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A REMOTE BRIDGE HEALTH MONITORING SYSTEM USING COMPUTATIONAL SIMULATION AND GPS SENSOR DATA.

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Abstract

In 2001, The University of Nottingham was awarded a three year research grant from the UK's Engineering and Physical Sciences Research Council. The grant, entitled "A Remote Bridge Health Monitoring System Using Computational Simulation and GPS Sensor Data" is collaborative effort with Cranfield University, Railtrack, W S Atkins and Pell Freischman. The work expands and carries forward previous work started at the University of Nottingham in 1994. The work focuses on using kinematic GPS to create and validate finite element models of bridges, allowing the deflections and vibrations of the structures to be analysed for any uncharacteristic movements.

The following paper details the progress of the work to date, including the way in which the field data gathered and analysed by the Nottingham group is used by the Cranfied Group in order to assess the quality of structures. In addition, the use of a Cyrax laser scanner to create a finite element model of a bridge is discussed.

1. Introduction

The Institute of Engineering Surveying and Space Geodesy (IESSG) at the University of Nottingham is an internationally renound centre of excellence, providing research postgraduate work at a high standard in surveying. The IESSG runs MSc and short courses in surveying, GPS and geodesy as well as undeertaking research at PhD and postdoctoral level. The following paper details one of the research areas currently under investigation.

The IESSG has been involved in bridge monitoring through using GPS for a number of years [Ashkenazi et al, 1996, Ashkenazi et al, 1997].

The work started off by investigating typical results obtained from a 2Hz Ashtech ZXII receiver placed upon the Humber Bridge. The Humber Bridge had until recently the longest suspended single span in the World at 1.4km, Fig. 1.

These initial trials showed that it was indeed possible to measure deflections at a rate of 2Hz, with a precision of a couple of millimetres in plan and a centimetre in height. The next stage was to use this data with a purpose i.e. allow the bridge engineers to use it.

Fig. 1, The Humber Suspension Bridge.

2. Collaborative Work

The work developed into a collaborative effort with colleagues at Brunel University, who had previously been commissioned to provide the Humber Bridge Borard with a Finite Element Model (FEM) of the Bridge. The FEM was to be used as a tool for the Bridge-master to assess whether the Bridge was in fact safe to operate following an incident such as a car crash. The Humber Bridge Board was keen to evaluate the FEM through using real data, and hence brought the two groups together and developed a firm working relationship.

Trials were conducted upon the bridge, the most elaborate of which included taking 5 fully laden lorries over the bridge in unison, weighing approximately 160 tons, and comparing the actual movements to that predicted by the FEM [Brown et al, 1997, Roberts et al, 1999]. The results proved very encouraging, and showed that the results could be used not only to measure the deflections of such structures, but also to determine the frequencies at which they move. This however, was at the time limited to the data gathering rate of the GPS receiver, at best 5Hz. But for such a long suspension bridge as the Humber, this was adequate as the bridge has a natural fundamental frequency of 0.116 Hz. Fig. 2 illustrates the locations of the GPS receivers during this trial, and Figs. 3 and 4 illustrate some of the initial results. Further work was carried out, including the occupation of the Millennium Bridge in London, as well as further work on the Humber.

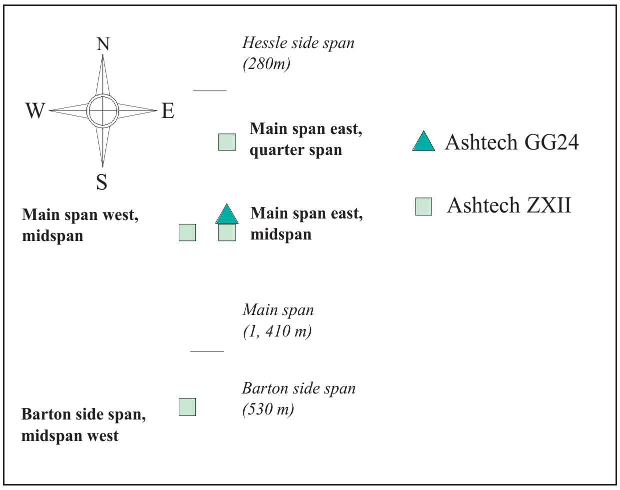


Fig. 2, Plan of the Humber Bridge showing the receivers' locations

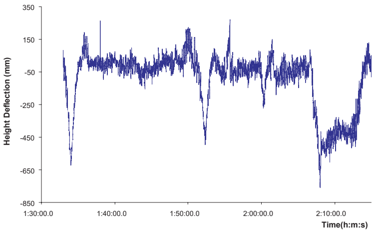


Fig. 3, Height deflection of main span east mid span

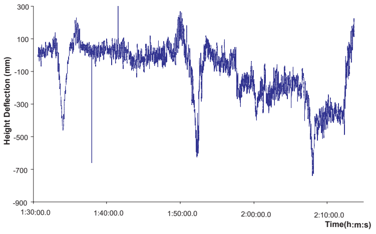


Fig. 4, Height deflection of main span west mid span

3. Collaboration with Cranfield University

Recently the IESSG has been in collaboration with Cranfield University working on a project entitled "A Remote Bridge Health Monitoring System Using Computational Simulation and GPS Sensor Data" sponsored by the UK's Engineering and Physical Sciences Research Council (EPSRC) through a half million pound research grant.

The project investigates the use of GPS and FEM to develop a system that can be used to detect anomalies in bridge movement characteristics.

The research was aimed at developing a pilot remote condition monitoring system for bridge and other structures to provide continuous health information. This is achieved by bringing together the FEM work with that of the monitoring work, so that they compliment each other. The work so far has concentrated on the Wilford Suspension Bridge in Nottingham, Fig. 5. This bridge was chosen due to its locality to The University of Nottingham. It is hoped that later on in the project, once the techniques have been perfected, that another more substantial bridge may be used to monitor.

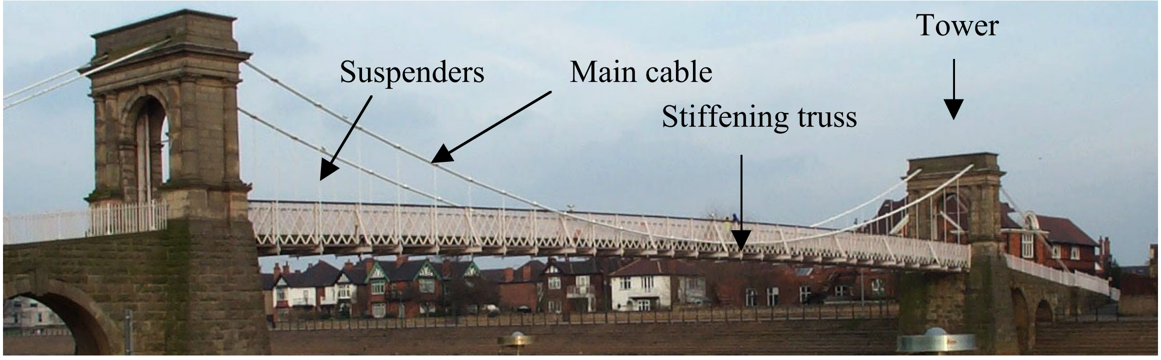


Fig. 5, Wilford Suspension Bridge

The construction of a finite element model, capable of accurately replicating the behavior of the real world structure, was undertaken using the SAFESA™ Method, to formalise the structural qualification process [Meng *et al*, 2003]. In order to create such FEMs it is vital to have precise information about the structure such as its dimensions, type of material th estructure is built from etc. The Wilford Bridge is over 100 years old, and such information about the bridge was difficult to find. Plans were found of the bridge which were used to create the FEM, inaddition, a Cyrax laser scanner, Fig. 6, was used to create a point cloud of the bridge, and hence this information could also be used to measure the dimensions of all the individual bridge components.

Fig. 6, A Cyrax laser scanner being used to measure the dimensions of the bridge

Examples of the FEM results are illustrated in Figs. 7, 8 and 9.

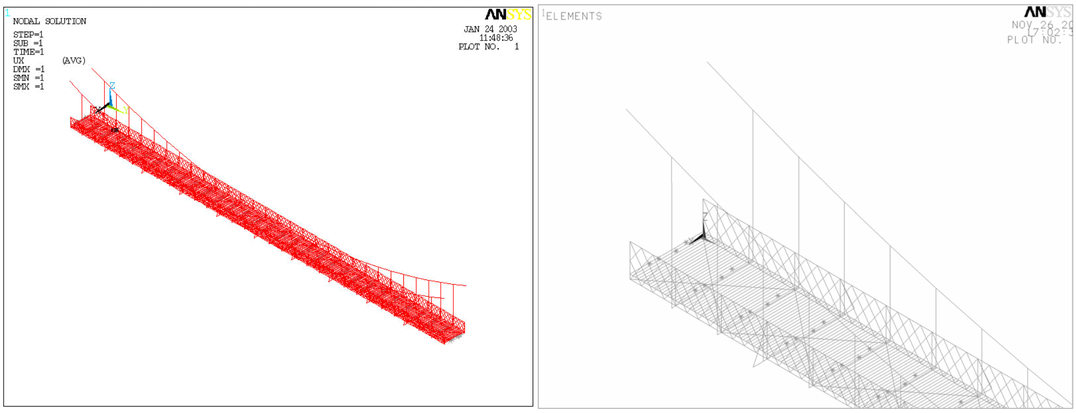


Fig. 7, 3D FE Bridge Model

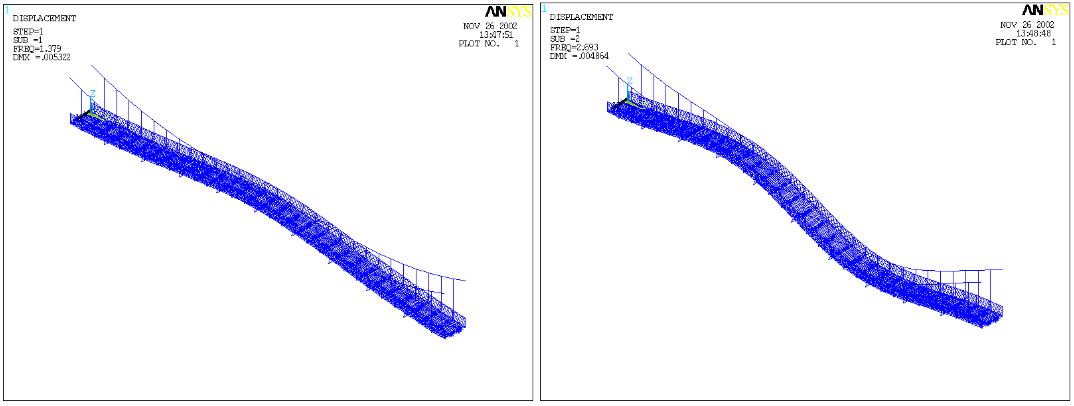


Fig. 8, Mode Shapes One and Two of the Wilford Bridge

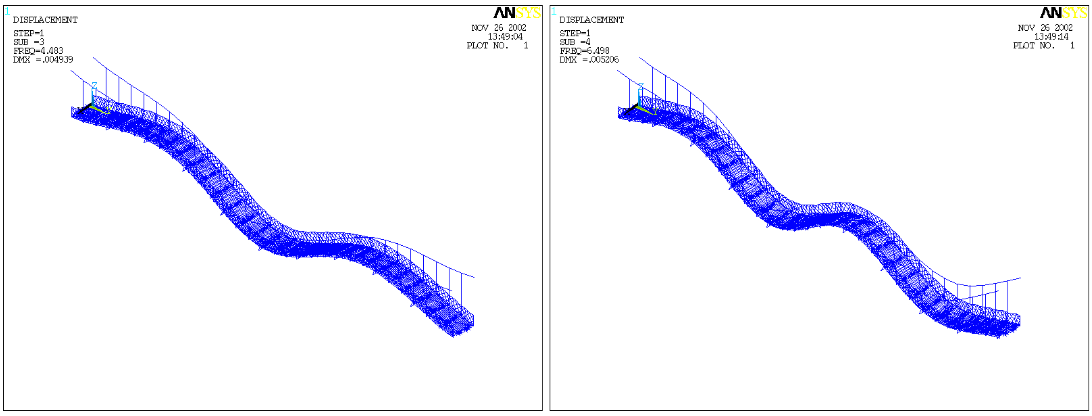


Fig. 9, Mode Shapes Three and Four of the Wilford Bridge

4. Current GPS Work

The work at the IESSG aims at integrating the GPS results into the FEM. However, for this to work to its optimum level, the position results obtained need to be as precise as possible. In order to do this, the current GPS work focuses on five areas:

1. Integrating GPS with accelerometers
2. Mitigating multipath from GPS data
3. Integration of pseudolites into the system
4. The use of single frequency GPS receivers
5. Investigate the tropospehereic effect on GPS data gathered from two points with a considerable difference in height

The Integrating the kinematic GPS output with the accelerometers, in addition to mitigating multipath [REF Dodson *et al,* 2001] is conducted using a variety of techniques, including the use of Adaptive Filtering, Fig. 10.

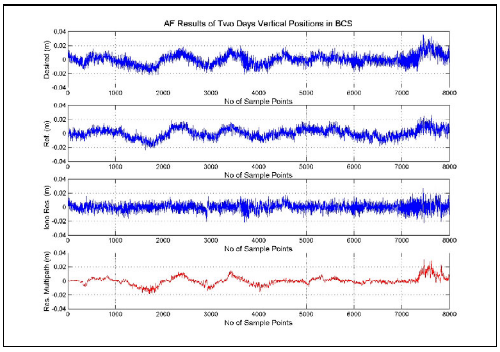
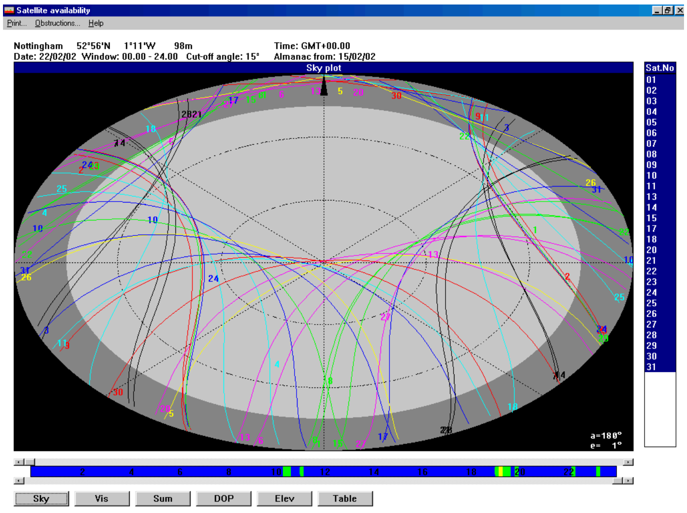


Fig. 10, GPS AF results using two day's position solution

The GPS receivers only measure GPS data at a rate of 10Hz, which is not quick enough for some of the possible deflection frequencies experienced by bridges. Accelerometers can measure such data up to a rate of 1,000 Hz or greater. However, accelerometers do have a tendency to drift, therefore integration with kinematic GPS will allow the drift to be reduced. This is achieved through directly attaching the GPS anetnna to the accelerometer, Fig. 11, and using the AF technique to integrate the two data together.

Due to the nature of the GPS constellation, there is a big hole due north of the UK where no GPS satellites will ever be seen. This is a similar tale for many countries at mid latitudes, Fig. 12.

Fig. 11, The accelerometer and GPS antenna co-located



Nottingham 52°56'N 1°11'W 98m
Date: 22/02/02 Window: 00.00 - 24.00 Cut-off angle: 15°
Time: GMT+00.00
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Fig. 12, A sky plot of Nottingham showing a hole in the GPS satellite constellation

One way to overcome this issue, as well as to improve the height component of the results, is augment the GPS with pseudolites. The researchers at the University of Nottingham have, in collaboration with colleagues at the University of New South Wales, been investigating this. So far, the research has been focused on obtaining good results from the pseudolites, and applying them onto structures, notable at Nottingham and at Sydney. The results to date look promising.

Fourthly, the focus of the GPS research is to incorporate single frequency code/carrier GPS receivers into such research, with small lightweight antennas, hence reducing the cost of a system based on using dual frequency receivers with choke ring antennas. As the bridge is not moving, a full on the fly search is not vital, as the system should have a good idea of the antennas location. Furthermore, research is underway looking at the possibility of applying the knowledge of the ionospheric errors present in a dual frequency GPS receiver, and applying this to a single frequency receiver's L1 data to create virtual L2 data. So far, this has shown to be possible, but does have limitations [Meng *et al*, 2002].

Many structures result in the GPS receivers at the reference station and at the rover station having a considerable difference in altitude. Research is underway investigating the effect the troposphere has on the results from such a scenario [Roberts *et al*, 2001]. Again, the results do show that there is a need to be aware and calculate such effects.

5. Conclusions

The paper has tried to bring the reader up to date with the ongoing work at The University of Nottingham in bridge monitoring by GPS. Due to the extent of this work, the paper has only been able to outline the different areas, but has tried to point the reader in the right direction for further references.

Acknowledgements

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