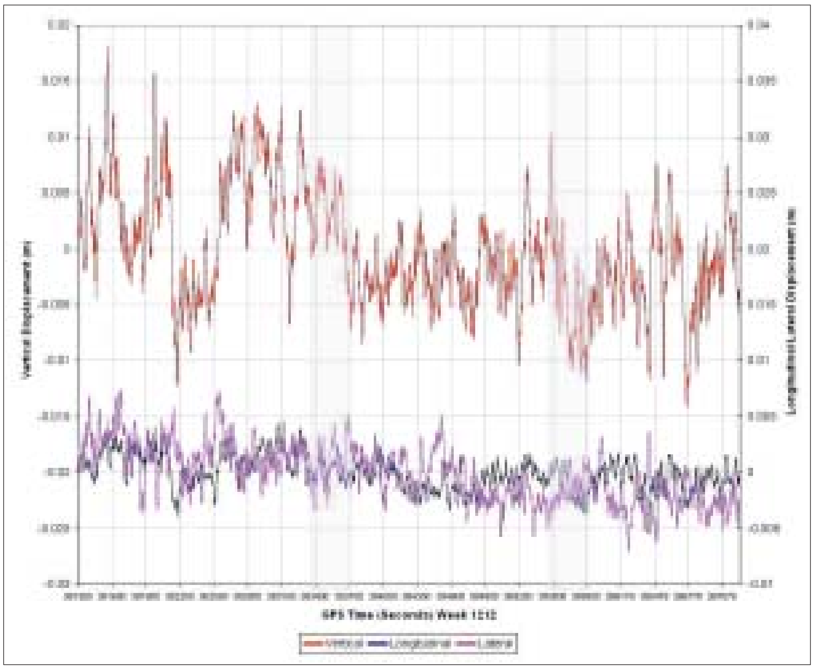


Fig 6. Average displacements (averaged over 10 seconds)

were able to identify the frequencies related to the movement of the structure. The method could also monitor and quantify how the structure moved when known loads were applied allowing the reaction to these loads to be studied.

The trials found that the Wilford suspension bridge has a natural frequency of approximately 1.7Hz, and that there was damping present in the structure, and the load provided extra damping.

An important outcome of the trial was the fact GPS showed a number of different structural properties, and not just the static or dynamic movement.

Acknowledgments

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The Model Analysis Award is an annual competition for experimental projects carried out by final year undergraduates and first year postgraduates. The competition is organised by the Institution's Study Group on Model Analysis as a Design Tool and is launched in March each year.

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