Structural Time-Dependent Reliability Assessment: Advanced Approaches for Engineered Structures

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https://doi.org/10.1061/AJRUA6.RUENG-1010

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This special collection of the *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering* contains nine technical papers and one state-of-the-art review dealing with time-dependent reliability problems of civil structures. Time-dependent reliability is the ability of a structure to withstand extreme events with an acceptable level of safety during its future service life. In assessing structural time-dependent reliability, it is essential to model the time variation of structural resistance and that of external loads. The former accounts for the deterioration of structural performance with time due to aggressive environmental or operational attacks, while the latter reflects the nonstationarity characteristics of loads (e.g., increasing magnitude with time). Time-dependent reliability assessment of an aging structure is also relevant in adaptive design and risk management in an environment (ASCE Committee on Adaptation to a Changing Climate 2018) where risk profiles are changing (nonstationary) and climate change is a reality with significant uncertainties.

Wang et al. (2021) present a comprehensive review of time-dependent reliability assessment, including simulation-based methods, extreme value–based methods, and outcrossing-based methods (in the presence of either a discrete or a continuous load process). Applications of time-dependent reliability assessment, such as service life prediction, life-cycle cost assessment and optimization, system reliability assessment, and resilience analysis are also discussed.

Of the nine technical papers, five deal with novel methods for structural time-dependent reliability assessment.

Ahmadivala et al. (2021) propose an active learning and Kriging-based system for structural time-dependent reliability analysis called AK-SYS-t for short. In this method, the reference period of interest is first subdivided into small intervals based on which time-dependent reliability is transformed into series-system reliability. AK-SYS-t extends AK-SYS, initially developed to assess series system reliability, to the temporal scale. The AK-SYS-t procedure is detailed and numerical case studies are provided.

Guo et al. (2021) develop a new method for time-dependent reliability assessment based on point-evolution kernel density estimation (PKDE) and the equivalent extreme performance function. They model the deterioration of structural resistance as a linear combination of progressive and shock deteriorations, and introduce a factor φ, which is less than 1, to account for the effect of preventive maintenance on progressive deterioration. They further treat structural reliability as a first-passage problem and employ PKDE to evaluate the probability distribution of the equivalent extreme performance function.

Li et al. (2021a) propose a method for structural time-dependent reliability analysis using inspection data. They apply the Smolyak-type quadrature formula to obtain the first three posterior moments of the imprecise parameters, based on which three-parameter lognormal distribution is used to approximate posterior probability distributions. Subsequently, time-dependent reliability considering Bayesian updating is evaluated in the presence of these updated random variables.

Sun and Chen (2022) focus on the global evolution–based generalized density evolution equation (GE-GDEE), which is a powerful tool for reliability evaluation of nonlinear high-dimensional structures. The equivalent drift coefficient is a key ingredient in GE-GDEE and is derived for a class of additive white noise–excited nonlinear multidegree-of-freedom (MDOF) systems that achieve energy equipartition in their stationary stage. Results are verified by applying GE-GDEE to the stochastic response analysis of two nonlinear MDOF systems excited by Gaussian white noise.

Xu and Ding (2021) investigate first-passage seismic reliability of complex nonlinear structures under random seismic excitations. They use an adaptive Hermite polynomial normal transformation (A-HPNT) model to evaluate the extreme-value distribution (EVD) of response, based on which the failure probability and reliability index can be obtained via an integral over the EVD. Probability-weighted moments matching is used for parameter estimation, and a two-step criterion is developed to determine the optimal degree involved in the A-HPNT model. The applicability and effectiveness of the A-HPNT model against competitive methods are demonstrated through two examples.

The following four technical papers focus on reliability assessment methods in engineering practice.

Kim and Song (2021) present a framework for time-dependent reliability assessment of post-tensioned concrete box girder bridges. In this framework, corrosion-related data collected in current structure safety inspection practice are used to formulate probabilistic models of time-varying flexural strengths. Traffic environment data obtained through weigh-in-motion devices and traffic investigation are also used to account for traffic load nonstationarity. Time-dependent reliability of bridges is computed based on estimated strengths and load effects. The reliability framework is applied to a safety evaluation of the real-world cable-stayed Hwayang-Jobal Bridge in South Korea.

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Li et al. (2021b) evaluate the time-dependent reliability of a buried water distribution network by combining finite-element analysis (FEA) and a probabilistic approach. The uncertainty associated with stress at various stages of a pipeline's life is obtained through a series of FEAs, and time-variant failure probability is determined by comparing the pipeline's circumferential stress and tensile failure strength at the burst limit state. Additionally, the reliability of a water distribution network is calculated based on the minimum cut set and graph decomposition methods.

Muscolino et al. (2022) study the reliability bounds of structural systems exposed to a set of recorded accelerograms with spectra. They analyze the spectral content of a large set of accelerograms recorded on rigid soil deposits and characterize the main parameters of the pertinent power spectral density (PSD) function by modeling ground motion acceleration as a stationary Gaussian random process. The imprecise PSD function is then embedded into the first-passage reliability problem to obtain an interval for structural reliability due to the imprecision of the excitations.

Zhang et al. (2021) focus on the durability life prediction of reinforced concrete (RC) structures in a chlorine-eroded environment. They use a Gamma process to describe chloride concentration on the surface of RC structures, based on which structural service life is predicted given a predefined chloride concentration threshold. The parameters in the Gamma process are calibrated by maximizing the log likelihood function based on splash zone and tidal zone simulation data.

The guest editors thank all the authors for their contributions and the reviewers for constructive comments that helped improve the quality of the submissions. In particular, the guest editors thank Professor Bilal M. Ayyub, the former-Editor-in-Chief of the *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems*, for his kind support during the preparation of this special issue.

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