GROUND MOTION SELECTION AND SCALING METHODS FOR SEISMIC DESIGN: EXISTING GUIDELINES AND THE WAY AHEAD

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INTRODUCTION

Seismic provisions in current model building codes and standards include rules for design of structures using nonlinear response-history analysis which are based, in large part, on recommendations for analysis of seismically isolated structures from more than 20 years ago. In Indian scenario, unfortunately, there is currently no consensus in the earthquake engineering community on how to appropriately select and scale earth-quake ground motions for code-based design and seismic performance assessment of buildings using nonlinear response-history analysis.

Ground motion selection provides the necessary link between seismic hazard and structural response, the first two components in Performance Based Earthquake Engineering (PBEE).[1] It determines input ground motion for a structure at a specific site for nonlinear dynamic analysis (i.e., response history analysis). As non-linear dynamic analysis becomes more common in research as well as in practice, there is a need for a clear guidance on appropriate ground motion selection methods. [2-4]

> **Ground motion selection provides the necessary link between seismic hazard and structural response.**

One common state-of-the-art practice in performance-based earthquake engineering is Incremental Dynamic Analysis that scales the same suite of ground motions up and down to cover a range of ground motion intensity levels. [5]

RESPONSE HISTORY ANALYSIS

Response history analysis is a form of dynamic analysis in which response of the structure to a suite of ground motions is evaluated through numerical integration of the equations of motions. In nonlinear response history analysis, the structure's stiffness matrix is modified throughout the analysis to account for the changes in element stiffness associated with hysteretic behaviour and P-delta effects.

Nonlinear response-history analysis is performed for a number of reasons, including:

- Designing new buildings, especially those equipped with seismic isolators or energy dissipation devices.
- Designing seismic upgrades of existing buildings per ASCE 41-17,[6] Seismic Rehabilitation of Existing Buildings (ASCE, 2017).
- Designing non-conforming framing systems in new buildings per ASCE 41-17.

- Assessing performance of new and existing buildings per ATC-58-1,[7] Seismic Performance Assessment of Buildings (ATC, 2011).

PERFORMANCE OBJECTIVES

Performance objectives are always associated with Non-Linear Time History Analysis (NLTHA) and Performance based Design (PBD) methods. ASCE 7-05 and ASCE 7-10,[8] specified that nonlinear response history analyses be performed using ground motions scaled to the design earthquake level and that design acceptance checks be performed to ensure that mean element actions do not exceed two-thirds of the deformations at which loss of gravity-load-carrying capacity would occur. [9]

In ASCE 7-16,[10] a complete reformulation of these requirements was undertaken to require analysis at the Risk-Targeted Maximum Considered Earthquake (MCER) level and also to be more consistent with the target reliabilities as shown in Table 1.

Table 1: Target Reliability (Conditional Probability of Failure) during an MCER Earthquake

Risk Category	Member Category	ASCE 7-10	ASCE 7-16
I or II	Critical	10%	10%
	Non-critical	25%	25%
III	Critical	6%	5%
	Non-critical	15%	15%
IV	Critical	3%	2.5%
	Non-critical	10%	9%

GROUND MOTION SELECTION

The selection and scaling of earthquake ground motions serves as the interface between seismology, thus, playing a key role in determination of seismic load to a structure. Ground motions are generally selected from previous recorded earthquake events or generated by physics-based simulations where there is a lack of appropriate recordings, such as large magnitude earthquakes at short site-to-source distances.

One of the most common concern of every designer is how many ground motions to be selected (3, 5, 7, 11, 22 or more).[11] Ground motions have different characteristics and there also exists record to record variability in structural response. ASCE 7-05 and ASCE 7-10 suggest to use of either three (or more) or seven (or more) appropriate ground motions for analysis. If 3 sets of ground motions were used and analyses were performed, then maximum value of peak response among three were used for component checking. If seven set of ground motions are used, then average value of the seven peaks is used for component checking. ASCE 7-16 the minimum number of motions is increased to 11. Larger number of motions is to properly identify the performance level of the structure that the structure is not allowed to shown unacceptable response in more than one motion; this would indicate that the structure fails to meet 10% target collapse reliability. However, this rule doesn't have statistical or technical basis, moreover to estimate mean response with confidence it requires goodness of fit of the scaled motion to the target spectral shape.

> **"The selection and scaling of earthquake ground motions serve as the interface between seismology and seismic design."**

Section of ground motions generally occurs in two steps. Step 1 involves factors such as Source Mechanism, Magnitude, Site Soil Conditions, Usable Frequency of ground motion, Period Sampling and Site to Source Distance. Step 2 involves evaluating the selected ground motion based on the Spectral Shape, Scale Factor and Motions from single event.

GROUND MOTION SCALING

Period Range for Scaling or Matching

A period range is needed to be determined which corresponds to the vibration period that significantly contribute to the building's lateral dynamic response. The period range for scaling of ground motions is selected such that the ground motions accurately represent the MCER hazard at the structure's fundamental response periods, periods somewhat longer than this to account for period lengthening effects associated with nonlinear response and shorter periods associated with a higher mode response.

In ASCE 7-05 and ASCE 7-10 ground motions were required to be scaled in between 0.2T to 1.5T, where T used to be the fundamental period of the structure in the fundamental mode for the direction of response being analysed. In ASCE 7-16 edition, the upper bound has been increased to 2.0T, where T is maximum fundamental period of building in both transitional direction and in torsion. Increment in upper bound to capture the increment in time period due to ductile frame structures.[12] For lower bound period of 0.2T, an additional requirement is put that it needs to capture 90% of mass participation in both the directions and T is redefined for lower bound as the smallest fundamental period among the two horizontal directions.

Two procedures for modifying ground motions for compatibility with the target spectrum are available: amplitude scaling and spectral matching.

Amplitude Scaling

Amplitude scaling consists of applying a single scaling factor to the entire ground motion record such that the variation of earthquake energy with structural period found in the original record is preserved. Amplitude scaling preserves record-to record variability; however, individual ground motions that are amplitude scaled can significantly exceed the response input of the target spectrum at some periods, which can tend to overstate the importance of higher mode response in some structures.

> "Amplitude scaling consists of applying a single scaling factor to the entire ground motion record"

Method adopted and requirements for amplitude scaling are shown in Table 2. It could be seen in Table 2 that conservatism is being removed in 2016 edition which arises due to average spectrum being greater than target spectra at every period with in the range.

SPECTRUM MATCHING

Spectral matching is introduced in 2016 edition of ASCE 7. In spectral matching shaking amplitudes are modified by differing amounts at differing periods, and in some cases additional wavelets of energy are added to or subtracted from the motions, such that the response spectrum of the modified motion closely resembles the target spectrum. Spectral matching captures the mean response but is incapable of preserving record to record response variability and velocity pulses in near field ground motions. So, it is recommended not to use spectrum matching for near fault sites. In spectral matching technique it's

Table 2: Amplitude Scaling Criteria's in American Standards

Code Edition	Method Adopted	Requirements for Amplitude Scaling
ASCE 7-05	SRSS	Average of SRSS spectra ≥ 1.3 times design response spectra for scaled period
ASCE 7-10	SRSS	Average of SRSS spectra ≥ design response spectra for scaled period
ASCE 7-16	Maximum directional spectrum	Average spectrum does not fall below 90% of the target spectrum in entire period range

> It is recommended not to use spectrum matching for near fault sites.

required to have each pair of ground motion scaled such that average of average of the maximum-direction spectra for the suite equals or exceeds 110% of the target spectrum over the period range of interest. This is more stringent requirement as compared to amplitude scaling so as to avoid lower prediction of mean response.

CONCLUSION

This paper provides guidance to professionals and basis of current guidelines of ASCE/SEI 7-16 on selection and scaling of ground motions for nonlinear response history analysis. This paper also shows modifications in previous editions of ASCE/SEI 7 and the technical basis of these changes.

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MAN MADE LAKE CAUSES STRANGE EARTHQUAKES IN SOUTH CAROLINA

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As per research, a man-made lake which was built over 40 years ago in the northwest of Columbia, South Carolina is causing multiple small earthquakes. South Carolina’s Lake Monticello has time and again recorded rare earthquakes solely owing to its man-made nature of existence. These earthquakes – though low in magnitude – are numbered in thousands which have startled geologists.

Something called reservoir-induced seismicity is the reason behind these quakes. It’s extremely rare, occurring at just a few man-made lakes around the world. It happens when the reservoir is built over rocks that have tiny fractures. The weight of the water forces it to down into those cracks, which builds up pressure until, ultimately, that pressure forces the rocks to move - and that is what creates an earthquake.