A Structural Response Prediction Engine to Support Advanced Seismic Risk Assessment.

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A STRUCTURAL RESPONSE PREDICTION ENGINE TO SUPPORT ADVANCED SEISMIC RISK ASSESSMENT

D. Cook[1], K. Wade[2], C. Haselton[3], J. Baker[4], and D. J. DeBock[5]

ABSTRACT

One impediment to widespread use of the advanced FEMA P-58 method for building-specific seismic risk analysis is the need for running full response-history analyses (RHA) to predict the story drifts and floor accelerations of the building. The FEMA P-58 Guidelines provide the Simplified Method calculation method, which allows for approximate prediction of building responses based on ground motion level and building properties (modal information, strength, etc.). However, this Simplified Method is limited to regular buildings only up to 15-stories. This presentation outlines the development of the new Seismic Response Prediction Engine method, which provides a broader toolkit for estimating structural responses buildings of many types (taller buildings, weak-story buildings, nearly all types of structural systems, etc.). The goal of this Seismic Response Prediction Engine work is to broaden the applicability of the FEMA P-58 method by allowing the FEMA P-58 method to be used without needing to complete full RHA (so it can be used for preliminary design before the RHA is completed or can be used without RHA for applications such as mortgage and insurance risk assessments).

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Introduction

Understanding seismic risk and vulnerability plays a key role in risk mitigation, preparedness and in achieving resilience in our infrastructure. Recent developments in seismic risk assessment methods, such as the FEMA P-58 methodology [1], have enabled engineers and stake holders to achieve a more detailed and accurate understanding of building specific seismic risk. However a more rigorous approach to seismic risk drives the need for more in-depth understanding of building

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specific behavior; for the P-58 method, this means understanding the structural response of a building for various intensities of hazard. The engineering solution to this problem is to create a nonlinear model of the structure and run it through a suite of ground motions in order to understand the response of the structure at various hazard intensities. This is both a computationally heavy and time consuming process which impedes the adoption of advanced seismic risk assessment methods, such as FEMA P-58. As a solution to this challenge, this paper presents an outline of a recently developed Structural Response Prediction Engine that enables rapid estimations of structural responses for the purpose of seismic risk analysis by means of the observed behavior from a large database of advanced nonlinear structural models.

A Brief Overview of FEMA P-58

FEMA P-58 is a probabilistic performance prediction methodology that was developed for the Federal Emergency Management Agency (FEMA) by the Applied Technology Council (ATC) in 2012. The methodology outlines a comprehensive and standardized building-specific risk assessment method that uses the site hazards, building structural responses (primarily interstory drift ratio and peak floor accelerations), and structural and nonstructural component fragilities in order to assess the risk of the building in terms of economic loss, repair time, and casualties. FEMA P-58 provides a Simplified Method for the approximate prediction of building responses. However, this Simplified Method is limited in scope to regular buildings only up to 15-stories, and is in general not considered rigorous enough to achieve accurate building-specific results.

Construction of a Structural Response Database

The Structural Response Prediction Engine was developed using a large set nonlinear structural models, all based on high quality models that have been widely accepted and used in previous research: RC moment frame models from Haselton [3] and Liel [4], rigid-wall flexible-diagrams models from Koliou [6], as well as others. Each model was analyzed in OpenSEES [5] using incremental dynamic analysis (IDA [8]) with the FEMA P-695 [9] far-field ground motion suite. Engineering Demand Parameters (EDPs), such as interstory drift ratios (IDR) and Peak Floor Accelerations (PFA) were recorded for each of the stripes of the IDA to create a database of structural responses across various hazard intensities for the broad set of architype buildings.

Predicting Structural Responses

The goal of the Structural Response Prediction Engine is to provide building specific structural response estimates across a range of ground motion intensities. In order to create a prediction method to be more building-specific than just the archetype models, a system was set up to normalize the results by building specific parameters such as mode shape(s), fundamental period, base shear strength and so on. After normalizing the structural response database, a method was formulated that uses common structural analysis information (e.g. strength and period) to estimate building-specific structural responses.

Predicting Roof Displacement

Building roof displacement is a function of the target drift outlined in the nonlinear static procedure of chapter 7 of ASCE 41-13, as shown in Equation 1. The ASCE 41 target displacement is based on the fundamental building period, modal participation factor, and a few other nonlinear and hysteretic correction factors. The target displacement is then modified based on normalized data from the structural response database.

$$\delta_t = C_0 C_1 C_2 S_a \frac{T_e^2}{4\pi^2} g \qquad (1)$$

Predicting Interstory Drift Ratio

Interstory drift ratios are based on a modification to an elastic modal response spectra analysis procedure. The results from the modal analysis are scaled to an average interstory drift deriving from the predicted roof displacement modified by the structural response database. This gives an estimation of elastic IDR as shown by the dotted line in Figure 1. The elastic drift is then modified by the normalized data in the structural response database to provide an estimation for nonlinear interstory drift ratios as shown by the dashed line in Figure 1. Note that drifts tend to concentrate in the lower stories at large intensities for which significant damage is expected.

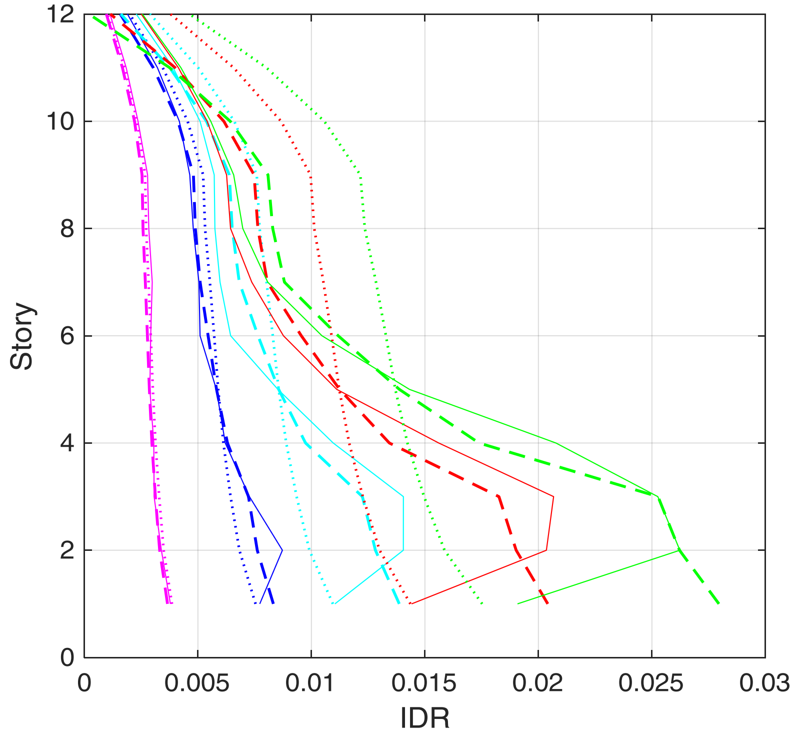

Figure 1. Estimated IDR (dashed line for inelastic, dotted for elastic) as compared with archeptye Opensees results (solid line) for a 12 story RC special moment frame.

Predicting Peak Floor Acceleration

Peak floor acceleration are based on a modification to an elastic modal response history analysis. First a linear elastic modal response history analysis is performed using a suite of ground motions based on periods and mode shapes of the first three modes. The modal responses are combined and the elastic PFA is found as shown by the dotted line in Figure 2. The elastic PFA is then modified by the normalized data in the structural response database to provide an estimation for nonlinear response PFA as shown by the dashed line in Figure 2.

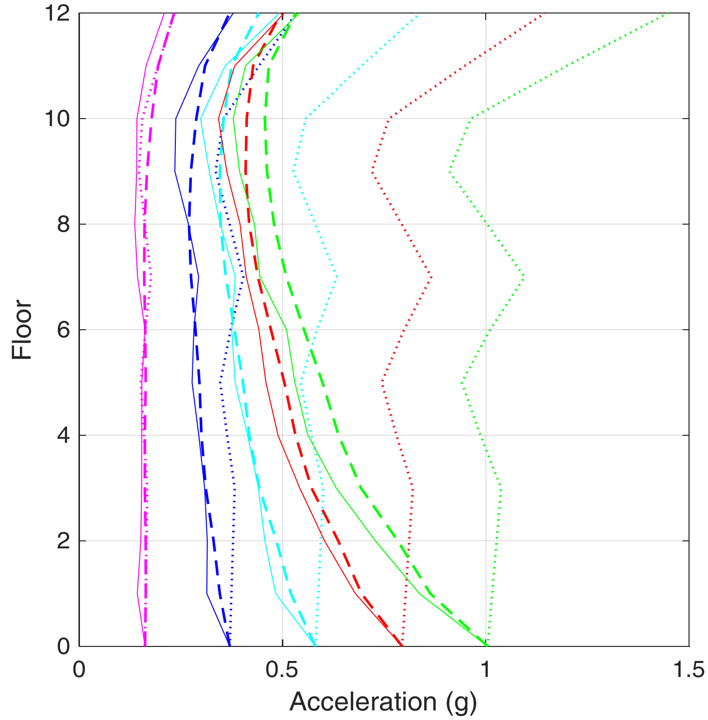

Figure 2. Estimated PFA (dashed line for inelastic, dotted for elastic) as compared with archeptye Opensees results (solid line) for a 12 story RC special moment frame.

Conclusions

This paper outlines the basic methodology for a recently developed Structural Response Prediction Engine. The engine enables rapid estimation of structural responses across various ground motion intensities for use in building-specific seismic risk assessments. The method used to formulate the Structural Response Prediction Engine also provides a consistent building-specific framework for predicting structural responses from a database of architype responses.

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