Sustainable Cities and Society 1 (2011) 142–151

Contents lists available at ScienceDirect

Sustainable Cities and Society

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

Sustainable building design under uncertain structural-parameter environment in seismic-prone countries

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ARTICLE INFO

Keywords:
Sustainable buildings
Uncertainty
Earthquake engineering
Interval analysis

ABSTRACT

The structural member stiffness and strength of buildings are uncertain due to various factors resulting from randomness, material deterioration, temperature dependence, etc. The concept of sustainable building design under such uncertain structural-parameter environment may be one of the most challenging issues to be tackled recently. By predicting the response variability accurately, the elongation of service life of buildings may be possible. In this paper, it is shown that interval analysis in terms of uncertain structural parameters is an effective tool for evaluating the sustainability of buildings in earthquake-prone countries. All the combinations of uncertain structural parameters become huge numbers and this difficulty can be overcome by introducing the sensitivity or Taylor series expansion analysis. In order to demonstrate the usefulness and reliability of the proposed method, a shear building model is used including passive viscous dampers with supporting members. It is demonstrated that the proposed method is actually useful for the development of the concept of sustainable building design under such uncertain structural-parameter environment.

1. Introduction

The structural control with passive dampers has a successful history in mechanical and aerospace engineering. This may result from the fact that these fields usually deal with predictable external loading and environment with little uncertainty. However, in civil engineering, it has a different situation (Casciati, 2002; Cheng, Jiang, & Lou, 2008; Christopoulos & Filiatrault, 2006; de Silva, 2007; Housner, Masri, & Chassiakos, 1994; Housner et al., 1997; Johnson & Smyth, 2006; Kobori, Inoue, Seto, Iemura, & Nishitani, 1998; Soong & Dargush, 1997; Srinivasan & McFarland, 2000; Takewaki, 2009). Building and civil structures are often subjected to severe earthquake ground motions, wind disturbances and other external loading with large uncertainties (Takewaki, 2007). It is therefore inevitable to take into account of these uncertainties in their structural design and application to actual structures.

While the structural control is a promising and smart tool for sustainable building design (Fujita, Moustafa, & Takewaki, 2010; Takewaki, Fujita, Yamamoto, & Takabatake, 2011), it is also true that a lot of uncertainties should be quantified for reliable implementation of these techniques (Takewaki & Ben-Haim, 2005). The sustainable building design under uncertain structural-parameter environment may be one of the most challenging issues in the building structural engineering. Even if all the design constraints are satisfied at the initial construction stage, some responses to external loadings (earthquakes, strong winds, etc.) during service life may violate such constraints due to various factors resulting from randomness, material deterioration, temperature dependence, etc. To overcome such difficulty, response evaluation methods for uncertain structural-parameter environments are desired. By predicting the response variability accurately, the elongation of service life of buildings may be possible.

In this paper, it is shown that interval analysis (see, for example, Alefeld & Herzberger, 1983; Chen, Ma, Meng, & Guo, 2009; Chen & Wu, 2004; Koyluoglu & Elishakoff, 1998; Moore, 1966; Mullen & Muhanna, 1999; Qiu, Chen, & Song, 1996; Qiu, 2003) in terms of uncertain structural parameters is an effective tool for evaluating the sustainability of buildings in earthquake-prone countries. All the combinations of uncertain structural parameters become huge numbers and this difficulty can be overcome by introducing the sensitivity or Taylor series expansion analysis.

In order to demonstrate the usefulness and reliability of the proposed method, a shear building model including passive viscous dampers with supporting members is subjected to a set of scaled earthquake ground motions and the time–history response analysis is used for simulating the earthquake response. The critical combination of interval parameters is found by introducing

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doi:10.1016/j.scs.2011.07.001

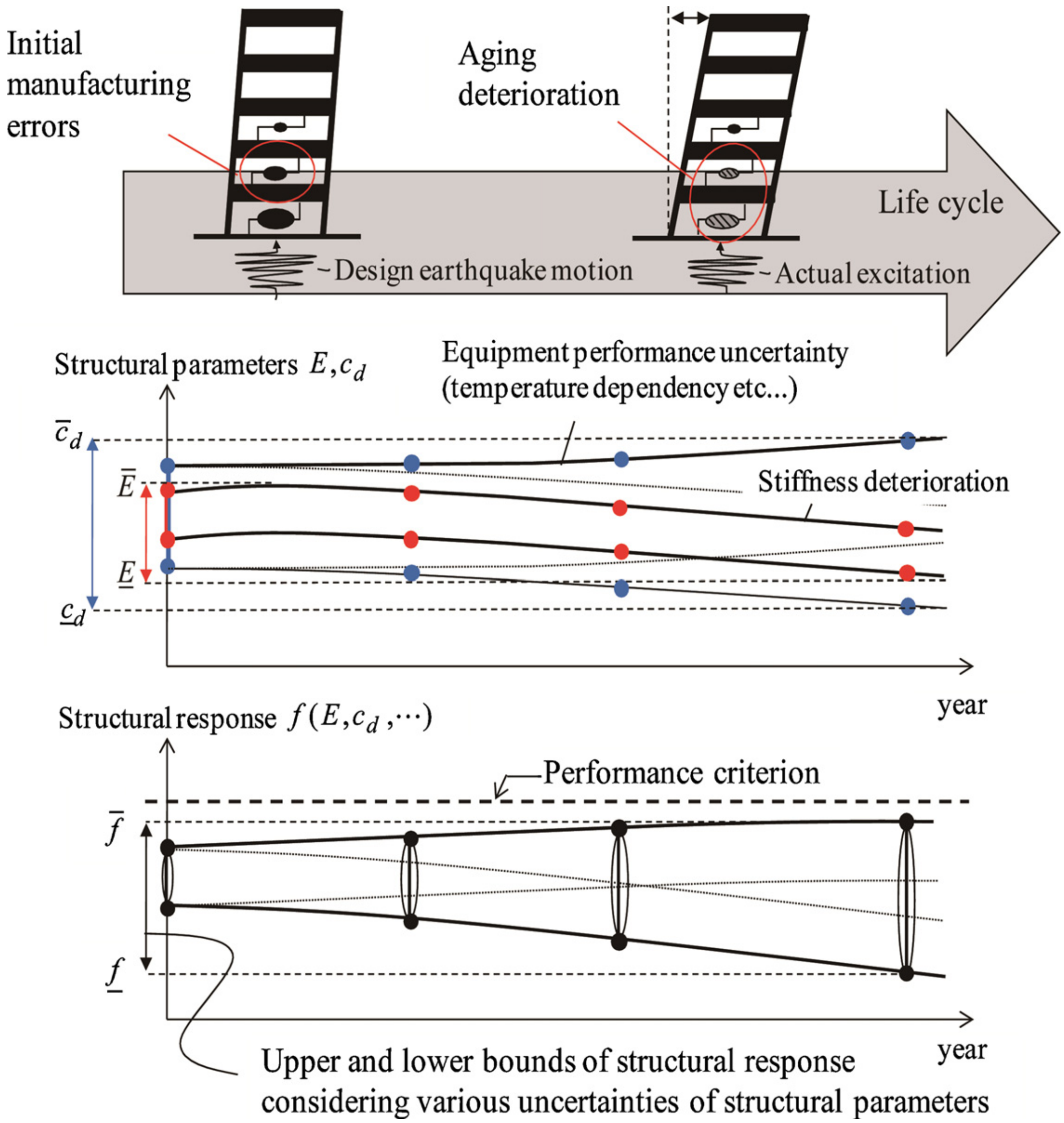

Fig. 1. Concept of sustainable design considering varied structural performance caused by various uncertainties of structural parameters.

an assumption of 'inclusion monotonic' and the sensitivity information by Taylor series expansion. It is demonstrated that the proposed method is actually useful for the development of the concept of sustainable building design under uncertain structural-parameter environments.

The design earthquake ground motions change from time to time when a new class of ground motions (e.g. long-period ground motions due to surface waves) is observed or a new type of damage appears during severe earthquakes. Because the proposed method can easily add these earthquake ground motions, the flexibility of the proposed method is expected to be high.

2. Concept of sustainable building design under uncertain structural-parameter environment

The concept of sustainable building design under uncertain structural-parameter environments is illustrated in Fig. 1 where f, E and c_d denote a structural response as the objective function, Young's modulus and a damping coefficient, respectively. The member stiffness and strength of buildings are uncertain due to various factors resulting from randomness, material deterioration, temperature dependence, etc. The damping coefficients of structural members and/or passive dampers may also be uncertain (Takewaki & Ben-Haim, 2005). The time variation of Young's modulus and damping coefficients are shown in Fig. 1 as representative examples. Karbhari and Lee (2010) discuss the service life estimation and extension of civil engineering structures from the viewpoints of material deterioration. These member and/or damper uncertainties lead to response variability of buildings under earthquake ground motions. Efficient and reliable methods are desired for predicting the upper bound of such building response.

3. Interval analysis methods for uncertain structural parameters

Fig. 2 shows the relationship between the variation of the objective function f (response quantity) and a structural parameter combination for the cases of '*inclusion monotonic*' and '*inclusion non-monotonic*'. In the case of inclusion monotonic as shown in Fig. 2(a) where $\bar{X}_i$, $\underline{X}_i$ $(i = 1, 2)$ denote the upper and lower bounds of uncertain parameters, the maximum and minimum points occur