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A random field based technique for the efficiency enhancement of bridge network life-cycle analysis under uncertainty

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ABSTRACT

Studies associated with distributed civil infrastructure systems are usually very demanding from a computational point of view, especially when they involve life-cycle analysis, uncertainty, and optimization. For this reason, computational tools that enhance the efficiency of the analysis and make it feasible for complex practical applications are of utmost importance. In this paper, a computational technique for the efficiency enhancement of bridge network life-cycle analysis under uncertainty is presented and its impact in terms of CPU time reduction is investigated.

The proposed technique consists in the joint use of random field theory and probabilistic reliability models for the simulation of the individual bridge service states over the life-cycle of the infrastructure. This random field based approach is extremely efficient and takes simultaneously into account the deterioration in time of the bridge reliability and the correlation in space of the service states of bridges belonging to the same transportation network. Compared to other techniques previously used to perform the same task, the proposed methodology is theoretically more solid and improves the computational efficiency by more than two orders of magnitude.

A numerical example is provided to validate the proposed technique. Moreover, a second example involving the life-cycle performance analysis of a complex bridge network in Santa Barbara, CA, is presented.

1. Introduction and problem statement

Very recently, a significant amount of research effort has shifted the focus from the analysis of individual components of the infrastructure to the investigation of entire distributed civil infrastructure systems and networks. In particular, with respect to the ground transportation infrastructure, many recent papers deal with bridge networks [1]. As expected, when considering systems on a much larger scale, the number of variables and uncertainties increases dramatically. Especially for studies that involve computationally demanding tasks, such as probabilistic simulation and numerical optimization, there is a strong need for efficient techniques and approaches that can help keeping the computational effort feasible for practical applications. This paper addresses the above issue, with emphasis on life-cycle analysis of bridge networks.

In studies dealing with network life-cycle analysis and reliability assessment, there are three major sources of uncertainty [2]. The first source is the incomplete knowledge of the deteriorating reliability profile of the individual bridges. This is often overcome by means of probabilistic reliability models developed by Frangopol and his co-workers [3–7]. Based on a few characteristics of the bridge, the models can be calibrated and the reliability is described as a function of random variables. Since the uncertainty propagates over time, the variance of the reliability index increases along the bridge life-cycle. These models involve three to five random parameters. Hence, every bridge for which one of these models is used, introduces three to five random variables into the problem. The second source of randomness is associated with the effects of maintenance actions. In fact, even though maintenance actions might be planned in advance for the entire life-cycle, their actual impact on the bridge conditions and on the reliability is uncertain. For this reason, usually these effects are assumed to be functions of random parameters [8]. This introduces even more random variables into the problem, where the actual number depends on the quantity and type of maintenance actions that are applied on all bridges. The third source of uncertainty in bridge network life-cycle analysis is related to the correlation among the

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