Instrumented Trains as a Probe for Structural Health Monitoring of Railway Infrastructure

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ABSTRACT: Railway infrastructure throughout the world is degrading and the Structural Health Monitoring (SHM) of this infrastructure can be effective. As a part of INTERREG project SIRMA, it is being investigated in instrumented trains can be used as a moving sensor for SHM of bridges and rail lines. Off-the-shelf calibrated sensors will be connected to trains and the instrumentation regime will be decided based on each SHM need. Output-only algorithms for anomaly detection and system identification will be implemented. Damage Sensitive Features (DSF) will be investigated to assess the best markers for the proposed SHM. A combined set of instrumentation and algorithms will be developed and assessed for their use using numerical and small-scale experimental results - along with potential use in Irish rail network.

KEY WORDS: Railways, Structural Health Monitoring, Natural Hazards, Infrastructure Maintenance Management.

1 INTRODUCTION

Our bridge infrastructure is degrading over time (Znidaric et al., 2011) and there is not enough resource to support them (ASCE, 2013). This ageing infrastructure is making it the risk and exposures to the structures during their operational lifetime, especially when the exposure conditions (natural and anthropogenic) are becoming harsher. Recent bridge failures (Calvi et al 2019; abc.net, 2019) have led us thinking about such infrastructure assets. Data-driven decisions (Matos et al., 2005; Hanley et al., 2017) with sensors can be important in future in this regard. Bridge live loads have increased over time since their construction (Hanley et al., 2016;) and climate hazards (corrosion, flooding) exacerbates this (Enright & Frangopol, 1998; Ganesh Prasad & Banerjee, 2013).

Figure 1. A decommissioned train on a decommissioned railway line in Ireland.

Climate variability and change will also play a role in future loading (Imam, 2019). On the other hand, resilience is becoming a popular approach in bridge monitoring (Nogal et al., 2016; Martinez-Pastor B, 2018) to achieve better safety and service. As a symbol of such change, Figure 1 presents a degrading rail on a defunct railway line on the west of Ireland.

2 OVERVIEW OF SIRMA PROJECT

The EU Interreg Atlantic Area funded project Strengthening Infrastructure Risk Management in the Atlantic Area (SIRMA) addresses some of these challenges in a collaborative and trans-national manner. Most of the transportation of people and goods in the Atlantic Area is made through rail and road. The performance of this infrastructure is directly affected by extreme natural events and by the strong corrosion processes that result from proximity to the Atlantic Ocean. SIRMA will develop a robust framework for the management and mitigation of risks, by implementing immediate, medium and long-term measures, thus increasing the resilience of transportation infrastructure. It will address the transportation infrastructures by developing a systematic methodology for risk-based prevention and management; developing a real-time process to monitor the condition of transportation infrastructure; and enhancing the inter-operability of information systems in the Atlantic Area, by taking into account the data normalization and specificity of each country. SIRMA intends to develop a holistic toolset to anticipate and mitigate the effects of extreme natural events and strong corrosion processes, including climate change-related impacts for both road and rail sectors. These tools will be deployed for critical hazards that are affecting the main Atlantic corridors that are largely covered by this consortium presence and knowledge. SIRMA also targets to develop an innovative infrastructure risk management system related to extreme events, as well as to integrate knowledge about short-term actions (e.g. management of emergency situations) and medium to long-term actions (e.g. strategic measures to improve structural response of critical assets). This will lead to optimal risk mitigation measures and strengthening the territory resilience to several types of risk. The long-term effects of this project will be the risk reduction of extreme natural hazards on transportation infrastructure and to ensure the assets and population are prepared for such hazards. The developed framework will be tested and used by two public operators that will disseminate it through other public and private operators in and outside the Atlantic Area. These entities, together with supporting partners (e.g. government, municipalities, etc.) will ensure these effects. The developed framework aims to support more sustainable decisions concerning the resilience improvement and risk mitigation on transportation infrastructures in the Atlantic Area. In order to achieve that, it is planned to undertake a set of optimal risk mitigation measures. Through these measures, the risks to society and environment will be diminished. There are direct risks, such as consequences for people (injuries and deaths), and indirect consequences, such as the unavailability of transportation infrastructure, that put at risk the sustainable development of the Atlantic Area, and that will be mitigated through the application of this framework. When selecting the most suitable risk mitigation measures, their effects will be also included, and, consequently, the effects on the surrounding environment. At the end, users (people and goods) will be able to use the transportation infrastructure in the Atlantic Area in a more efficient and safe way, the infrastructure being more prepared to face climate change effects. Natural hazards do not recognize political boundaries and a transnational cooperation will bring new and complementary knowledge among all participating countries and will improve the cross-coordination, information exchanges and risk mitigation procedures. Eventually, an Atlantic area dynamic map will be created with critical transportation infrastructure for different hazards types, based on vulnerability indicators, addressing climate change scenarios, allowing for a better, more precise, and more reliable decision-making process. A methodology for integrating sensor data into performance indicators quantification, and consequently on performance predictive models will be made. Advanced risk-based forecasting models which address infrastructure performance and consequences (direct and indirect) will be developed. Database with identification of effects and costs (direct and indirect) of risk mitigation measures will be established, resilience-based decision-making framework will be created, allowing to identify optimal risk mitigation plan. Lastly, it will influence EU decision making bodies on bridge maintenance management.

3 PROGRESS AND CHALLENGES AROUND INSTRUMENTATION

Since trains and trucks travel a large part of the transportation network it is a part of, one of the ways SIRMA intends to develop conceptual, numerical and experimental evidence base is by instrumenting such vehicles as mobile monitoring probes for infrastructure elements throughout the network. The infrastructure elements are expected to be important as well. In particular, this approach works based on the fact that operational responses are representative of the health of a structure and such operational effects and their changes will be picked up by the variation of the dynamic responses obtained by the moving vehicles traversing the structures. The excitation by a truck or train can thus lead to detection of features of interest by instrumenting a bridge or the vehicle.

While the opportunities of such an approach is extensive, there exists significant challenges which are to be overcome. This paper illustrates some of these opportunities and challenges.

Figure 2 presents a 3-D Laser scan of an Irish bridge affected by a truck strike. Such methods can be also used for railways and other bridges in different countries and an evidence base will be relevant to decide its application advantages and boundaries by full-scale deployment.

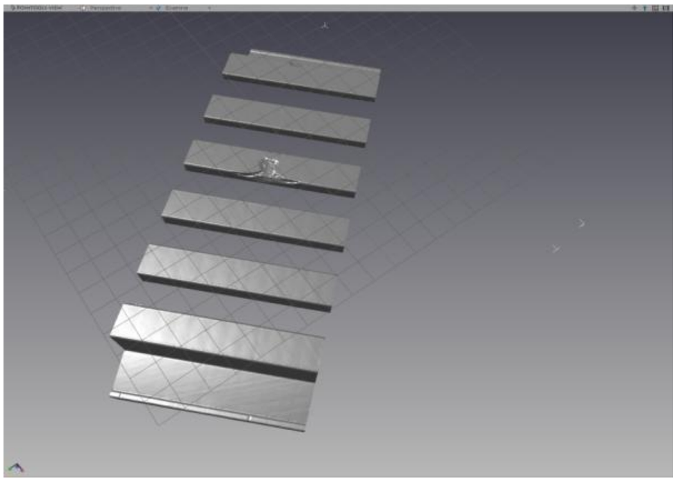
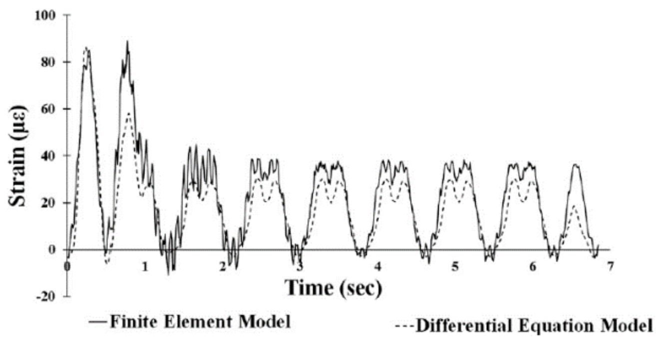


Figure 2. 3D Laser scan of a bridge struck by a truck.

Using the interaction of a bridge and a passing vehicle for structural health monitoring and assessment of features of interest of a bridge is another aspect that this project is currently looking into. In this regard, both the bridge and the vehicle are being designed for instrumentation.

There exists a wide range of damaged bridge-vehicle interaction model with various complexity and detail (Delgado, 1997; Zhu & Law, 2002; Pakrashi et al., 2010). A detailed model can be obtained from Pakrashi et al (2007) for completeness. The effect of damage changes the stiffness



locally or globally. Overall, this has an effect on the natural frequency, mode shape, statistical parameters of various output-based detection and other aspects (Krishnan et al, 2018; Bhowmik et al., 2019; OBrien & Keenahan, 2015; Malekjafarian & Obrien, 2014). While this has led to good matches between simulated and experimental results for bridge-vehicle interaction (Figure 3), robust markers for damage is a still an important need, irrespective of the model (Figure 4) or experiment.

Figure 3. The matching of a train-bridge interaction model with finite elements and fundamental differential equations.

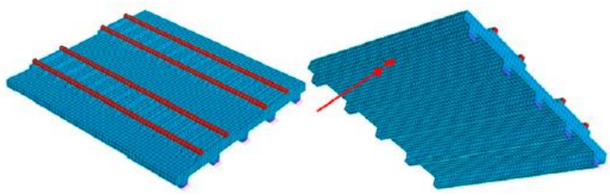


Figure 4. A Finite Element (FE) model of a damaged bridge with multiple train passages.

The instrumentation and choice of sensors are also relevant. Recently, energy harvesting based structural health monitoring has been popular and it has been observed that it is possible to represent the bridge responses for various speeds of traversing trains through the open circuit voltage responses form energy harvesting by piezoelectric materials (Figure 5).

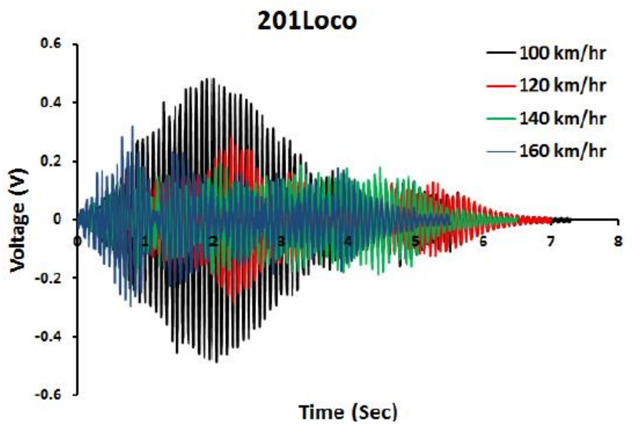


Figure 5. Voltage response simulation of piezoelectric energy harvesters from an Irish 201Loco train traversing a bridge in various speeds.

4 CONCLUSIONS

Data driven decision making and monitoring of railway infrastructure can be beneficial. In particular, this instrumenting both the bridge and the traversing vehicle can be relevant in this regard. There remain key challenges in damage detection and system identification of these bridges in terms of sensor choice, instrumentation design, robust markers of features of interest and full-scale implementation of monitoring. However, with recent developments in computing and technology, it seems that this is an appropriate time to address this problem in an unprecedented detail.

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