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A 3-stage Method for Selection of Ground Motions for Dynamic Time History Analysis

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ABSTRACT: In this study, a three-step screening process is presented for selection of consistent earthquake records in which number of suitable earthquakes is quickly screened and reduced from a few thousands to a handful number for practical use in the time history analysis. Records that remain at the end of this screening process are the most appropriate for the studied structures meaning that they considerably reduce the dispersion of structural responses.

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1- Introduction

Procedures suggested for the ground motion selection can generally be categorized in three groups regarding their level of complexity. In the first group simply the general seismicity and seismotectonic characteristics of the region are considered. Parameters such as the fault mechanism, earthquake magnitude, distance to the causative fault and etc., have been used for sorting of earthquakes. This approach has been adopted mainly by the public databases of earthquake records on the Internet, such as the PEER NGA strong motion data bank [1].

In the second group, similarity of spectral shapes is the basis of selection. For this purpose, the response spectrum of the record at hand is compared with the design spectrum. If enough similarity is satisfied, the record is selected for dynamic analysis. As the basis of comparison, the code-based constant-shape design spectrum can be used among other choices. To determine how similar a response spectrum is to a basis spectrum, many options are available. When using the design spectrum as the basis, the average of deviations from the basis spectrum between two certain periods can be calculated and compared.

The criteria used in the third group are generally called the advanced intensity measures. They usually combine the spectral characteristics of a ground motion with certain nonlinear responses of multi-story structures. After computing the above intensity measure (IM) for many records, those with IM's nearer to the average IM are selected.

When a record is scaled, the main idea is to minimize deviation of its response spectrum from the target (basis) spectrum in a certain period range. The period range can be defined using T_1, the period of the first mode of vibration. It is usually taken to be extending from $0.2\,T_1$ to $1.5\,T_1$ to include both the effects of higher modes and the nonlinear response of structure [2]. In the Conditional Mean Spectrum (CMS) method [3], derivation of the scale factor is targeted at equalizing sum of the spectral amplitudes in the required period range from the CMS to that of the response spectrum. Scaling of records can also be accomplished using code-based prescribed procedures. ASCE7-10 requires that the scale factor be determined such that the average response spectrum of the suit of records does not fall below the design spectrum in the mentioned period range [2].

The aim of this research is to sort out a suitable methodology for earthquake record selection and modification. The main criterion for recognizing the suitability of the method is chosen to be having a minimum scatter in nonlinear structural responses.

2- The proposed method for selection of ground motions

In this study, a three-stage procedure for screening of earthquake records is presented. During the stages, the selection criteria become more strict and number of records that pass each screen sharply decreases. The three stages are called loose, medium and tight screens that are explained in the following sections.

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2- 1- The loose screen

In stage 1, some global characteristics of earthquakes are utilized as the basis of record selection. These are: earthquake magnitude (M), distance to the fault (R), soil type or the shear wave velocity (V_s) and peak acceleration at the ground surface (PGA).

For illustration, the following values are chosen to get forward with the next stages:

$$6 \leq M \leq 8$$
$$10 \leq R \leq 90, \text{ Km}$$
$$375 \leq V_s \leq 750, \text{ m/s}$$
$$0.2g \leq PGA \leq 1.2g$$

With the database of PEER, the selected records will be 47 motions.

2- 2- The medium screen

For the medium screen, the more promising options, after testing several procedures, seemed to be the following two methods:

-The CMS approach; selection based on the spectral shape factor ε.

The ε factor is determined using Eq. (1):

$$\varepsilon(T) = \frac{\ln Sa(T) - \mu_{\ln sa}(M,R,T)}{\sigma_{\ln Sa}(M,R,T)} \tag{1}$$

where $\ln Sa(T)$ is the natural logarithm of the spectral acceleration of the record, $\mu_{\ln Sa}(M,R,T)$ is the average of $\ln Sa(T)$ for the records of the ground motion suit, and $\sigma_{\ln Sa}(M,R,T)$ is their standard deviation; all calculated at the fundamental period of building. The records with smaller ε's are less deviated from the average and are deemed more suitable for analysis.

-The spectral intensity approach

In this method the records with spectral intensities nearer to that of the design spectrum are picked up for the next screen. The spectral intensity (SI) is calculated using Eq. (2):

$$SI = \int_{0.1}^{2.5} S_V \, dT \tag{2}$$

in which S_V is the spectral velocity. This method only needs the response velocity spectrum of each earthquake and the design velocity spectrum and therefore is simpler than the above method based on ε. Moreover, numerical analysis in this study has shown that selecting based on SI results in less scattering of structural responses compared with ε [4]. Therefore only the earthquakes selected based on SI are introduced here. For selection of earthquakes in this stage, the ratios of spectral intensities of the records at hand to that of the design spectrum are calculated. The earthquakes with ratios nearer to unity are selected. The design spectrum, S_a, used for this analysis is that of ASCE7-10.

Based on Eq. (2), 20 earthquakes with spectral intensity ratios closer to unity are selected.

2- 3- The tight screen

Among the methods suitable for a tight screen, referred in Section 1, the CMS method is selected for analysis. Of course use of more advanced intensity measures is possible too, but they have been left aside after examining, for their unwanted complexity [4].

The CMS method needs a design spectrum and involves constructing a mean spectrum with the condition that intersects with the design curve at a certain period. This period is taken to be the fundamental period of the buildings under study. The structures designed for the purposes of this study are 2, 4, 6, 8 and 10 story two-way steel moment resisting frames. There are three bays each way spanning 5 m between columns. The floor-to-floor heights of stories are uniformly 3 m. The fundamental periods of 2 to 10-story buildings are determined to be 0.42, 0.79, 1.07, 1.23 and 1.52 sec, respectively.

The CMS must be constructed for each building. It is determined as follows [4]:

1) Calculation of the mean, $\mu(\ln S_a)$ and standard deviation, $\sigma(\ln S_a)$ of the natural logarithm of the spectral accelerations. For the 20 earthquakes selected out the medium screen, $\mu(\ln S_a)$ and $\sigma(\ln S_a)$ are calculated at each period T as follows:

$$\mu_{\ln Sa}(M,R,T) = \frac{1}{20}\sum_{i=1}^{20} \ln Sa(T)_i \tag{3}$$

$$\sigma_{\ln Sa}(T) = \sqrt{\frac{1}{20}\sum_{i=1}^{20}\left(\ln Sa(T) - \mu_{\ln Sa}(M,R,T)\right)^2} \tag{4}$$

2) Determination of ε and the correlation factor ρ

The spectral shape parameter ε is calculated using Eq. (1) at the fundamental period T. The ρ factor is determined using Eq. (5):

$$\rho(T_{\min}, T_{\max}) = 1 - \cos\left(\frac{\pi}{2} - \left(0.359 + 0.163 I_{T_{\min}<0.189} \ln\frac{T_{\min}}{0.189}\right)\ln\frac{T_{\max}}{T_{\min}}\right) \tag{5}$$

where I equals unity for T_{min}<0.189 and zero elsewhere. Also, for periods less than T, T_{min} is the desired period and $T_{max}=T$. For periods larger than T, The above definition is reversed.

3) Calculation of CMS

The conditional mean spectrum is calculated using Eq. (6):

$$CMS(T_L) = Exp\left\{\mu_{\ln Sa}(M,R,T_i) + \rho(T_i, T^*)\varepsilon(T^*)\sigma_{\ln Sa}(T_i)\right\} \tag{6}$$

where (T_i) is the desired period. Similarity of each response spectrum to the CMS is measured in this method using the SSE and SF indices, introduced as follows:

$$SSE = \sum_{j=1}^{n}\left(\ln Sa(T_j) - \ln Sa_{CMS}(T_j)\right)^2 \tag{7}$$

$$Scale\ Factor = \frac{\sum_{j=1}^{n} Sa_{CMS}(T_j)}{\sum_{j=1}^{n} Sa(T_j)} \tag{8}$$

where $Sa(T_j)$ is the value of the response spectrum at the descried period T_i and Sa_{CMS} the CMS value at the same period. Then, 10 records with smaller SSE's and with SF's closer to unity are finally picked up for structural analysis.

3- Conclusions

In this paper a three-stage method for selection of earthquake ground motions suitable for nonlinear dynamic analysis of structures was presented. The selection method uses the general characteristics of earthquakes as used in online databases for an initial selection. Then it uses two stricter measures for finally picking up the suitable records. It is a fast method. It has the advantage that the stricter measures are used with a far less number of records. It was shown that the proposed method resulted in the least scatter in most cases.

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