

Review on the selection of ground motion prescribed by seismic code recommendations

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ABSTRACT: The selection of ground motions can be developed on the basis of code provisions, and codes provisions are quite similar worldwide, for example, the main prescription is the compatibility with the design spectrum in a specified range of periods, and the minimum set size is typically from 3–7 records. Here, the provisions of the codes such as FEMA 456, Eurocode 8, and the Italian code NTC 2008 are mainly summarized.

INTRODUCTION

Geotechnical hazard evaluation requires analysis with respect to some level of shaking, design ground motion is herein adopted to describe a design level of shaking for which satisfactory performance is expected. Design ground motions are often expressed in terms of design spectra, and for sites that could be subjected to shaking from more than one seismic source, development of a design spectra can be complicated, under such circumstances, uniform hazard spectra is allowed, in which spectral ordinates are obtained by individual PSHAs, with proper consideration of all possible seismic source.

Ground motion parameters alone, on many occasions, cannot sufficiently describe the effects of ground shaking, and thus time histories of motion that match design response spectra or uniform hazard spectra within a period range of interest are required. Time histories that can be used are basically of three types: real, artificial and synthetic accelerograms, and the generation or selection of the records to match the reference spectrum has been controversially developed recently^[1-3].

The selection of ground motions can be developed on the basis of code provisions, and codes provisions are quite similar worldwide, for example, the main prescription is the compatibility with the design spectrum in a specified range of periods, and the minimum set size is typically from 3–7 records. Here, the provisions of the codes such as FEMA 456, Eurocode 8, and the Italian code NTC 2008 are mainly summarized^[4-6].

Seismic code recommendations

Eurocode 8

Eurocode 8 outlines the requirements for the selection of seismic input in sec.3.2.3: The seismic motion may be represented in terms of ground acceleration time-histories and depending on the nature of the application and on the information actually available, the description of the seismic motion may be made by using artificial accelerograms, and recorded or simulated accelerograms. For all these three types of accelerograms, the following selection criteria should be satisfied:

- A minimum of 3 accelerograms should be used;
- The mean of the zero period spectral response acceleration values (calculated from the individual time histories) should not be smaller than the value of a_{gS} for the site in question;
- In the range of periods between $0.2T_1$ and $2T_1$, where T_1 is the fundamental period of the structure in the direction where the accelerogram will be applied; no value of the mean 5% damping elastic spectrum, calculated from all time histories, should be less than 90% of the corresponding value of the 5% damping elastic response spectrum.

Specially, artificial accelerograms shall be generated so as to match the elastic response spectra for 5% viscous damping, and the duration of the accelerograms shall be consistent with the magnitude and other relevant features of the seismic event underlying the establishment of PGA hazard. When site-specific data are not available, for artificial accelerograms, the minimum duration T_s of the stationary part of the accelerograms should be equal to 10s.

For recorded accelerograms, the samples are required to have the seismogenetic features of the source and to the soil conditions at the site. Records need to be scaled to the peakground acceleration atop of soil layers ($a_g \cdot S$).

Simulated accelerograms, generated through a physical simulation of source and travel path mechanisms, should comply with the requirements for recorded accelerograms.

Eurocode assigns the spectral shape distinguishing between low and high magnitude events. For surface wave magnitude larger than 5.5, the spectral shape is expressed by:

$$0 \leq T \leq T_B : Se(T) = a_g \cdot S \cdot \left[1 + \frac{T}{T_B} \cdot (h \cdot 2.5 - 1) \right] \quad (1)$$

$$T_B \leq T \leq T_C : Se(T) = a_g \cdot S \cdot h \cdot 2.5 \quad (2)$$

$$T_C \leq T \leq T_D : Se(T) = a_g \cdot S \cdot h \cdot 2.5 \left[\frac{T_C}{T} \right] \quad (3)$$

$$T_D \leq T \leq 4s : Se(T) = a_g \cdot S \cdot h \cdot 2.5 \left[\frac{T_C T_D}{T^2} \right] \quad (4)$$

Where T is the vibration period of a linear SDOF; a_g is the design ground acceleration on type A site class; S is the soil factor; T_B, T_C are the limiting periods of the spectrum's plateau; T_D is the lowest period of the constant spectral portion; h is the damping correction factor, and it is equal to one for 5% viscous damping.

The spectral ordinates and shapes depend on the seismic hazard level as well as site class. The five site classes, based on the shear-wave velocity in the upper 30m range, are summarized in Table 1. The controlling parameters describing the elastic response spectra are shown in Table 2, and the resulting curves can be plotted as figure 1.

Table 1. Site classification based on the shear-wave velocity.

Site class	V_{s30} (m/s)
A-Rock or other rock-like geological formation	> 800
B-Deposits of very dense sand, gravel, or very stiff clay (stiff soil)	360-800
C-Deep deposits of dense or medium-dense sand, gravel or stiff clay (soft soil)	180-360
D-Deposits of loose-to-medium cohesionless soil (very soft soil)	<180
E-A soil profile consisting of a surface alluvium layer (Alluvional)	V_s values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with $V_s > 800$ m/s

Table 2. The controlling parameters of the elastic response spectra.

Site class	S-factor	TB (s)	TC (s)	TD(s)
A	1	0.15	0.4	2.0
B	1.2	0.15	0.5	2.0
C	1.15	0.2	0.6	2.0
D	1.35	0.2	0.8	2.0
E	1.4	0.15	0.5	2.0

It may be argued that the code spectrum represents a crude approximation of the uniform hazard spectrum, because the connection between the code spectrum and the seismic hazard is set anchoring the spectra to a_g values with a certain exceedance probability.

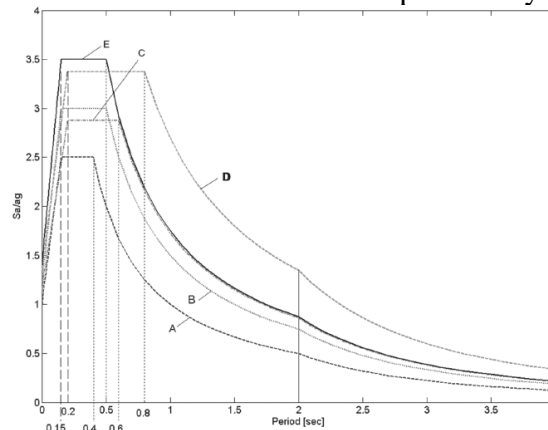


Figure 1 The design spectrum corresponding to different soil site classifications.

It may be argued that the code spectrum represents a crude approximation of the uniform hazard spectrum, because the connection between the code spectrum and the seismic hazard is set anchoring the spectra to a_g values with a certain exceedance probability.

Italian seismic code(NTC, 2008)

The NTC outlines the requirements for the seismic input for dynamic analysis in section 3.2.3.6, after specifying the elastic response spectrum. The signals that can be used for theseismic structural analysis can belong to the following three categories: artificial waveforms, simulated accelerograms, and natural records from real events. Artificial records should have duration of at least 10 seconds in their pseudo-stationary part, and they cannot be used in the assessment of geotechnical structures. Synthetic generated by simulation of earthquake rupture and propagation process should refer to a characteristics scenario for the site in terms of magnitude, distance and other source seismological characteristics; finally, real records should reflect the event dominating the hazard at the site.

The main condition to be satisfied by artificial records is that the average elastic spectrum (of the chosen set) does not underestimate the 5% damping elastic code spectrum, with a 10% tolerance, in the larger range of periods between $[0.15 \text{ s}, 2 \text{ s}]$ and $[0.15 \text{ s}, 2 T_1]$ for safety checks at ultimate limit state (T_1 is the fundamental period of the structure in the direction where the accelerograms will be applied) or in the larger period ranges between $[0.15 \text{ s}, 2 \text{ s}]$ and $[0.15 \text{ s}, 1.5 T_1]$, for structural safety checks at serviceability limit states. For seismically isolated structures, the code provides a narrow range of matching around the fundamental period, $[0.15 \text{ s}, 1.2 T_1]$, where T_1 is the equivalent period of the isolated structure.

Natural accelerograms or accelerograms generated through a physical simulation of source mechanism, travel, and path, may be used, provided that the samples used are adequately qualified with regard to the seismogenic features of the source and the soil conditions appropriate to the site. Selected real records have to be scaled to match the elastic response spectrum in range of periods of interest for the shaking of the structure.

NTC 2008 describes the spectral shape distinguishing between horizontal and vertical components of accelerograms. For the horizontal components, the elastic spectral shape is expressed by: (5)

$$0 \leq T \leq T_B : Se(T) = a_g \cdot S \cdot h \cdot F_0 \cdot \left[\frac{T}{T_B} + \frac{1}{h \cdot F_0} \left(1 - \frac{T}{T_B}\right) \right] \quad (5)$$

$$T_B \leq T \leq T_C : Se(T) = a_g \cdot S \cdot h \cdot F_0 \quad (6)$$

$$T_C \leq T \leq T_D : Se(T) = a_g \cdot S \cdot h \cdot F_0 \cdot \left[\frac{T_C}{T} \right] \quad (7)$$

$$T_D \leq T \leq 4s : Se(T) = a_g \cdot S \cdot h \cdot F_0 \cdot \left[\frac{T_C T_D}{T^2} \right] \quad (8)$$

For the vertical components, the elastic spectral shape is expressed by:

$$0 \leq T \leq T_B : Sve(T) = a_g \cdot S \cdot h \cdot F_v \cdot \left[\frac{T}{T_B} + \frac{1}{h \cdot F_v} \left(1 - \frac{T}{T_B}\right) \right] \quad (9)$$

$$T_B \leq T \leq T_C : Sve(T) = a_g \cdot S \cdot h \cdot F_v \quad (10)$$

$$T_C \leq T \leq T_D : Sve(T) = a_g \cdot S \cdot h \cdot F_v \cdot \left[\frac{T_C}{T} \right] \quad (11)$$

$$T_D \leq T \leq 4s : Sve(T) = a_g \cdot S \cdot h \cdot F_v \cdot \left[\frac{T_C T_D}{T^2} \right] \quad (12)$$

The Standards New Zealand (2004a)^[7]

The standard states in section 5.5.1 that: “The ground motion records shall be selected from actual records that have aseismological signature (i.e. magnitude, source characteristic (including faultmechanism) and source-to-site distance) the same as (or reasonably consistent with)the signature of the events that significantly contributed to the target design spectra ofthe site over the period range of interest. The ground motion is to have been recordedby an instrument located at a site, the soil conditions of which are the same as (orreasonably consistent with) the soil conditions at the site.”

FEMA 45

For both 2D analysis and 3D analysis, the following requirements in FEMA 450 should be matched:

- Appropriate acceleration histories shall be obtained from records of events having magnitudes, fault distance and source mechanisms that are consistent with those that control the maximum considered earthquake.
- A suite of not fewer than 3 appropriate ground motions shall be used in the analysis.
- Where the required number of appropriate recorded ground motion records are not available, appropriate simulated ground motion records shall be used to make up the total number required.

For 2D analysis, it is required that:

- Each ground motion shall consist of a horizontal acceleration history selected from an actual recorded event
- The ground motions shall be scaled such that for each period between 0.2 T and 1.5T, the average of the five-percent-damped response spectra for the suite of motions is not less than the corresponding ordinate of the design response spectrum.

For 3D analysis, on the other hand, certain provisions should be satisfied as following:

- Ground motions shall consist of pairs of appropriate horizontal ground motion acceleration components that shall be selected and scaled from individual recorded events
- For each pair of horizontal ground motion components, an SRSS spectrum shall be constructed by taking the square-root-of-the-sum-of-the-squares(SRSS) of the five-percent-damped response spectra for the components (where an identical scale factor is applied to both components of a pair)
- Each pair of motions shall be scaled such that for each period between 0.2T and 1.5 T the average of the SRSS spectra from all horizontal component pairs is not less than 1.3 times the corresponding ordinate of the design response spectrum.

In addition, some specific suggestions for input selections of accelerograms to be used in analyses are also provided, for example, in Part3, Section 3.4, several acceleration time-histories of rock motions, typically at least four, should be selected for site response analysis. These acceleration time-histories should be selected after evaluating the types of earthquakes sources, magnitudes, and distances that predominantly contribute to the seismic hazard at the site.

According to the above code provisions, the following selection criteria can be concluded:

- For accelerogram types, artificial accelerograms are accepted in Eurocode 8, while NEHRP 2003 gives preference to recorded accelerograms;
- Compatibility between selected time-histories and target response spectrum should be satisfied;
- Due to the probabilistic nature of seismic action, a number of records, with the minimum number from 3 to 7, are required;
- For the period range of interest, the lower limit (0.2T) accounts for higher modes of vibration, while the upper limit (1.5-2.0T) accounts for ‘softening’ of the structure due to inelastic response.

There are also certain limitations in the above codes, for example, the duration of the records are not directly mentioned in the code provisions, on the other hand, these codes take into account site effects by lumping groups of similar soil profiles together so that their provisions apply to broad ranges of soil conditions, within which the local conditions of a particular site are expected to fall, thus the accelerograms developed from code provisions are usually conservative.

CONCLUSIONS

The provisions of the codes such as FEMA 456, Eurocode 8, and the Italian code NTC 2008 are mainly summarized. Codes provisions are quite similar worldwide, for example, the main prescription is the compatibility with the design spectrum in a specified range of periods, and the minimum set size is typically from 3–7 records. There are also certain limitations in the codes, that is, the accelerograms developed from code provisions are usually conservative.

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