Engineering Structures 33 (2011) 2509–2524

Contents lists available at ScienceDirect

Engineering Structures

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

Estimation of the Park–Ang damage index for planar multi-storey frames using equivalent single-degree systems

Siddhartha Ghosh *,[1], Debarati Datta [2], Abhinav A. Katakdhond [3]

Department of Civil Engineering, Indian Institute of Technology Bombay, Mumbai 400076, India

ARTICLE INFO

Article history:
Received 13 October 2010
Received in revised form
13 April 2011
Accepted 26 April 2011
Available online 1 June 2011

Keywords:
Park–Ang damage index
Equivalent systems
Modal pushover analysis
Performance-based evaluation
Performance-based design

ABSTRACT

A detailed characterization of potential structural damage is essential to performance-based seismic design. The Park–Ang damage index is selected in this work as the seismic damage measure, since it is one of the most realistic measures of structural damage. Response spectra constitute the most common tool used for characterizing the seismic hazard at a site, and these spectra represent the demand on single-degree oscillators. To use these spectra for estimating the Park–Ang damage index demand on an MDOF system, three equivalent single-degree system-based approximate schemes are proposed. These schemes are tested on three moment resisting frames under several ground motion scenarios. The effectiveness of an equivalent system scheme is measured by comparing with the estimates from a nonlinear response-history analysis of the MDOF model. These schemes are tested for both global and storey-level damage indices. Variation of the non-dimensional parameter β is also considered in these case studies. Overall, all the three schemes are found to be effective with varying degrees of accuracy. The proposed methods are recommended for damage-based seismic design and performance evaluation of structures because these schemes can use response spectra for demand estimation and reduce computation cost.

1. Performance-based seismic design

For over more than a decade now, performance-based seismic design (PBSD) has been at the forefront of earthquake engineering research. One of the prime aspects of PBSD is the realistic characterization of seismic structural damage and its direct incorporation in the design or performance evaluation methodology. In addition, a major emphasis is also placed on the consideration of all the uncertainties in the design and evaluation (or lifecycle engineering, for more advanced design approaches). The various modes of characterizing the seismic damage potential lead to various PBSD approaches. The SEAOC Vision 2000 document [1], which was one of the first major publications providing a roadmap for prospective PBSD approaches, listed three broad categories for advanced seismic design approaches:

(i) Displacement-based design.
(ii) Energy-based design.
(iii) Comprehensive design considering lifecycle cost.

It should be noted that these three approaches can also be adopted for a performance-based seismic performance evaluation procedure. So far, the most commonly proposed (and even adopted in some cases) approach for PBSD is the displacement-based design approach in which a structure is designed for a target inelastic displacement, maximum (inelastic) interstorey drift, ductility demand, etc. [2]. For performance assessment of structures, the same parameters are used to define various performance levels or limit states. Among many research publications on displacement-based design methods, a small set [3–7] can be selected to represent a variety of approaches. Although an inelastic displacement-based approach to structural damage is more realistic than elastic and force-based methods, many researchers argued that the energy dissipated due to cyclic–plastic deformations in a structure during earthquakes (that is, hysteretic energy) is a better indicator of seismic structural damage [8–10], because the dissipated energy is a cumulative parameter as opposed to an instantaneous parameter, such as peak roof displacement. Ghosh and Collins [10], in their work on developing a reliability-based method considering hysteretic energy demand, suggested that more complex damage parameters, such as the Park–Ang damage index [11], which combine the cumulative energy demand with the ductility demand, would eventually prove to be even better measures of seismic damage potential. The effectiveness of using the Park–Ang and other similar damage indices has been supported by many researchers from the mid-1980s, although not always in the context of PBSD.

* Corresponding author. Tel.: +91 22 25767309; fax: +91 22 25767302.
E-mail address: sghosh@civil.iitb.ac.in (S. Ghosh).

[1] Associate Professor.

[2] Former doctoral student.

[3] Former graduate student.

0141-0296/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.engstruct.2011.04.023