ASSESSMENT AND FORECAST OF THE CULVERT'S PERFORMANCE WITHIN A ROAD INFRASTRUCTURE MANAGEMENT SYSTEM. LITERATURE REVIEW

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SUMMARY

During the 21st century, within road infrastructure management there is a strong enforcement on preserving assets and prevent roadway collapses. As a result, public agencies have to implement periodic inspections and asset condition assessments. As pavements and bridges also culverts management play a special role in roadway safety, because they prevent roadbed erosion. The scope of this investigation is the assessment and forecast of culverts performance regarding rating condition and network reliability forecast. In addition, it intends to analyze hazards influence in the culvert serviceability, modelling the hazards actions on the infrastructure.

In this paper, is performed the literature review of studies done during the past decade comparing advantages and limitations. Five main subjects are identified in the development of a culvert management system, since the inventory and inspection framework, to forecasting models and risk assessment. Moreover, it will determine the correlation between subjects and will find gaps for improvement.

Keywords: *Culverts management system, culverts inventory, culvert inspection, risk assessment, hazards influence.*

1. INTRODUCTION

The highways infrastructure deterioration became a major challenge in the 21st century for roadway's administration and researchers. An accurate management of periodic inspections and assets condition rating implementation could avoid failures and road collapses. All around the world, road conservation agencies implemented some routines for the assets inventory, inspection and life service estimation, with a special focus on pavement and bridges.

However, in the past decade agencies got more concerned about culverts because they let the water go through the roadbed preserving it from erosion and also, the failure of such construction may lead to the interruption of significant part of the road [1]. Factors such as poor asset management, ineffective maintenance practices or even inadequate inspection programs may result in a sudden failure of the deteriorated underground infrastructures. Deteriorated culverts and drainage structures requires the road conservation agencies to implement proper inventory and inspection programs [2].

Firstly, to make a culvert inventory it is mandatory to establish a database structure taking into account all the components and features that can provide information about the culverts operation and possible behavior during its life cycle. Having significant relevance in particular, the location and surrounding area information, section and material type, culvert age, and flow characteristics. The culvert's service life may differ from its design life, and it depends largely on the supporting soil, local environment and corrosive/abrasive properties of the transported fluid and solids [3]. Adequate inspection and maintenance practices can improve culvert's serviceability mitigating premature failure or degradation progress.

The inspection type and schedule are dependent from the culvert's inventory, mainly culverts age, size, materials, and importance. Therefore, regarding the variety of culvert types and sizes in a highway drainage system, the condition rating is evaluate with different methods or tools. However, the final condition states mostly provide the same information on the network reliability.

In addition, culverts have to support and maintain structural integrity during hazardous occurrences, like floodings or downpours, so risk assessment of culvert performance should take into account the hazards effects in the condition rating attributed in the inspection and life service estimation. Accordingly, it is important to measure actual culverts resilience and forecast future behavior to determine possible unsafety scenarios of the infrastructure [4].

Therefore, the concept of Culvert Relevance can be inserted to correlate different aspects, characteristics and database information, and hierarchize culverts network in the roadway infrastructure. As a result, culverts have different grades of importance and different concerns during a flood or a downpour, and that will depend on:

- Hydrological aspects, like design peak flow, watershed dimension, flow type (road platform drainage or natural stream), etc.;
- Culvert condition state, including maintenance issues, culvert age and remaining estimated service life, structural performance and materials, etc.;
- Culvert geographic information, with special attention to location and surrounding area information, soil and cover material, etc.;
- Roadway service information, regarding traffic classification and characterization, traffic evolution, social and economic influence, etc.;

The objective of this paper is to review studies and strategies done in culverts management and assessment. It also aims to compare methods and identify their advantages and limitations, or improvement opportunities to the continuous enhancement of the infrastructure management systems.

2. SURVEY SEARCH STRATEGY

In order to achieve the main goal of this paper, firstly a search was done on the scientific databases using keywords directly related to the assessment of culverts performance and infrastructure management system, such as:

- Culverts management system;
- Culverts inspection;
- Culverts reliability;
- Risk assessment models;

Likewise, the hazards impact is considered in the asset management and forecast. Searching for studies that would correlate the occurrence of these events with culvert failure modes.

Hence, it is possible to identify the most important subjects related to the culvert's assessment, which are the inventory data (age, span, location, type, etc.) and featuring every component of the culvert (invert, end protection, embankment, etc.). In addition, it must also be considered the inspection schedule and criteria providing the culvert condition rating. Furthermore, the use of the condition rating and inventory data in the infrastructure risk assessment, forecasting maintenance, and culvert repair or replacement. Due the application of predictive deterioration models to estimate the life cycle [5].

Finally, the information was organized in table 1 resuming the concepts and results from previous studies selected besides the advantages and knowledge evolution. Also, are identified the gaps or development opportunities to improve culverts management system.

Table 1. *Concept matrix of the research. Subjects and observations of the articles.*

	OBSERVATIONS	
ARTICLES	**ADVANTAGES**	**LIMITATIONS / OPPORTUNITIES**
Fernando Delgado-Ramos et al., 2014	Good organization for the culverts inventory and characterization, with well-defined stages. Possible to diagnose pathologies nature. Decision-making support with GIS optional maps.	Culvert identification should provide more information about the structure (length, slope, embankment, etc.) Pathologies location do not consider the cross-section or the affected extension. Decision-making support is incomplete without risk assessment or forecast of the culvert's performance
Akvan Gajanayake et al., 2018	Understand community led adaptation practices during a disaster induced road failure. Interview residents of a community after two flooding events and comparing different types of adaptation techniques with the literature review.	It is a sociological research based on qualitative data collected from the interviews and community capabilities. Road failure is not analyzed to understand the collapse mechanism or other issues that reduce the capability of infrastructure service.
Yanqing Lian and Ben Chie Yen, 2003	Comparison of 28 different methods for culvert's risk calculation. Analysis of the proper method to apply in each situation of culvers failure. Definition of culvert failure ("Logic tree"). Consideration of failures related to hazards like floodings.	Focus only in failures caused by floodings. Does not consider structural failure or collapse. The analysis focus in the risk of rainfall overcome the culvert capacity, and doesn't consider other aspects that can be related with culvert failure or reliability.
Mohammad Najafi and Deepak Bhattachar, 2010	Proper culvert's inventory and data collection format, with well-defined modules of characterization. Inspection program and condition assessment framework. Field inspection to validate the culvert's assessment.	Pathologies location does not consider the cross-section or extension affected on invert and footing. Does not consider hazards occurrence for pathology diagnosis. Decision-making support is incomplete without risk assessment and predictive models.
M. G. Ryumin andE.S. Shepitko, 2017	Condition rating obtained by scoring every observed defect (Defect gradation system). Culverts forecast taking into account the relation between the culvert degradation, age and technical condition. Determination of the time to repair or inspect by the culvert degradation speed.	There isn't an inventory of the culvert's characteristics and design aspects including culvert components. Does not consider the defects location in the rating and condition assessment. Forecast does not indicate degradation increase due to hazards occurrence.
Jay N. Meegoda et al, 2005	Decision to inspect, repair, rehabilitate or replace culverts based in the condition state, culvert's size and age. Budget control and network-level decision to prioritize culverts maintenance, repair or replacement.	Forecast does not indicate the degradation increase due to hazards occurrence.
J. N. Meegoda et al., 2017	Development of the Drainage Information, analysis and Management System (DIAMS) are described. Budget control and network-level decision to prioritize drainage infrastructure maintenance, repair or replacement.	Forecast does not indicate the degradation increase due to hazards occurrence.
J. N. Meegoda and Zhenting Zou, 2015	Decision to inspect, repair, rehabilitate or replace culverts based in the condition state, culvert's size and age. Budget control and network-level decision to prioritize culverts maintenance, repair or replacement.	Forecast does not indicate the degradation increase due to hazards occurrence.
Boriss Misnevs et al., 2015	Assessment of natural factors that impact railway transportation. Risk assessment models for emergency situation. Algorithm of hazards and vulnerability analysis model of weather risks regarding railway transport.	The analysis and forecast of risk and vulnerability are applied to the transportation context and railway safety. Does not analyze hazards impact on the infrastructure deterioration or structural safety of the railway components.
Ossama Salem et al., 2012	Survey study about the use of culvert's condition assessment in various DOT's (Department of Transportation). Implementation of preliminary deterioration model to circular metal culverts based on the condition rating and repair needs evaluation.	There is not an inventory of the culvert's characteristics and design aspects including the culvert's components. Pathologies location does not consider the cross-section or extension affected on the invert and footing. Forecast does not indicate the degradation increase due to hazards occurrence.

3. RESULTS AND DISCUSSION

The objective to implement a Culverts Management System (CMS) in a roadway or railway, as a life cycle estimation based on the present condition rating and taking into account the design information and location [6]. Moreover the risk assessment of the infrastructure during the remaining life service, with the possibility of hazards occurrence, that can influence transportation safety or induce the collapse [7].

Therefore, in table 1 is resumed the literature review with identification of five main subjects that are correlated in the development of the CMS, and outlined in figure 1:

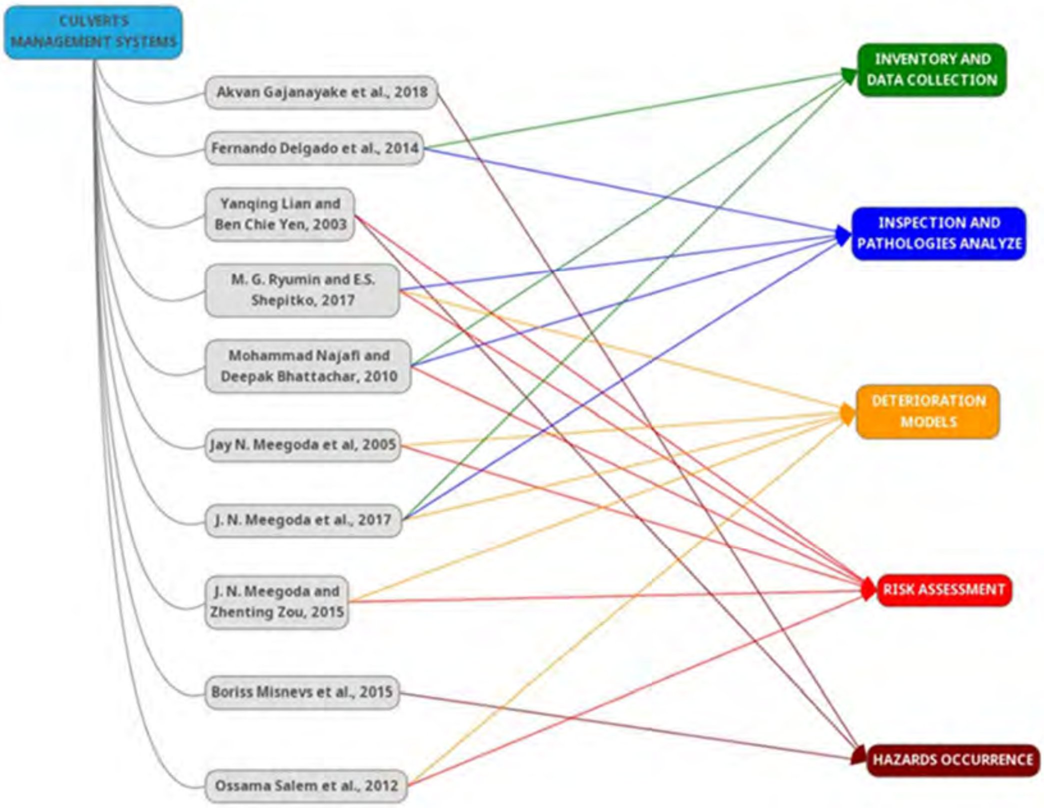

Fig. 1. *Five main subjects in the CMS implementation. Relation regarding the literature review.*

3.1. Inventory and Data collection

Regarding culverts characterization and design or location information. The scope is the construction of a database [8] containing general data (date of inventory, year built, inventory code, place code, etc.), structural data (shape, material, length, span, etc.), hydraulic information (design peak flow, drainage area, slope, etc.) and additional information related to the end treatments type and materials. Each culvert should have their own identification code, providing some information for the user, like explained at figure 2.

Fig. 2. *Culvert code ID explanation – Relation between culvert geographic location and inventory code.*

Likewise, culvert's components and every specific information need to be organized and stored in the database, always related with the culvert code ID, supplying all the information needed to the data collection and culvert management. Figure 3 presented a proposal database structure.

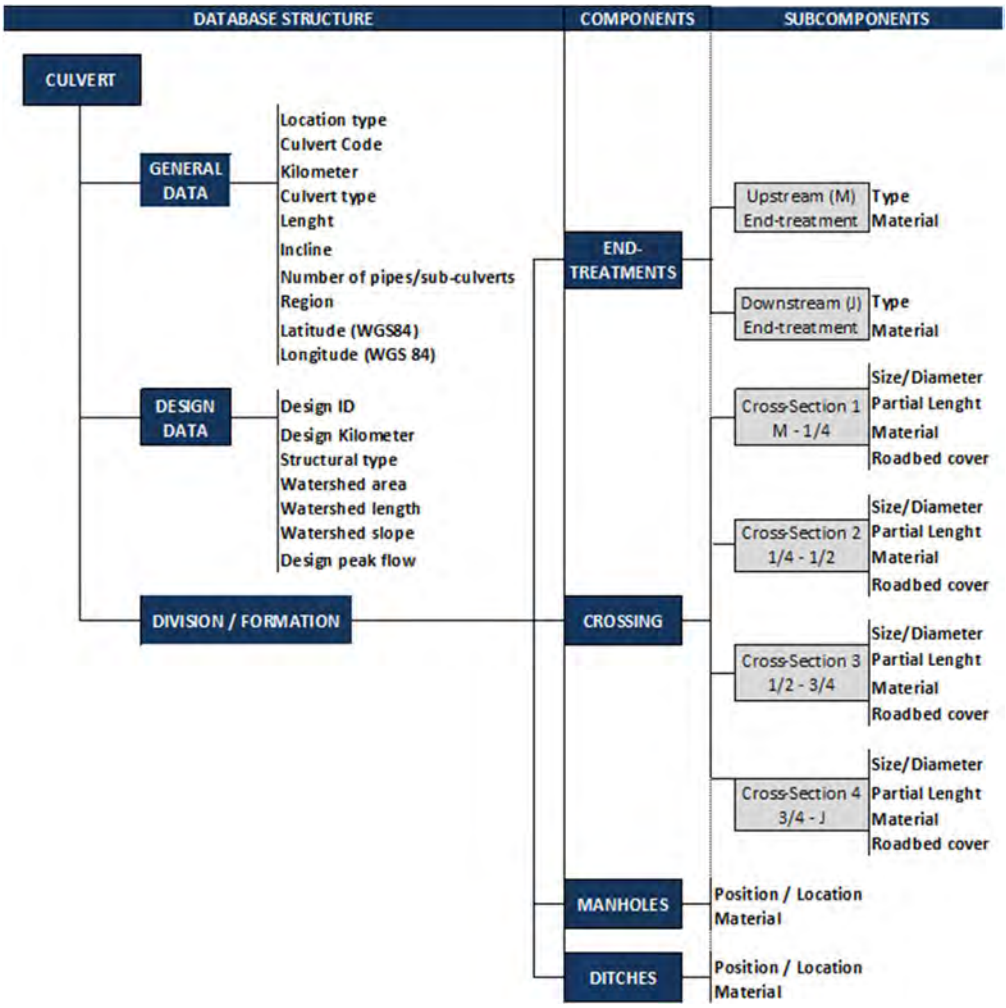

Fig. 3. *Culverts database structure from a Portuguese Roadway Administration –Ascendi, S.A.*

The database integrates two different types of data, divided into general and design data, with organized information obtained during the project inventory and information concerning the conception and construction of the roadway. In contrast, the culvert formation or division is established to organize information about field inventory, and so, culverts are separated in four different components, being two of them with subcomponents. For each component or subcomponent is mandatory to define their attributes, for example the type of end treatment and material applied. It is important to underline the crossing division into four subcomponents named "Cross-section" (figure 4), because enabling the measure and inventory of the roadbed cover for each cross-section along the crossing culvert, and therefore, embankment loads consideration. They also, have special importance in order to verify cross-sections impact in the road safety if some defects are identified during inspection program.

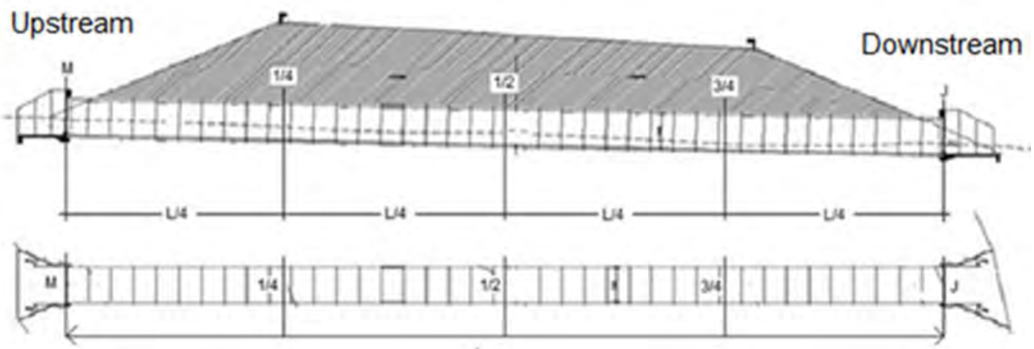

Fig. 4. *Illustrative crossing culvert division.*

3.2. Inspection and pathologies analyze

Implementation of the condition assessment framework based on field inspection reports from the experts. The various culvert components are inspected for defects through a condition rating system in order to obtain their performance score [2]. The condition rating defines all components with different weights considering the location and asset importance. For instance, considering figure 4 is possible to realize that the same pathology with the same extension, have different impacts if identifying in the cross-section 1 (M - ¼) then cross-section 2 (¼ – ½). On contrary, the same defect occurring in the downstream end treatment can be very acceptable and has no effect in the performance score.

The Culvert Management System (CMS) has to be applied to all roadway culverts independently of the type of culvert and size or inspection type (visual or video CCTV). So, it is important to define optimized conditions rating system transversal to both inspections and with the same performance score. During the literature review, the most common performance score has five levels, but with different interpretations. However, across Europe is more accepted the use of a five level score, where Level 1 is good condition and Level 5 the worst condition or imminent collapse.

Besides that, it is important to take into consideration different damage processes and they should be graded with regarding their nature, intensity, extent and location [9]. It is relevant to list defects that can be observed during the components inspection and relate to the materials and damage process, allowing the same interpretation of the degradation mechanisms and impact on the culvert.

Culvert's performance score is important to define the inspection schedule and intervention or repair, depending on the action proposed to comply with quality control plans and restore the infrastructure's safety and security. In table 2 is presented the correlation between the culvert's performance score and the CMS quality control applied to highway administration.

Table 2. *Proposal relation between Culverts Performance score and Quality Control Actions.*

Performance Score	Description	Code	Condition and Action
1	Good	PI01	No significant defects
2	Suficient	PI02	Minor defects, not urgent
3	Bad	PI03	Defects to be addressed with medium term repair (2 - 4 years)
4	Very bad	PI04	Severe defects requiring short term action (1 - 2 years)
5	Imminent Failure	PI05	Very severe defects and dangerous to users safety. Immediate intervention is required

3.3. Deterioration models and Risk Assessment

Stochastic and predictive models application to determine the culvert's performance and reliability during the remaining life service and maintenance requirements. The deterioration models are function of culvert material once the degradation speed is distinct. More importantly, those models are function of culvert's age and remain in the lifetime service. Therefore, in literature review are presented various methods for example the Culvert Degradation Speed using Fuzzy Logic [1] and the Culvert Deterioration Curve applying Weibull Model [10]. Culvert failure Probability is calculated, due to structural defects or insufficient capacity, depending of the performance score obtained by the damage processes analysis. Culverts can experiment different types of failure associated to the condition rating, loads and unpredicted events. The main purpose is to determine the associated risk to each asset and establish strategies to maintain transportation service and safety before collapses occurrence and accomplish quality control plans. It's possible to use different methods by different teams analyzing different types of failures, by combining the results to determine the total risk [5].

3.4. Hazards Occurrence

Analyze reduction of the infrastructure serviceability during natural disasters. Culverts have an important role during disasters, mainly flooding and downpours, for that reason their vulnerability facing natural risks must be assessed [7]. The CMS framework, beyond the inventory, condition assess and deterioration modelling could be a complement for culverts forecast performance during flooding or downpours.

Complementary to the structural defects also hydrological capacity due to sudden events should be taking into account, regarding the erosive strength associated to downpours and load effect into embankment soil. Firstly, culverts hydraulic capacity and behavior in a flood scenario must be evaluated, using the design data of the culverts inventory, and inspection and maintenance information to the model. Secondly, the impact on road and traffic safety, the alternatives routes have to be on the equation, crossing geographic information with traffic data and socioeconomic aspects. Therefore, culvert resilience to natural disasters has to be measured and then forecast future behavior, and intersect these information with the risk assessment due to damage process. So in order to take into account the culvert exposure due to sudden events, we can define the parameter Culvert Relevance (Ʀ) function of culvert hydrological information, the condition state and reliability information, geographic data and culvert location, and also roadway service information and socioeconomic impacts that can be measured.

$$Ʀ_{CULVERT} = f(\text{HYDRO, CONDST, GEOGR, SERVINF}).$$

The figure 5 presents all the proposed attributes to be considers on this approach, and correlation with inventory data and field information.

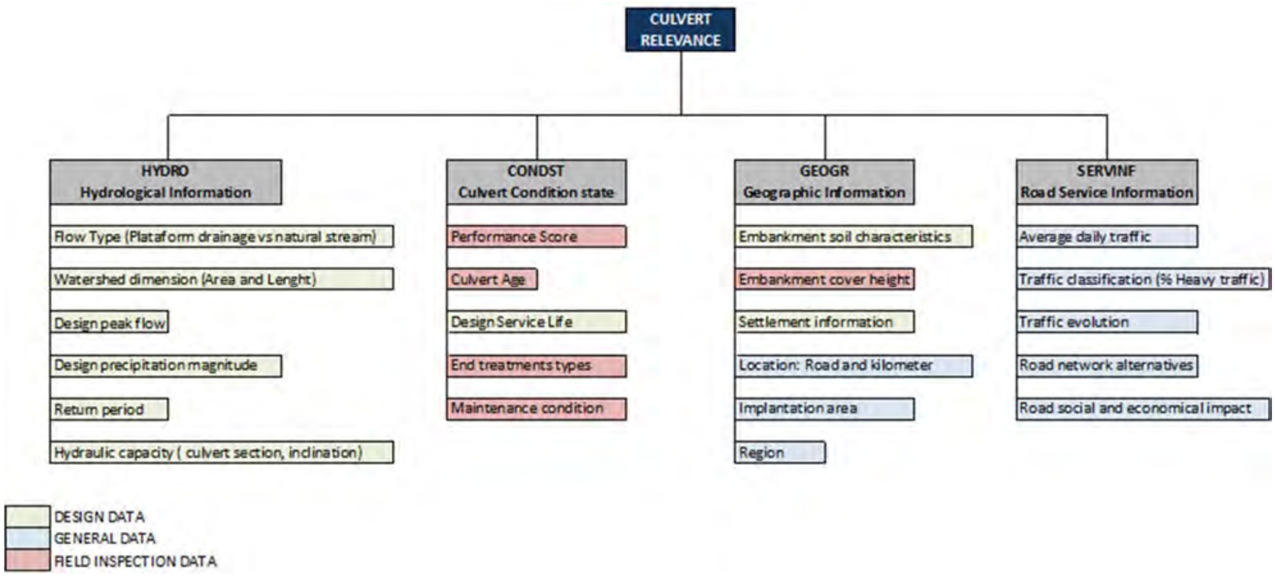

***Fig. 5.** "Logical tree" of parameter Culvert Relevance.*

Hence, culvert relevance evaluation enables to hierarchize all culverts crossing the roadway, regarding all available information, and establish priorities for intervention and inspection. It also can provide important information about the actions and measures to apply during extreme rainstorms, minimizing impacts to users and infrastructure serviceability.

4. CONCLUSIONS

This paper made a literature review starting from a search about experimental and theoretical studies on culvert management systems and reliability. This analysis includes studies from a few countries and so it was possible to identify similar approaches to the subject. However, improvements in the culvert's assessment and forecast are still needed. For instance in the USA, the DIAMS (Drainage Information, Analysis and Management System) development was a requirement for Phase II of the Governmental Accounting Standards Board, Statement No. 34 (GASB-34) [6]. Following this example, perhaps the performance standards definition for the public agencies could lead to the development of assessment frameworks enhancing the infrastructure systems service level. These standards should take into account the culvert's age and lifetime service, but also the inventoried components, materials and design properties. All this factors affect the culvert's condition rate and reliability, therefore should be considered in the predictive models and performance forecast.

In a brief summary, it was possible to identify gaps or improvement opportunities in previous studies, with special focus on inspections, assessment framework and the hazards consequences in the culvert's serviceability. In spite of these facts, the correlation between culvert condition states and predictive deterioration due hazards occurrence has not been studied yet. In addition, inspection methodology should result from a rigorous pathology analysis, featuring the severity, extension and location around the cross-section. Measures are also important in order to provide quantitative data during the assessment, mainly due the span's deformations and cross-section variation.

To sum up, Culverts Management Systems (CMS) has five main subjects since the inventory up to the assessment and forecast. To improve the reliability of CMS it is relevant to develop a model that correlates hazards with culverts assessment, taking into account the culverts relevance in the infrastructure. Inducing adaptations in culverts inventory, inspection framework and schedule. For example, a detailed cross-section characterization enables to identify pathologies location and extension. In the same way, pathologies could be catalogued by nature, severity and evolution probability due to hazards. Therefore, culvert condition rating is determined correlating damages severity and extension in function of culvert's age and lifetime service. However, the system reliability evaluation, needs to be complemented with the culvert resilience during sudden events.

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IABSE SYMPOSIUM
Wrocław 2020

Synergy of Culture and Civil Engineering
– History and Challenges

REPORT

Publisher

IABSE
Jungholzstrasse 28
8050 Zurich
Switzerland
Tel: +41 43 433 97 65
e-mail: secretariat@iabse.org
Web: http: //www.iabse.org

ISBN: 978-3-85748-169-7

The first

IABSE Online SYMPOSIUM
Wrocław 2020

Synergy of Culture and Civil Engineering – History and Challenges

Editors

Jan Bień, Jan Biliszczuk, Paweł Hawryszków

Maciej Hildebrand, Marta Knawa-Hawryszków, Krzysztof Sadowski

Wrocław, Poland
October 7-9, 2020

All papers have been reviewed by the International Scientific Committee of the IABSE Symposium Wrocław 2020, October 7-9.

All authors bear full responsibility for the content of their papers and the origin of presented photos and figures. Editors have not made any substantive changes to the published papers.

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PREFACE

On behalf of the International Association for Bridge and Structural Engineering (IABSE) we have great pleasure to welcome at the IABSE Symposium "Synergy of Culture and Civil Engineering – History and Challenges" on October 7-9, 2020 (Wrocław, Poland). The IABSE Symposium is organised by the Polish Group of IABSE and Wrocław University of Science and Technology (WUST).

The main goal of the Symposium is the creation of a forum for debate on the development of bridge and structural engineering as part of worldwide culture, and on current challenges in this area. The Symposium will be an important international event for scientists, experts, designers, contractors and all those who are interested in problems of bridges and other civil engineering structures, including not only technical issues, but also their presence in everyday life and in culture. A special invitation goes out to our younger colleagues, the builders of the future, to join us. Those born in or after 1986, should take advantage of the "IABSE Young Engineers Programme", including Young Engineers' Contribution Award sponsored by the IABSE Fellows and the Organising Committee.

The Scientific Committee, chaired by Jan Bień, Chair of the Polish Group of IABSE, and the Organising Committee, chaired by Jan Biliszczuk and Paweł Hawryszków, Secretary of the Polish Group of IABSE, have prepared a very attractive and innovative event, including Keynote, Plenary and Parallel Sessions. It has accepted 163 papers for presentation on the Symposium themes: Civil Engineering Structures as Monuments of Culture and Technical Development; Condition Assessment of Contemporary and Historical Structures; Conservation, Upgrading and Management of Contemporary and Historical Structures as well as the Future of Civil Engineering Structures.

We would like to thank the Authors of the papers for their valuable contribution, all members of the Scientific Committee for preparing the technical programme of this Symposium, and also we present our gratitude to all members of the Organising Committee for arranging all Symposium activities.

We are sure it will be a very fruitful event and we look forward to building new friendships and enhance old ones.

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Published by

IABSE
Jungholzstrasse 28
8050 Zurich
Switzerland
Tel: +41 43 433 97 65
e-mail: secretariat@iabse.org
Web: http: //www.iabse.org

ISBN: 978-3-85748-169-7