1. PUBLISHABLE SUMMARY

(i) summary description of the project objectives

The technical objective of this project was to develop physics based and data based models for a bridge and to examine how information from these models might be used/integrated to inform decisions about the bridge. To achieve this objective the project was split into a series of distinct stages and these are described below.

(ii) description of the work performed since the beginning of the project

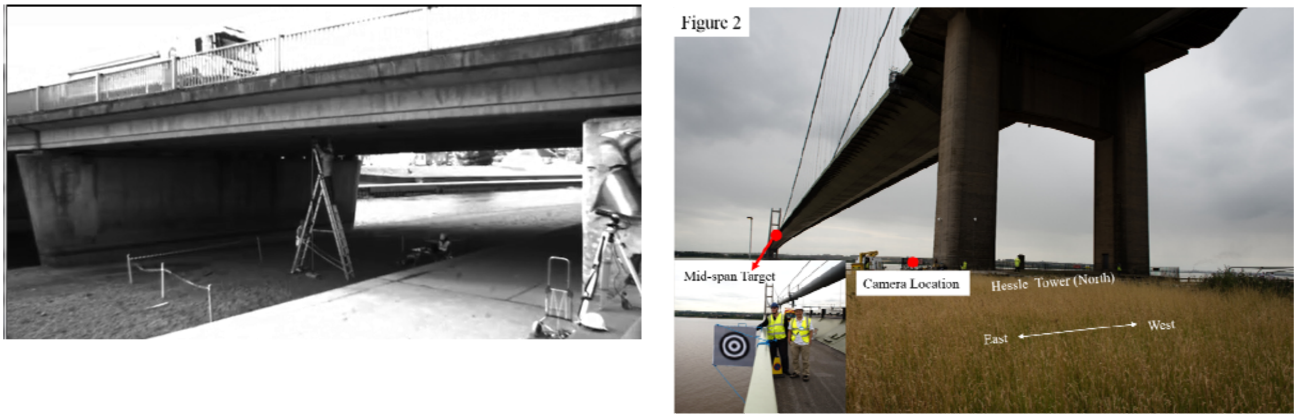
Stage 1 stakeholder engagement. The first step in the project involved discussions with bridge owners to identify what difficulties/challenges bridge operators are facing, and to identify what (if any) measurements they would like to be able to take on their bridges. We also wanted to identify if there were any specific problems that they would like information on. Discussions were undertaken with a number of bridge operators such as road authorities (e.g. Highways England), rail infrastructure authorities (e.g. Network Rail) and local authorities (e.g. Devon County Council)

Stages 2 and 3 physics based models. Physics-based models utilise our physical understanding of the system. Equations that define relationships between the different system variables are used to construct numerical models of the system. Then these models can potentially be used to make decisions about the structure. Figure 1(a) below shows a photo of one of the bridges modelled in this project and Figure 1(b) shows the corresponding Finite Element model of the bridge.

(a) (b)

Figure 1 physics based model (a) photo of the bridge (b) Finite Element model.

Stage 4 Instrumentation. Traditionally there have been very few commercially available bespoke sensors for time varying deformation monitoring of civil infrastructure, historically this has made the task of monitoring infrastructure more difficult/costly. For example, long term monitoring has typically required power and coms which is expensive, and there is relatively little specialist equipment available for short term campaign style monitoring. Therefore fairly early in the project it became apparent that having an awareness of the latest technology was really important as there are potentially better ways of doing things than those traditionally used. Therefore in this project a number of new and exciting technologies/approaches were applied to structural monitoring and they were benchmarked against existing technologies. In particular 3 new technologies/approaches were field tested, namely: new rapid deployment wireless accelerometers for structural monitoring, calculating bridge displacement to a moving load using ultra high spec force balance accelerometers, and using camera technology to track bridge movements.



(a) (b)

Figure 2, trialling novel systems for monitoring bridge displacement, (a) calculating bridge displacement to a moving load using ultra high spec force balance accelerometers (b) using camera technology to monitor displacement of Humber suspension bridge.

Stage 5 Data based systems Data-driven approaches are appropriate when the understanding of first principles of system operation is not comprehensive or when the system is sufficiently complex that developing an accurate model is prohibitively expensive. One of the main challenges of applying data based systems to bridges is the prohibitive cost of long term monitoring. In this project a novel low cost long term monitoring system was developed and field tested in the bridge shown in Figure 1(a). The system combined a number of commercially available components that were integrated to provide a bespoke acceleration & temperature monitoring system, see Figure 3.

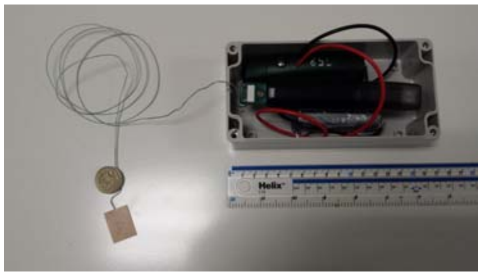


Figure 3

Stage 6 Integrating physics based and data based information for decision support
In essence stage 6 is really a drawing together of the work in stages 1-5 and the aim is to try and see how can data based and/or physics based information help a bridge operator. The results of stage 6 are that it has been found that, it is possible on relatively limited budget to develop a data based and physics based model of the bridge. To do this cost effectively has required us to use new technology for example using opals to get frequencies and mode shapes, using a camera and/or ultrahigh spec accelerometer to get displacement during load test, and using cheap accelerometer/battery to track frequency long term.

<u>(iii) Description of the main results achieved so far</u>
In essence research on bridge monitoring concerns the dual challenges of data capture, and data interpretation. On the data capture side, (for most situations) the rapid deployment wireless accelerometers were as capable as the conventional wired system, for measuring structural vibrations. This is a significant finding as the wireless system is much easier to deploy on a live bridge, and as such the overall performance for monitoring is greater. For the load tests carried out, the displacements calculated from ultra-high spec accelerometer was very similar to those measured directly with conventional displacement monitoring systems. This is significant as the accelerometer more convenient to deploy than conventional systems. On the data interpretation side the physics based and data based models have provided insight into bridge behaviour and initial indications are that this is useful for decisions on structural intervention. The work described above has generated sufficient material for a number of conference and journal articles on the topic of bridge monitoring. The results from the project are reported in detail in these articles, (further information on these articles is given in section 5).

(iv) Potential impact of the results

Future growth and development in the European Community requires reliable/resilient transport infrastructure. Bridges are a critical link in our transport infrastructure, a good example of this is the disruption caused this month (December 2015) by the sudden closure of Forth road bridge (in Scotland) due to damage. Much of the work in this project has involved field trialling the latest sensing technology, and applying it the problem of bridge monitoring. Although the methodologies described above are not yet mature enough to be deployed on a large scale, they never the less represent an important contribution toward the development of reliable monitoring systems for European bridges. Ultimately this project has increased the knowledge on this important topic in the host institution and in the Fellow's new institution (both of which are in Europe). Therefore, going forward this knowledge can be leveraged to generate further development of the technology which should have a positive impact on European transport infrastructure.

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