Bridge piers damage subjected to multiple earthquakes: Markov model vs Regression model

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Recently developed methodologies based on a probabilistic seismic demand model (PSDM) and based on a Markovian model for the prediction of damage accumulation in structures subjected to multiple earthquakes within their lifetime are compared. A stochastic earthquake hazard model is used for generating sample sequences of ground motion records providing the reference solution and then used to estimate the probabilistic distribution of the damage accumulated during the time interval of interest. Besides evaluating the effectiveness of each approach, possible improvements of the cumulative demand model are tested. A reinforced concrete bridge model with a single pier is examined as case study and Park-Ang damage index is considered to describe the damage accumulation. The results demonstrate the importance of considering the occurrence of multiple shocks.

Keywords: Multiple earthquake, seismic damage index, accumulation process, exceeding probability, bridge piers.

1. Introduction

In earthquake-prone regions infrastructure are subjected to repeated seismic excitations resulting in a progressive reduction in structural capacity and eventually lead to collapse. This study review, evaluate, and compare two methodologies for the prediction of damage accumulation in structures subjected to multiple earthquakes. The method of Ghosh et al. (2015) and Iervolino et al. (2016) are considered. The effectiveness of each approach are evaluated, and possible improvements of the cumulative demand model of Ghosh et al. (2015) tested.

2. Framework for damage accumulation

The failure condition of a system under a seismic sequence is expressed as follows:

$$P[D \geq d] = \sum_{1}^{\infty} P[D \geq d|n] * P[n,T] \quad (1)$$

where $P[D \geq d|n]$ is the probability that the demand D exceeds d, conditional on having the occurrence of n shocks, and $P[n,T]$ is the probability of having n shocks within a time frame T. $P[n,T]$ can be expressed by means of a homogeneous Poisson model. The Ang-Park damage index (Park et al. 1985) is considered to describe the damage accumulation D. For practical purposes, the sum of Eq. (1) is carried out up to a value of n equal to N, beyond which the probability of occurrence becomes negligible. The approach by Iervolino et al. (2016) is here denoted as "Markovian Method (MM)" while the approach by Ghosh et al. (2015) as "Regression-based Method (RBM)". Spectral acceleration is chosen as intensity measure (IM) and the following multi-linear regression models (RM1-RM4) are considered to describe the relationship between the damage index D, and the IM:

$$\ln D_n|IM_n, D_{n-1} = a_n + b_n \ln D_{n-1} + c_n \ln IM_n + d_n \ln D_{n-1} \ln IM_n + \ln \varepsilon|IM_n, D_{n-1} \quad (2)$$

$$\ln D_n|IM_n, D_{n-1} = (e_n + f_n \ln D_{n-1})H_n + (g_n \ln IM_n + h_n \ln IM_n \ln D_{n-1})(1 - H_n) + \ln \varepsilon|IM_n, D_{n-1} \quad (3)$$

where H_n is a step function that is $H_n = 1$ for $IM_n \leq IM^*$ and $H_n = 0$ for $IM_n > IM^*$. The IM^* parameter identifies the breakpoint, which is defined as the intersection point of the two surfaces.

$$\ln D_n|IM_n, D_{n-1} = \max \begin{cases} i_n + l_n \ln D_{n-1} + \\ m_n \ln IM_n + n_n \ln D_{n-1} \ln IM_n \\ D_{n-1} \end{cases} \quad (4)$$

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$$+\ln \varepsilon_n \,|IM_n$$

$$\ln D_n | IM_n, D_{n-1} = \max \begin{cases} a_n + b_n \ln D_{n-1} \\ + c_n \ln IM_n + d_n \ln D_{n-1} \ln IM_n + \ln \varepsilon_n \,|IM_n \\ D_{n-1} \end{cases} \quad (5)$$

Monte Carlo simulation is used to generate 5000 earthquakes (representing the reference solution) in the form of a train, representative of multiple main-shocks, with *IM* sampled on the basis of the site-specific seismic hazard curves. A RC bridge piers denoted as 815 in Lehman et al. (2000) is selected as case study.

3. Results

The performance of RBM as a function of the number of *IMs* sampled was carried out and shown in Fig. 1. The curves referring to RM3 and RM4 are more stable and closer to the reference curve. Table 1 shows the P-values of the two-samples K-S test (Simard et al. 2011): the test is verified for RM4 and for RM3; it is rejected for the other models. It is concluded that 200 samples are sufficient for a good estimate of the exceedance probability.

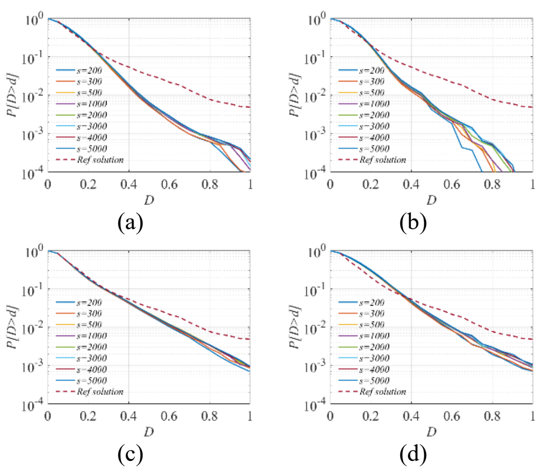

Fig. 1. Estimate the damage exceedance probability with RBM using (a) RM1 (b) RM2 (c) RM3 (d) RM4.

Table 1. P-values of the two-sample K-S at 95% confidence (the values below 5% are in bold).

	s=200	*s*=500	*s*=1000	*s*=5000
RM1	**8,08e-6**	**6,97e-5**	**6,97e-5**	**6,97e-5**
RM2	**5,86e-8**	**7,62e-7**	**7,62e-7**	**8,08e-6**
RM3	**0,049**	0,090	0,090	**0,049**
RM4	0,428	0,453	0,453	0,351

Fig. 2 shows the comparison between the exceedance probability curves calculated with MM and corresponding P-values listed in Table 2. An accurate estimate can be obtained considering *N*≥10 and 500 samples.

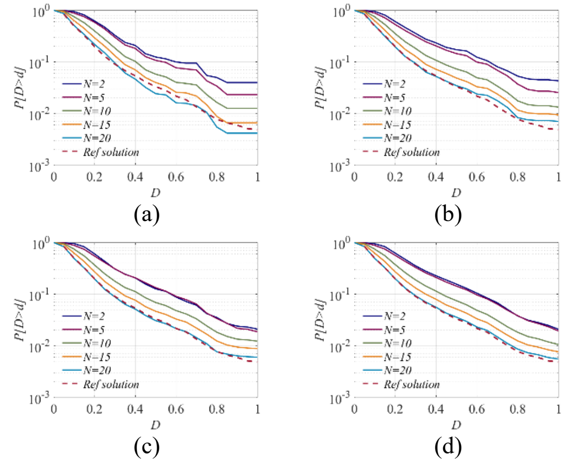

Fig. 2 Estimate the damage exceedance probability with MM for (a)200 (b)500 (c)1000 (d) 5000 samples.

Table 2. P-values of the two-sample K-S test for the MM (the values below 5% are in bold).

	s=200	*s*=500	*s*=1000	*s*=5000
N=2	**0,00073**	**0,00024**	0,116	0,059
N=5	**0,00073**	**0,028**	0,116	0,116
N=10	**0,00073**	0,210	0,210	0,116
N=15	**0,00073**	0,210	0,210	0,116
N=20	**0,00073**	0,210	0,210	0,116

4. Conclusions

The study results demonstrate the importance of considering the possibility of occurrence of multiple shocks and concluded that the RBM is the most advantageous model as it requires the lowest computational effort.

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