Engineering Structures 33 (2011) 2458–2471

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Time-dependent performance indicators of damaged bridge superstructures

Duygu Saydam, Dan M. Frangopol *

Department of Civil and Environmental Engineering, ATLSS Engineering Research Center, Lehigh University, 117 ATLSS Dr., Bethlehem, PA 18015-4729, USA

ARTICLE INFO

Article history:
Received 14 January 2011
Received in revised form
22 April 2011
Accepted 24 April 2011
Available online 12 June 2011

Keywords:
Bridges
Structural performance indicators
Structural damage
Damage tolerability
Redundancy
Finite element analysis

ABSTRACT

The ability of a structure to survive an extreme event without collapse reduces in time due to deterioration processes. Therefore, in the lifetime management of structures and infrastructures, the resistance to sudden local damage has to be considered together with the effect of progressive deterioration. The aim of this paper is to present a framework for computation of time-dependent performance indicators of civil structures and infrastructures, with emphasis on bridges, including reliability, vulnerability, robustness and redundancy. A brief theoretical background and selected structural performance indicators regarding vulnerability, redundancy and robustness are presented. The approach is based on probabilistic performance assessment supported by finite element analysis and applied to an existing bridge. Time-variation of vulnerability, redundancy and robustness associated with various damage scenarios under uncertainty and the effects of several loading conditions on performance are investigated.

1. Introduction

Structures and infrastructures are supposed to maintain adequate levels of serviceability and safety throughout their lifetime. However, deterioration processes due to harsh environmental conditions and sudden localized damage caused by extreme events may lead to unacceptable levels of functionality and/or safety. Traditionally, structural design codes focus on the safety of individual components and connections in order to ensure the overall safety of a structure. Nevertheless, the catastrophic failures in the past (e.g., terrorist attack on World Trade Center and collapse of I-35W Mississippi River Bridge in Minneapolis) showed that including system-based performance measures in the design is required in order to ensure the global safety of structures.

A common terminology on damage tolerance is not available yet, even though it is an important structural property. Several researchers focused on the field of damage tolerant structures and they referred damage tolerance with various related measures. These measures include collapse resistance [1], vulnerability and damage tolerance [2], robustness [3–6], and redundancy [7].

Civil structural and infrastructural systems are subjected to deterioration in strength and performance due to the aggressive environmental conditions (e.g., corrosion, fatigue). The serviceability and/or safety of these systems are highly influenced by their deterioration levels. Furthermore, the ability of a structure to survive an extreme event reduces in time due to the deterioration process. Therefore, in the lifetime management of structures and infrastructures, the resistance to sudden local damage has to be considered together with the effect of progressive deterioration. Time-dependent redundancy of structures, in the context of availability of warning before structural failure under live loading, was studied by Okasha and Frangopol [8–10]. Saydam and Frangopol [11] studied time-dependent vulnerability of structural systems under progressive and sudden damage separately. Risk-based robustness of structures under deterioration was investigated by Baker et al. [5]. However, to the best of the authors' knowledge, time-dependent redundancy, as the availability of alternative load path under sudden local damage, time-dependent vulnerability including combined effects of deterioration, and time-dependent robustness based on reliability have not been investigated yet.

The aim of this paper is to present a framework for estimation of time-dependent performance indicators of civil structures and infrastructures including vulnerability, redundancy and robustness. A brief theoretical background and selected structural performance indicators regarding vulnerability, redundancy and robustness are presented. The framework is applied to an existing bridge, the I-39 Northbound Bridge over Wisconsin River. The approach is based on probabilistic performance assessment supported by finite element analysis. A detailed finite element (FE) model of the bridge is built using FE software ABAQUS [12]. Nonlinear incremental static analysis is performed to find the load carrying capacity of the bridge superstructure. Several local

* Corresponding author. Tel.: +1 610 758 6103; fax: +1 610 758 4115.
E-mail addresses: dus207@lehigh.edu (D. Saydam), dan.frangopol@lehigh.edu (D.M. Frangopol).

0141-0296/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.engstruct.2011.04.019