Soil Dynamics and Earthquake Engineering 31 (2011) 512–520

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

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

A framework for validation of seismic response analyses using seismometer array recordings

Brendon A. Bradley

Department of Civil and Natural Resources Engineering, University of Canterbury, Private Bag 4800, Christchurch 8020, New Zealand

ARTICLE INFO

Article history:
Received 10 March 2010
Received in revised form
1 August 2010
Accepted 24 November 2010

ABSTRACT

A framework for the validation of computational models used to predict seismic response based on observations from seismometer arrays is presented. The framework explicitly accounts for the epistemic uncertainty related to the unknown characteristics of the 'site' (i.e. the problem under consideration) and constitutive model parameters. A mathematical framework which makes use of multiple prediction–observation pairs is used to improve the statistical significance of inferences regarding the accuracy and precision of the computational methodology and constitutive model. The benefits of such a formal validation framework include: (i) development of consistent methods for determination of constitutive model parameters; (ii) rigorous, objective, and unbiased assessment of the validity of various constitutive models and computational methodologies for various problem types and ground motion intensities; and (iii) an improved understanding of the uncertainties in computational model assumptions, constitutive models and their parameters, relative to other seismic response uncertainties such as ground motion variability. Details regarding the implementation of such a framework to achieve the aforementioned benefits are also addressed.

1. Introduction

The continuing evolution toward the seismic design of engineered facilities based on their expected seismic performance places increasing emphasis on the use of computational models to predict the seismic response of such facilities. Despite our best efforts in the design and assessment of facilities to reduce their vulnerability to earthquake-induced hazards, the occurrence of every large earthquake provides new evidence of the complex phenomenon producing strong ground motions at the earth's surface, and weaknesses in these contemporary seismic design and/or assessment methods [1–3].

Quantitative data from seismometer arrays (e.g. [4, 5]) represent one of the primary interactions between observations and computational simulation in earthquake engineering, with other interactions including: element testing, testing of subsystems, or testing of entire systems at full or reduced scales. Seismometer data offers several advantages over these other forms of quantitative data in that the instrumented facilities automatically have the correct in situ and boundary conditions which can be difficult, if not impossible, to reproduce in laboratory experiments. The reducing costs of deploying and maintaining seismometer arrays, as well as these perceived benefits are leading to a significant increase in the number, configuration and types of structures (both natural and man-made) being instrumented throughout seismically active areas of the world, e.g. [6–8].

This manuscript is devoted to the development of a framework in which seismic response models can be validated with seismic array recordings. First, details regarding the concepts of verification, validation and prediction as applied to seismic response modelling are discussed. The conventional use of seismometer arrays in validation of seismic response modelling and its limitations are discussed. The details of the proposed framework, which addresses conventional limitations, are developed and its benefits for use in seismic response prediction are examined. Finally, procedural aspects regarding the implementation of the framework in order to realise its stated benefits are discussed.

2. Validation in seismic response modelling

Computational seismic response models are used to predict the response of engineered facilities in future seismic events. Verification and validation are the primary means by which confidence can be built as to the predictive capabilities of a computational model [9]. Verification is the assessment of the accuracy of the computational implementation of a conceptual model, while validation is concerned with the assessment of the degree to which the (computational implementation of the) conceptual model is representative of reality [9].

Conventionally, the validity of seismic response models is examined by primarily three means, which examine different aspects of system behaviour, as illustrated in Fig. 1. First, element tests are used to gain an understanding of fundamental material behaviour. Second, model subsystem tests offer insight into the interaction of the various

E-mail address: brendon.bradley@canterbury.ac.nz

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doi:10.1016/j.soildyn.2010.11.008