CETRA 2018

5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

IRF GLOBAL

FEHRL

Organizer
University of Zagreb
Faculty of Civil Engineering
Department of Transportation

CETRA[2018]
5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

TITLE
Road and Rail Infrastructure V, Proceedings of the Conference CETRA 2018

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

ISBN
978-953-8168-25-3

DOI
10.5592/CO/CETRA.2018

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
“Tiskara Zelina”, May 2018

COPIES
500

Zagreb, May 2018.

Proceedings of the
5th International Conference on Road and Rail Infrastructures – CETRA 2018
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

EDITOR
Stjepan Lakušić
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Zagreb, Croatia

ORGANISATION

CHAIRMEN

Prof. Stjepan Lakušić, University of Zagreb, Faculty of Civil Engineering
Prof. emer. Željko Korlaet, University of Zagreb, Faculty of Civil Engineering

ORGANIZING COMMITTEE

Prof. Stjepan Lakušić
Prof. emer. Željko Korlaet
Prof. Vesna Dragčević
Prof. Tatjana Rukavina
Assist. Prof. Ivica Stančerić
Assist. Prof. Maja Ahac
Assist. Prof. Saša Ahac
Assist. Prof. Ivo Haladin
Assist. Prof. Josipa Domitrović
Tamara Džambas
Viktorija Grgić
Šime Bezina
Katarina Vranešić
Željko Stepan
Prof. Rudolf Eger
Prof. Kenneth Gavin
Prof. Janusz Madejski
Prof. Nencho Nenov
Prof. Andrei Petriaev
Prof. Otto Plašek
Assist. Prof. Andreas Schoebel
Prof. Adam Szeląg
Brendan Halleman

INTERNATIONAL ACADEMIC SCIENTIFIC COMMITTEE

Stjepan Lakušić, University of Zagreb, president
Borna Abramović, University of Zagreb
Maja Ahac, University of Zagreb
Saša Ahac, University of Zagreb
Darko Babić, University of Zagreb
Danijela Barić, University of Zagreb
Davor Brčić, University of Zagreb
Domagoj Damjanović, University of Zagreb
Sanja Dimter, J. J. Strossmayer University of Osijek
Aleksandra Deluka Tibljaš, University of Rijeka
Josipa Domitrović, University of Zagreb
Vesna Dragčević, University of Zagreb
Rudolf Eger, RheinMain Univ. of App. Sciences, Wiesbaden
Adelino Ferreira, University of Coimbra
Makoto Fujiu, Kanazawa University
Laszlo Gaspar, Széchenyi István University in Győr
Kenneth Gavin, Delft University of Technology
Nenad Gucunski, Rutgers University
Ivo Haladin, University of Zagreb
Staša Jovanović, University of Novi Sad
Lajos Kisgyörgy, Budapest Univ. of Tech. and Economics
Anastasia Konon, St. Petersburg State Transport Univ.
Željko Korlaet, University of Zagreb
Meho Saša Kovačević, University of Zagreb
Zoran Krakutovski, Ss. Cyril and Methodius Univ. in Skopje
Dirk Lauwers, Ghent University
Janusz Madejski, Silesian University of Technology
Goran Mladenović, University of Belgrade
Tomislav Josip Mlinarić, University of Zagreb
Nencho Nenov, University of Transport in Sofia
Mladen Nikšić, University of Zagreb
Andrei Petriaev, St. Petersburg State Transport University
Otto Plašek, Brno University of Technology
Mauricio Pradena, University of Concepcion
Carmen Racanel, Tech. Univ. of Civil Eng. Bucharest
Tatjana Rukavina, University of Zagreb
Andreas Schoebel, Vienna University of Technology
Ivica Stančerić, University of Zagreb
Adam Szeląg, Warsaw University of Technology
Marjan Tušar, National Institute of Chemistry, Ljubljana
Audrius Vaitkus, Vilnius Gediminas Technical University
Andrei Zaitsev, Russian University of transport, Moscow

CETRA 2018 17–19 May 2018, Zadar, Croatia
5th International Conference on Road and Rail Infrastructure

BRIDGE SMS – INNOVATIVE SOLUTION FOR MANAGEMENT OF BRIDGES OVER WATER

Damir Bekić[1], Igor Kerin[2], Paul Cahill[2], Panagiotis Michalis[1], John Lapthorne[3], Hrvoje Šolman[4], Gordon Gilja[1], Kristina Potočki[1], Vikram Pakrashi[5], Eamon McKeogh[2]
[1] *University of Zagreb, Faculty of Civil Engineering, Croatia*
[2] *University College Cork, MaREI, Ireland*
[3] *Cork County Council, Road Design Office, Ireland*
[4] *Arctis d.o.o., Croatia*
[5] *Dynamical Systems and Risk Laboratory, School of Mechanical and Materials Engineering, University College Dublin & MaREI, Ireland*

Abstract

Management of bridges over water requires a combination of knowledge from structural engineering, geotechnics and transport management together with expertise from hydraulics, hydrology and morphodynamics. Various quantitative and qualitative approaches and procedures have been developed for the assessment and management of structural and scour risk at bridges. Although scour is the leading cause of collapse of bridges over water, scour inspection is usually conducted as part of special inspection. The required inputs for bridge inspection differ in each approach and in some occasions the requirements on the number and details of data can be substantial for the asset management organisation. This paper presents a cost-effective solution for the management of structural and scour risk at bridges with emphasis on the efficient information management in the entire management process through BRIDGE SMS a Marie Curie Industry Academia Pathway Partnership (IAPP) project. With such aim, the suggested solution provides new aspects in the assessment of bridge scour risk by using standardised steps from data collection, inspections to reporting. On-site information from bridges are collected using tablet through a dedicated mobile app. Efficient monitoring of severe weather and hydraulic conditions at bridges is achieved through new weather and water level gauges in combination with a bespoke flood forecasting and warning system. A new user-friendly cloud-based platform is developed for quick and efficient processing, storage and management of inspection and monitoring data. In combination with weather and flood forecasting data the decision support system informs key personnel on the current and forecasted states and hazards on bridges and helps to seamlessly monitor on-going and planned activities on the network of bridges.

Keywords: bridge management, bridge inspection, bridge scour, bridge monitoring, decision support

1 Introduction

Flood-induced scour has been identified as the leading cause of bridge failures. Studies of bridge failures in USA showed that in period 1989-2000, 53 % (266) cases out of 503 failures are due to hydraulic factors [1] and that scour and flood accounts for nearly 50 % (153) of all 341 bridge failures in 2000-2012 [2]. River bed changes around a bridge is a combination of general channel erosion on a longer river section and local channel instabilities at the bridge.

An additional complexity is imposed by the interaction between flow pattern around piers/abutments and the river bed sediments. Scour can develop gradually over a longer period of time and/or during flood events. Because of various controlling and interconnected mechanisms of the phenomena and different spatial and temporal scales of scour development it is difficult to reliably estimate and project the scour hazard at bridges.
Various bridge management systems (BMS) have been developed over the years utilised by different agencies [3]. The systems differ in the evaluation, presentation and storage of scour hazard for bridges over water. The evaluation of scour hazard is a key step in which data are collected and which controls all subsequent activities in the bridge scour management chain. During routine or principal inspection, scour is usually evaluated as a single component/element and more in-depth evaluation is carried out as part of a special (underwater) inspection. Heterogeneity of approaches of bridge scour evaluation is evident through the following aspects:

- Number and type of scour indices and components
  - single or multiple scour elements/components
  - evaluation of local scour only or general/constriction/local scour
- Evaluation process
  - detection of defects only or jointly with condition assessment
  - engineering judgment or quantitative condition assessment
- Presentation and storage of scour condition
  - scour condition is part of overall bridge condition rating or it is recorded separately
  - information stored in pdf reports or in database

A combination of the complexity of scour phenomena and the variability of evaluation techniques makes comparison of different scour evaluation systems a challenging and demanding task [4, 5]. Such observations strongly evoke the need for some level of standardization in the bridge management systems as suggested in the IAMBAS report [3]. This paper presents objectives, methodology and main outcomes of the proposed concept which is developed around the general idea of a cost-effective solution of bridge scour management from data collection, evaluation and decision support activities.

2 Data and project area

As part of a pilot scheme, a total of six bridges over water have been chosen which are located throughout the Bandon River catchment in County Cork, Ireland. The road network in the Cork County consists of 12,419 km of roads and of approx. 3,000 bridge structures. The principal inspections on 1,413 bridges were carried out during 2012-2014 by using the Eirspan approach [6]. Inspections showed that the majority of bridge structures are arches of one or more spans (60.5 %) and simple span structure of constant cross section (30.0 %) and with 94.7 % being stone masonry. The analysis of damage types on all inspected bridges confirmed the high frequency of erosion/scour damage as the second most frequent damage after loss of pointing [7].

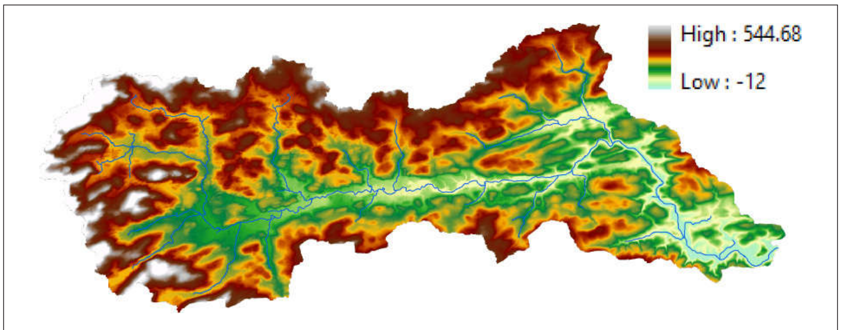

Figure 1 Digital Elevation Model of the Bandon Catchment (data source OSI)

At 72.5 km long, the Bandon River drains area of 591 km^2 with an average elevation of 111.5 mOD and slope of 9.8° (Fig. 1). The flood flows in the Bandon town are Q_{med} = 122 m^3/s (median Annual Maximum flow, 2-year return period) and $Q_{1\%}$ = 343.3 m^3/s (100-year return period). The geology of the Bandon catchment predominately consists of coarse loamy drift with siliceous stones (72.1 %) and peat (16.5 %). The pastures (72.7 %) and agricultural land (6.1 %) occupy the majority of catchment cover.

Figure 2 Elevation images of the six pilot bridges for the Bridge SMS project.

The set of chosen six bridges reflects the stock of bridges over water in the Cork County [7]. Due consideration was also given to both the hydraulic and structural vulnerability of the bridges, resulting in four masonry stone arch bridges and two reinforced concrete beam-slab bridges being chosen (Fig. 2). Three of the bridges are located on the main Bandon River, with the other three located on smaller tributaries located in the catchment. A summary of important parameters of the six pilot bridges are provided in Table 1.

Table 1 Pilot bridges information and assessment of condition rating

Bridge name	Meelon	Baxters	Ahakeera	Ardcahan	Knockane	Manch
Type	Arch	Arch	Beam	Beam	Arch	Arch
Spans	1	3	2	6	2	3
Length [m]	5.81	51.07	13.32	34.77	8.3	30.8
Width [m]	6.5	8.52	6.17	5.56	8.5	7.54
Material	Stone Masonry	Stone Masonry	Concrete & Steel	Concrete & Steel	Stone Masonry	Stone Masonry
Inspection level	Level 1	Level 2	Level 2	Level 2	Level 2	Level 2
Structural Condition	2	2	2	2	3	2
Scour Condition	2	4	3	2	3	4

3 Results

3.1 Guidelines for bridge inspections

As part of the proposed concept, standardised procedures for structural and scour inspection have been developed. The structural inspection is aligned to both National [6] and International inspection procedures [3] and adapted from such approaches, while the scour inspection and evaluation process was newly developed. The inspection procedure has been developed to allow for four different inspection levels, with the complexity and comprehensiveness of the inspections increasing with the levels. Level 0 Appraisal consider the bridge structure check-up during routine patrol on roads/railways. Level 1 General Inspection comprises smaller number of inspection components (11 structural elements and 11 scour components). In a case that a structure is not adequate for Level 1 Inspection then the assessment is progressed to Level 2 Detailed Inspection. Detailed structural inspection comprises 14 individual structural elements. Level 2 Scour Inspection evaluates and records all three types of scour (general, constriction and local scour, see Fig. 3) which can also help in identifying the appropriate mitigation measures.

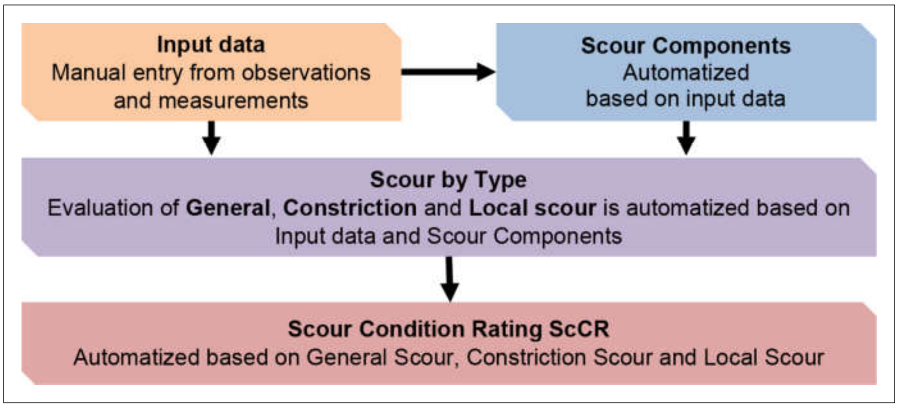

Figure 3 Flow chart for the calculation of the Scour Condition Rating (ScCR)

The procedure for inspecting bridge elements and components includes a detailed visual assessment [8], with any defects noted and photographed. Aside from visual inspection, the detailed scour inspection requires also inputs on river bed levels, foundation depth and data on general river channel instabilities. The inspector grades the element/component, ranging from a condition of very good (A) to a condition of failed (F). The condition rating between very good (0) to failed (5) is calculated separately for the structural and scour aspect and is accompanied with the time for the next inspection and the assessment of maintenance/repair costs. The structural condition rating is determined by using Worst Component Analysis (WCA) and the scour condition by a custom algorithm in Level 1 and by risk-based matrix in Level 2 combining the result of the general, constriction and total scour. The proposed concept has been tested on various bridges in the Bandon River catchment (see condition ratings in Table 1).

3.2 Bridge inventory

In order to allow for strategic management for a bridge network, all available parameters related to bridge assets, both at individual and network levels, are required for consideration when making informed decisions. In this regard, a detailed bridge inventory has been developed. Bridge structure has been divided into 10 components, which are in turn subdivided into 23 elements [8]. For each element, the inventory provided a detailed database of all attributes relating to the individual element on the bridge, including the element type, material and physical parameters, such as lengths, widths, heights, etc.

3.3 Environmental monitoring

Monitoring of environmental processes may increase preparedness for potentially hazardous flood events and in combination with other sensing devices can provide a real-time monitoring of hydrological [10] and structural [11] condition at the bridge. A real-time monitoring system was developed as part of the solution with different sensors to provide weather and environmental data inputs [12].

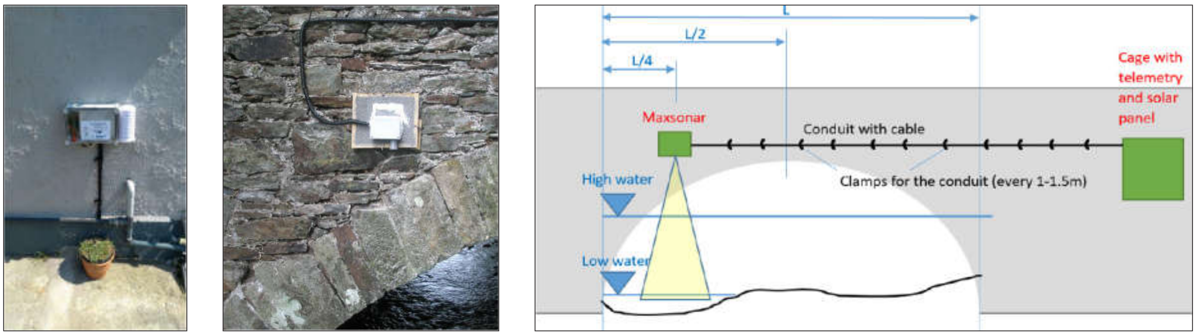

Figure 4 WILD and BIRD devices in operation in the Bandon catchment

The new weather system (WILD) collects data on rainfall, air temperature, air pressure and soil moisture while the new hydrologic system (BIRD) collects water level data at bridge sites. The two WILD and the two BIRD devices were installed in the Bandon River catchment (Fig. 4). The data loggers were developed on customised printed circuit board (PCB) with telemetry, secure digital (SD) card and real time clock (RTC) modules and auxiliary battery for additional power source. The charging of BIRD devices is from the solar panels. Devices were installed within an IP67 certified casing thus enabling a secure atmospheric conditions operational functionality.

3.4 Flood forecasting system

A flood forecasting system (FFS) provides information on magnitudes and locations of floods in advance of hazardous events and can be implemented on a network level. An operational and fully automated hydrological forecasting system have been developed for bridges in the Bandon River catchment. The Bandon FFS is a centralised system for monitoring and viewing of the weather and hydrological data in real-time as well as the results of the flood forecasts (Fig. 5).

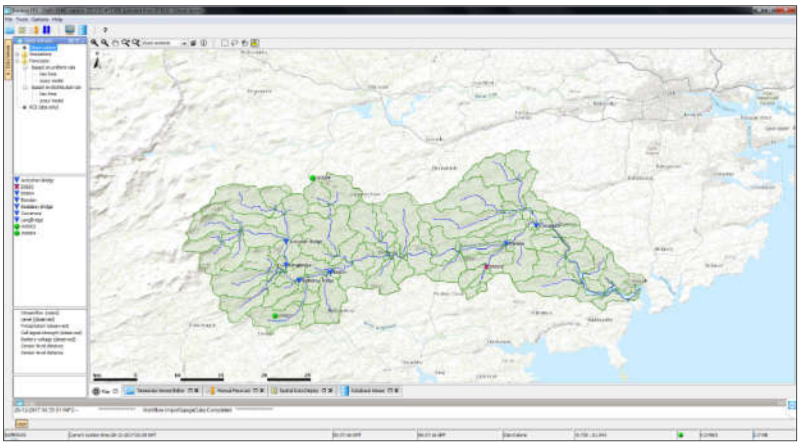

Figure 5 Layout of the Bandon Flood Forecasting System

The hydrological model is the core part of the Bandon FFS system and is built around a lumped HEC-HMS model with 57 river elements [13]. The Bandon FFS issues hourly flood forecasts for 94 sub-catchments and 58 junctions with a lead time of up to 10 days in advance. A considerable lead time in advance of flood event provides possibility to operational teams for preventative and preparatory actions and can give warnings to prepare for bridge closure or rerouting of road traffic in extreme cases.

3.5 Mobile application and platform

As the bridge inspection process is mainly related to the visual inspection of bridge components, a mobile application was developed for a quicker and more practical collection of on-site information and defects. The mobile application consists of the bridge inventory module and the inspection module. The inspection module comprises the entire scour and structural inspection procedure together with photo/notes documentation, an estimation of maintenance/repair works (Fig. 6), a core need for EU [14] and calculation of structural and scour condition rating. The mobile application also enables access, review and edit of collected information and presents the map with location of bridges, roads/railways, water bodies, etc. In such a need for an office work is minimised and the on-site inspection efficiency is maximise. An 8' tablet was acquired together with an IP67 certified casing to protect from fieldwork accidents.

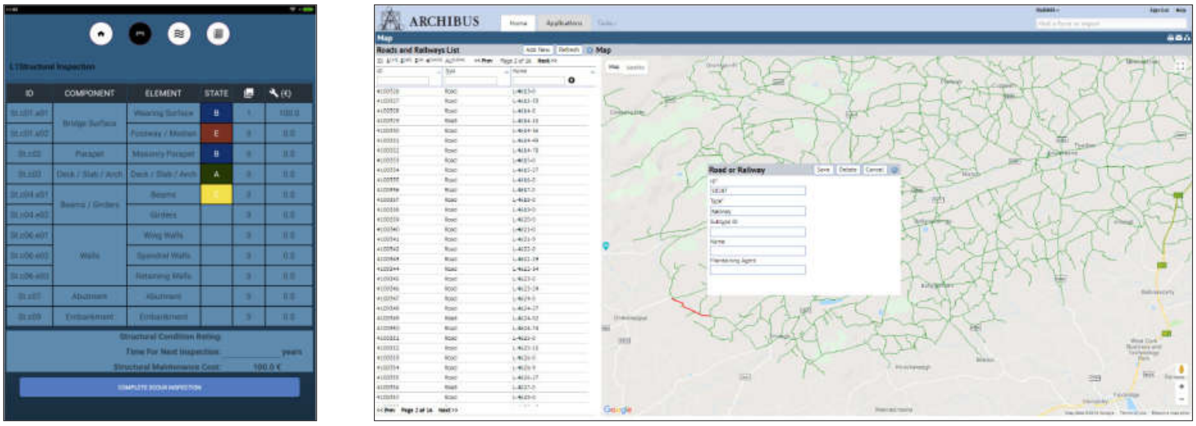

Figure 6 Mobile App and web-based GIS interface

The Archibus solution was selected as an appropriate software support for the BRIDGE SMS platform. This solution provides web-based interface, flexible and easy integration with other platforms, robust database system, support for desktop and mobile application and latest IT technology. The BRIDGE SMS platform consist of several modules: bridge inventory, bridge inspection module, bridge maintenance, weather monitoring, flood forecasting and decision support modules. Besides web-based access, GIS and BIM support the platform can be easily integrated with other systems.

4 Conclusions

The bridge scour evaluation is one of the key steps in the efficient bridge management. Due to a range of evaluation approaches, some of which oversimplify the phenomena and some require highly complex inputs, a need for more efficient system for the assessment and management of bridge scour emerges. The BRIDGE SMS concept provides a new solution for bridge scour management which is developed from the basic idea that an effective system should foremost effectively manage the data, from the selection and collection of input data, over evaluation and towards the decision support. The proposed concept comprised the development of several new and interconnected parts. Standardised methods for bridge scour and structural inspection implemented in a dedicated mobile application allows for a quick on-site collection of input data and evaluation of bridge condition. Operational flood forecasting system for roads and bridges, coupled with the new logging devices for on-line collection of weather and hydrological data, provides information on the magnitudes and locations of floods in advance of hazardous events. A modular database framework comprises a web-based access and GIS and BIM support. The creation of a standardised bridge inspection methodology coupled by new ICT technology and flood forecasting system makes an efficient system of data collection and presentation which allows for short-term preventative activities in advance of hazardous event as well as support for long-term decisions regarding maintenance and repair to be made by the asset owner.

Acknowledgements

The authors wish to acknowledge the financial support of the European Commission through the FP7 Marie Curie IAPP project "Intelligent Bridge Assessment Maintenance and Management System BRIDGE SMS" (612517).

References

[1] Wardhana, K., Hadipriono, F.C.: Analysis of recent bridge failures in the United States, Journal of Performance of Constructed Facilities, 17(3), 2003.

[2] Taricska, M.R.: An analysis of recent bridge failures in The United States (2000-2012), Ms Thesis. The Ohio State University, 2014.

[3] Mirzaei, Z., Bryan, T., Thompson, A.P., Klatter, L.: The IABMAS bridge management committee overview of existing bridge management systems – Report by the IAMBAS Bridge Management Committee, 2012.

[4] Bekić, D., McKeogh, E., Kerin, I., Hand, S., Bruton, G: Experiences from bridge scour inspections by using two assessment methods on 100 railway bridges, Proceedings of the 2nd International Conference on Road and Rail Infrastructure CETRA 2012, pp. 499-505, 7-9 May 2012, Croatia.

[5] Zevenbergen, L.W., Thorne, C.R., Spitz, W.J., Huang, X., Ayres Associates, Fort Collins: Evaluation of Bridge Scour Research: Geomorphic Processes and Predictions, NCHRP Web-only document 177, 2011.

[6] Duffy, L.: Development of Eirspan: Ireland's bridge management system, Proceedings of the Institution of Civil Engineers-Bridge Engineering, 157(3), pp. 139-146, 2004.

[7] Dromey, L., Murphy, J.J., O'Rourke, B., Ruane, K.: An analysis of a dataset of 1,400 bridge inspections in County Cork, Proceedings of Civil Engineering Research in Ireland – CERI 2016, pp. 85-90, Galway, Ireland, 29-30 August 2016.

[8] Quirk, L., Matos, J., Murphy, J., Pakrashi, V.: Visual Inspection and Bridge Management. Journal of Structure and Infrastructure Engineering, 14(3), pp. 320-332, 2018.

[9] Cahill, P., Michalis, P., Pakrashi, V., Bekic, D., Solman, H., Kerin, I., McKeogh, E.: Integration of ICT with Bridge Inspections and Maintenance Modules for an Intelligent Bridge Management System, Proceedings of Indian Bridge Management System (IBMS), Hyderabad, India, 22-26 October 2018.

[10] Michalis, P., Tarantino, A., Tachtatzis, C., Judd, M.D.: Wireless monitoring of scour and re-deposited sediment evolution at bridge foundations based on soil electromagnetic properties. Smart Materials and Structures, 24(12), pp. 125029, 2015.

[11] Brownjohn, J.M.W.: Structural Health Monitoring of Civil Infrastructure, Philosophical Transactions of the Royal Society A, 365(1851), pp. 589-622, 2017, doi: 10.1098/rsta.2006.1925.

[12] Michalis, P., Cahill, P., Kerin, I., Solman, H., Bekic, D., Pakrashi V., McKeogh, E.: WILD BIRD for Real-Time Assessment of Hydro-Hazards at Bridge Structures, HydroSenSoft, Madrid, Spain, pp. 290-296, 2017.

[13] Kerin, I., Bekic, D., Michalis, P., Solman, H., Cahill, P., Gilja, G., Pakrashi, V., Lapthorne, J., McKeogh, E.: Flood Early Warning in Bridge Management System: from idea to implementation, In EGU General Assembly Conference Abstracts, pp. 2364, 2017.

[14] Znidaric, A., Pakrashi, V., O' Connor, A., O' Brien, E.: A Review of Road Structure Data in Six European Countries. Proceedings of the ICE, Journal of Urban Design and Planning, 164(4), pp. 225-232., 2011.