PERFORMANCE PREDICTION EQUATIONS FOR DESIGN AND ASSESSMENT OF STRUCTURES

PEER NGA-West2 Research Program

Principal Investigator: Farzin Zareian, UC Irvine
Student Investigator: Marta De Bortoli, UC Irvine
Performance Based Earthquake Engineering Laboratory, University of California, Irvine

Introduction

The goal of this research is to develop analytical formulations that directly estimate the probability distribution of the structural response (EDP) as a function of structural and ground motion parameters. These Performance Prediction Equations (PPE) can be included in any hazard calculation program to obtain a direct estimate of the EDP hazard curve λ_{EDP}, improving the accuracy of the result by moving away from the IM-based 2-step approach.

Conventional approach ($\lambda_{IM} \longrightarrow \lambda_{EDP}$):

$$\lambda_{IM} = \sum_{i=1}^{n} \nu_i \int_{\boldsymbol{\theta}} P(im > IM \mid \boldsymbol{\theta})\, f_i(\boldsymbol{\theta}) d\boldsymbol{\theta}$$

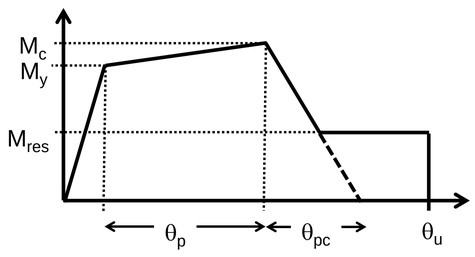
$$\lambda_{EDP} = \int_{IM} P(edp > EDP \mid im) \left| \frac{\mathrm{d}\lambda_{IM}(im)}{\mathrm{d}im} \right| \mathrm{d}im$$

Sophisticated approach: $\lambda_{EDP,\ PPE}$

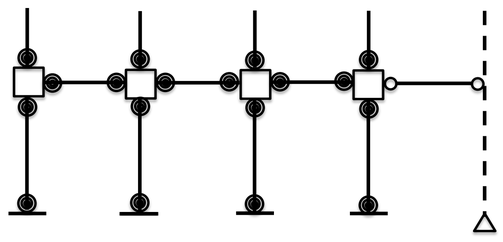
$$\lambda_{EDP} = \sum_{i=1}^{n} \nu_i \int_{\boldsymbol{\theta}} P(edp > EDP \mid \boldsymbol{\theta})\, f_i(\boldsymbol{\theta}) d\boldsymbol{\theta}$$

Phase 2: PPEs

A set of generic building frames was developed in OpenSees by changing the number of stories NS (4, 8, 12, 20), the first mode period (0.1NS, 0.15NS, 0.2NS), and the modified Ibarra-Medina-Krawinkler peak-oriented material properties θ_p and θ_{pc}. The plastic behavior is modeled using nonlinear hysteretic springs at beam and column ends.

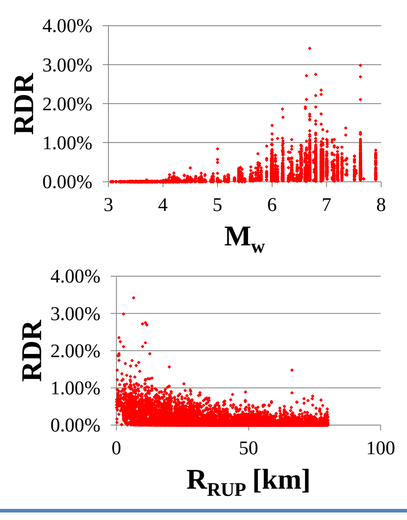


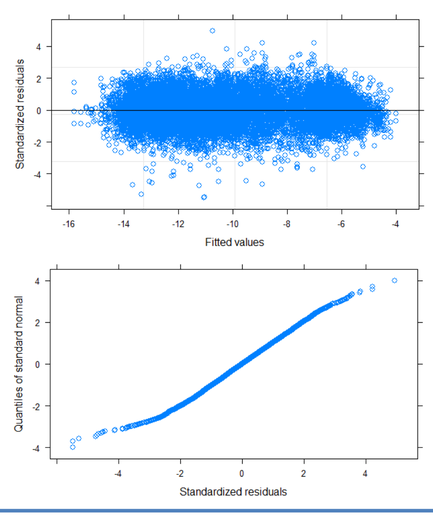
IMK spring material



1st story general layout

The full set of ground motions used to develop Campbell-Bozorgnia 2014 was applied to the structures, and PPEs were obtained using nonlinear regression with mixed effects for EDPs RDR, MIDR, and base shear V_b.





Phase 1: Linearized Equations

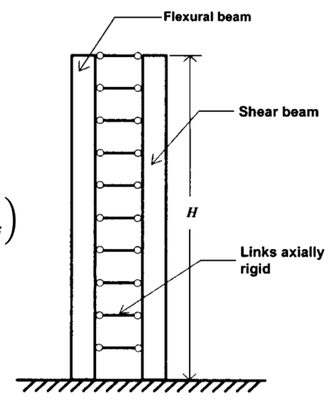
A first step toward the goal of removing the intensity measure IM from the hazard calculation is the development of equations that estimate the EDP probability distribution from the IM statistics. Pairing these equations with any Ground Motion Model allows to directly estimate μ_{EDP} and σ_{EDP} for any earthquake scenario.

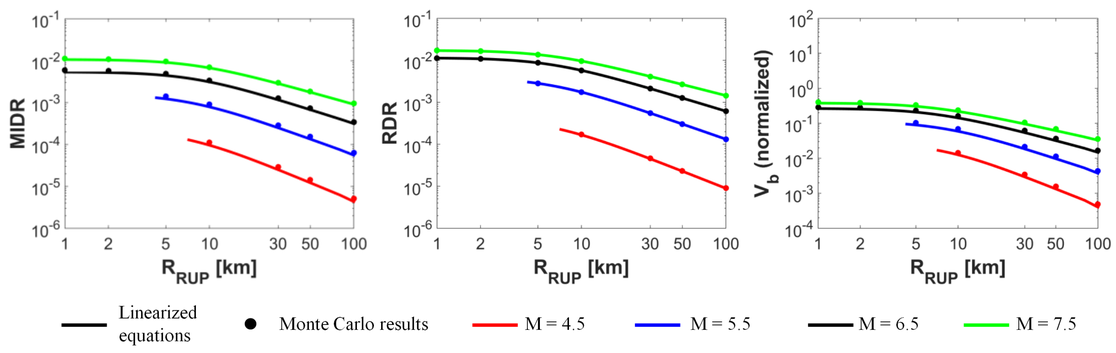
This was achieved by using the CQC modal combination to represent the EDP as a function of IM, and the First Order Second Moment approximation to linearize the relationship.

$$\delta_k = \sqrt{\sum_{i=1}^{n}\sum_{j=1}^{n} \delta_{i,k}\, \alpha_{T_i,T_j}\, \delta_{j,k}}$$

$$\begin{cases} \mu_{\ln EDP} = f\ \left(\ln S_{a,1},\ \ln S_{a,2},\ \ln S_{a,3}\ \right) \\ \sigma^2_{\ln EDP} = g\ \left(\ln S_{a,1},\ \ln S_{a,2},\ \ln S_{a,3}, \sigma_{\ln Sa,i},\ \sigma_{\ln Sa,j}, \rho_{\ln Sa,ij}\right) \end{cases}$$

Shear-flexural beam structure used in the study, from Miranda (2005).





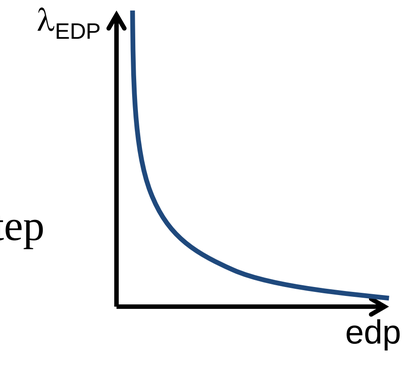
Sample distributions of EDPs as a function of R_{RUP} for strike-slip scenarios. Linearized results compare well with Monte Carlo simulations of the CQC modal combination.

Conclusions and Future Work

The linearized equations were a first step in removing the need to calculate an intensity measure to develop the EDP hazard curve λ_{EDP}. The results show very good agreement with the CQC simulations and the GMM used in their application.

Full PPEs based on regression analysis of EDP results on a set of generic frames are being developed by exploring several functional forms.

The last step of this research is the inclusion of the PPEs into a hazard calculation program to provide a direct estimate of the EDP hazard curve. Comparing it with the traditional two-step hazard curve will show the improved accuracy due to the PPE formulation.



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