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Reliability based life cycle management scenarios for the Suurhoff bridge

Irina Stipanovic[1*], *Lorcan* Connolly[2], *Sandra* Skaric Palic[1], *Marko* Duranovic[2]

[1]Infra Plan konzalting, Zagreb, Croatia
[2]ROD-IS, Dublin, Ireland
*Corresponding author: irina.stipanovic@infraplan.hr

ABSTRACT:

Steel and composite highway bridges are nowadays subjected to increasing dynamic actions with variable magnitudes due to increases in traffic loading. These dynamic actions generate and cause the propagation of fatigue cracks or in primary structural elements. Depending on the magnitude and intensity, these adverse effects can compromise the structural system reliability which may lead to a reduction in the expected bridge service life. In this case study the Suurhoff bridge has been analysed, as a part of H2020 European research project SAFE-10-T [1], in order to analyse various life cycle management scenarios for the bridge, which is suffering from serious degradation due to fatigue. The bridge was built in 1972 and provides a road and rail connection from the port towards the hinterland. The roadbridge is a highway bridge consisting of 4 lanes, while the railbridge consists of 2 tracks. Severe crack ing in the deck of the highway bridge during an inspection in 2006. The cause was deemed to be fatigue evolution in the structure

Due to the nature of the bridge design, the possibility of strengthening the bridge using high strength concrete was rejected. The current cracks - combined with ever increasing traffic loads due to the growing port demands - require a much faster response. Therefore, the cracks were repaired during several weekend closures in 2014 and 2016. To prevent any additional fatigue issues around the moving part of the bridge, it was closed in 2016.

As a result, plans were made to completely renew the bridge. An intense inspection program was also set-up including monthly inspections. [2]

Within this study a reliability-based structural model of the bridge was developed, which was used to predict the failure probability at the fatigue limit state. The model employed Dutch Weigh-In-Motion data in order to calculate stress signals at a number of hot-spots within the structure. A rainflow counting algorithm was employed to calculate stress range histograms. The model was calibrated to match the existing level of fatigue damage on the structure. Subsequently, the impact of various traffic growth scenarios was investigated by modifying the WIM data. The impact of structural patch repairs (spot welding) was also modelled in the life cycle analysis.

Various maintenance scenarios for the bridge have been taken into account with a view to increase the calculated safety level and extend the service life. The life cycle model employs the reliability based performance model in order to predict timely and adequate maintenance actions (e.g. welding, strengthening). Total life cycle costs are calculated and used for the optimization of life cycle planning.

Fig. 1. *Suurhoff bridge [3].*

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Incorporation of time-dependent and spatially distributed degradation in a pre-posterior decision making framework

Eline Vereecken[12,*], *Wouter* Botte[1], *Geert* Lombaert[2], and *Robby* Caspeele[1]

[1]Department of structural engineering, faculty of engineering and architecture, Ghent University
[2]Department of civil engineering, faculty of engineering and architecture, KULeuven
*Corresponding author: eivereec.vereecken@ugent.be

ABSTRACT:

All over the world, countries are facing the challenge of managing ageing infrastructure under tight budgetary as well as operational constraints. Information on the condition of the structure is the necessary basis for deciding on a multitude of actions that can be taken to ensure safe operation of the structure within its projected lifetime or for prolonging the lifetime of the structure. However, the acquisition of this information by monitoring and inspections also has an important share in the maintenance costs of the structure, which explains the need to address the problem of rational decision making in the management of deteriorating infrastructure. This decision-making should take its basis in a life-cycle perspective of the asset management [1], taking into account all relevant uncertainties and exploiting the potential for detailed information on the structural condition by state of the art Structural Health Monitoring (SHM) technology. To this purpose, the framework of pre-posterior decision analysis [2] has a large potential as a decision support tool in structural engineering. It seems ideally suited to tackle problems related to determining the value of SHM and is commonly applied in inspection and maintenance planning. It is an important tool in the determination of the Value of Information (VoI) of an inspection strategy and hence enables the comparison of different possible strategies. As such, decisions can be made on doing inspections or not, before these are implemented. Furthermore, out of different possible strategies, the most optimal one can be chosen to be the one with the largest VoI. However, the application of this methodology for integrated life-cycle cost decision making related to monitoring of time-dependent and spatial degradation phenomena in concrete structures, needs further investigation.

In this work, the time dependent and spatial degradation phenomena will be coupled to the pre-posterior decision making approach. To account for the time-dependent degradation, a deterioration model is assigned and failure probabilities and costs are evaluated at different time steps. For the spatial character, the structure is discretized in zones and elements, where hyperparameters and random fields account for spatial correlation. Subsystems with uniform degradation are analysed [3] and inspections on these different subsystems might provide information on the others, because of the modelled correlation. Although the framework is generally applicable, it is here applied to concrete structures subjected to corrosion, where the time-dependent degradation can be modelled for example according to service life model proposals of the *fib* Model Code for Service Life Design [4] and using specific degradation models after damage initiation [5] to derive time-dependent characteristics of the steel section in a reinforced concrete section. A framework is set up to determine the value of information of inspections enabling adequate decision-making, incorporating Bayesian updating based on the uncertain inspection outcomes. The framework is illustrated by an analytical example considering a simply supported beam and is applied on a case study, determining the best time and location to do inspections on the corrosion state of a bridge girder.

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Do nowadays Civil Engineers in Structural Reliability really have to know more about Maths than how to do Monte Carlo Experiments?

Karl Breitung [1*]

[1] Dep. of Civil, Geo and Environmental Engineering TU Munich
*Corresponding author: breitu@aol.com

ABSTRACT:
In the last decades there has been a development in structural reliability towards an intensive use of Monte Carlo methods. More and more publications give results based only on such procedures. This has two main disadvantages. First, it does not give an insight into the problem structure, i.e. one has for a given set of model parameters some numbers, but no idea what happens when something changes. Second, it is in most cases not possible to reproduce the results, since usually no code is supplemented. So the reader is forced more or less to trust the claims of the author if he does not want to imply that there was something done not quite correctly. But as Lenin said, trust is good but control is better. And in science this statement is quite true. The now verypopular way to present Monte Carlo results, which do not give any insight and might be even embellished in some way, is a quite dangerous development, as least in the eyes of the author.

Now this is more a consequence of a more general view on the role of maths in structural reliability. Problems in structural seem to be seen in many cases as forward mathematical problems. Given a mechanical-mathematical structure and then one has to calculate some properties of it, here it is in general the corresponding failure probability. This might work if there is a clear understanding how the structure looks like, for example if it is a simple framework. in such cases it will be not too complicated to see the relations which cause the failure. Monte Carlo calculations are the easiest way to obtain these probabilities, since they do not require any deeper insight of the structure.
But slowly the systems examined in structural reliability have become more and more complex. This has as consequence that an intuitive way of understanding and interpreting results stemming from programs which spit out only some failure probabilities is now impossible in most cases. Not understanding how the found results are related with the underlying structure leads the path to wrong conclusions and finally maybe to wrong decisions.
Structural reliability should be seen in the future more as an inverse problem. This means one should spend more time on trying to identify the structure parts which cause failure. Such an approach requires a tool set of statistical and mathematical methods which have been developed in other scientific fields, e.g. biology and medicine, where many problems are *a priori* of the inverse type.

Basically, the author thinks that the researchers should move a little bit away from producing numbers to producing just a little bit more insight. Soem ideas in context with are developed in [1].

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Advances on Life-Cycle Design, Assessment and Maintenance of Structures and Infrastructure Systems

Fabio Biondini[1,*] and *Dan M.* Frangopol[2]

[1]Department of Civil and Environmental Engineering, Politecnico di Milano, Milan, Italy
[2]Department of Civil and Environmental Engineering, Center for Advanced Technology for Large Structural Systems (ATLSS Center), Lehigh University, Bethlehem, PA, USA
*Corresponding author: fabio.biondini@polimi.it

ABSTRACT:

Research and implementation of life-cycle design, assessment, and optimal maintenance and management of structures and infrastructure systems are promoted within the Structural Engineering Institute (SEI) of the American Society of Civil Engineers (ASCE) by the Technical Council (TC) on *Life-Cycle Performance, Safety, Reliability and Risk of Structural Systems*. The TC and its three Task Groups provide a forum for reviewing, developing, and promoting the principles and methods of life-cycle performance, safety, reliability, and risk of structural systems in the analysis, design, construction, assessment, inspection, maintenance, operation, monitoring, repair, rehabilitation, and optimal management of civil infrastructure systems under uncertainty. In particular, Task Group 1 (TG1) on *Life-Cycle Performance of Structural Systems under Uncertainty* promotes the study, research, and application of scientific principles of safety and reliability in the assessment, prediction, and optimal management of life-cycle performance of structural systems under uncertainty. This is also part of the mission and objectives of the *International Association for Life-Cycle Engineering* (IALCCE) which hosted several mini-symposia and special sessions sponsored by TG1 at IALCCE Symposia.

The recent activities of SEI/ASCE TC TG1 included a Special Project for the development of a state-of-the-art report outlining the current status and research needs in the fields of life-cycle of civil structure and infrastructure systems [1]. This task included a Survey and an International Workshop on *Life-Cycle Performance of Civil Structure and Infrastructure Systems* [2]. The objectives of these activities were to overview the advances accomplished in the field of life-cycle civil engineering, promote a better understanding of life-cycle concepts in the structural engineering community, and discuss methodologies and tools to incorporate life-cycle concepts into structural design codes and standards [3]. In fact, despite relevant advances and accomplishments, life-cycle concepts are not yet explicitly addressed in structural design codes and the checking of system performance requirements is referred to the initial time of construction when the system is intact. In this approach, design for durability with respect to chemical-physical damage phenomena is based on simplified criteria associated with classes of environmental conditions. However, a durable design cannot be based only on such indirect evaluations of the effects of structural damage, but also needs to take into account the global effects of the local damage phenomena on the overall system performance of the structure. Therefore, for a rational approach to life-cycle design of deteriorating structures, the classical point-in-time design criteria need to be extended to account for more comprehensive time-variant performance indicators over the entire service life [3-6]. Furthermore, life-cycle performance metrics are necessary to effectively and quantitatively incorporate emerging environmental issues in structural design, such as the effects of global warming and climate change. Societal and political issues should be also included in framing life-cycle structural design criteria to comply with the different methods, metrics, needs and priorities addressed by public officials, infrastructure users, and owners. The SEI/ASCE TC TG1 state-of-the-art report is responding to these needs. An overview of this report is presented with emphasis on current status and research needs, including results of both the Survey and Workshop, for the implementation of criteria, methods and tools for life-cycle design, assessment and maintenance of civil structure and infrastructure systems under uncertainty.

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Modelling dependencies between multiple bridge deterioration mechanisms

Gareth Calvert[1]*, *Luis* Neves[1], *John* Andrews[1], and *Matthew* Hamer[2]

[1] Resilience Engineering Research Group, University of Nottingham, United Kingdom
[2] Network Rail, United Kingdom
*Corresponding author: gareth.calvert@nottingham.ac.uk

ABSTRACT:

To evaluate an estimate of the Whole Life Cycle Cost (WLCC) of a portfolio of bridges, a deterioration model and a decision model can be employed. The accuracy of an output from the decision model is fundamental to the overall estimate of the WLCC [1], although any quality decision output requires an accurate underlying deterioration model. Commonly in literature and industry, a stochastic predictive deterioration model is used to determine the probability of a single condition index, either the worst condition or some combination of all the defects present, throughout time.

Previous literature has proposed a multi-defect approach to predicting bridge deterioration, with an index for each distinct deterioration mechanism [2]. However, the multi-defect model uses a Markov chain based approach [3], which treats each defect mode independently. In this study, a Dynamic Bayesian Network (DBN) is proposed to model the initiation of different defect modes throughout time, and thus enabling the evaluation of causal influences of other defect mechanisms on the initiation of the considered defect mode. The progression of a defect mechanism once initiated, is then modelled using an independent Petri net. The deterioration of spalling, pointing and blockwork alongside the presence of hollowness and masonry cracking are the defect mechanisms considered, with the masonry bridges on the British railway serving as a case study.

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