

# Codes in Structural Engineering Developments and Needs for International Practice

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Topic 1.2: Comparison of Codes

## AN INTERNATIONAL COMPARISON OF GROUND MOTION SELECTION CRITERIA FOR SEISMIC DESIGN

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**Abstract:** *The use of ground motion records in the seismic design of structures is becoming more widespread due to the increasing availability of ground motion record databases and improving computing power. When designing significant structures, such as tall and important buildings, irregular structures, or long-span bridges in areas of high seismicity, engineers are increasingly required to perform dynamic analysis in order to show that the structure will perform satisfactorily in code design basis and rare design seismic events. Depending on the building code and structure involved, the engineer might be required to perform one or a combination of many types of seismic analyses including response spectrum analysis, nonlinear pushover analysis, and linear or nonlinear response history analysis. Those types of analysis are typically performed using artificial and/or recorded ground motion records that are usually scaled and/or modified to match the code's design spectrum for the design event of interest. Different codes specify different and sometimes ambiguous guidelines and requirements on how the selection and matching of the design records are to be performed. The actual process followed is often a function of the individual interpretation of the seismologist or engineer, and is influenced by local common practice and the interpretations of building departments and peer review committees. In this paper, a survey of current code requirements and common practices in several countries, including the United States, China, the European Union, New Zealand and Taiwan, is presented. The intent of the paper is to present and compare the current code requirements and practices in these regions, and investigate similarities and differences, and opportunities for harmonization.*

## 1. INTRODUCTION

The use of ground motion data has been increasing worldwide due to several factors. These factors include the increasing availability of ground motion records due to increased instrumentation and dissemination, and increased interest from the earthquake engineering and education community in using linear and nonlinear response history analysis in seismic analysis and design.

Performance based design methodologies often require the use of linear and nonlinear dynamic analysis for buildings beyond code height limits and those not satisfying prescriptive requirements [1]. In seismic retrofit applications (e.g. ASCE-41 [2]), nonlinear time history analysis is frequently performed to determine the extent and effectiveness of required repairs. Special buildings such as base isolated buildings, hospitals and others may also require nonlinear time history analysis.

## 2. SEISMIC DESIGN AND GROUND MOTION USE IN THE UNITED STATES

In the United States, ASCE-7 “Minimum Loads for Buildings and Other Structures” is the primary document that is referenced by building codes for determining design seismic forces for buildings and other structures [3]. The following discussion will focus on the latest 2005 edition of ASCE-7, with some comments on the upcoming changes in the 2010 edition which is currently under preparation.

### 2.1 Code Design Response Spectrum

Seismic maps prepared by the United States Geological Survey (USGS) are used to construct design spectra corresponding to the MCE (Maximum Considered Earthquake) and DBE (Design Basis Earthquake) [4]. The probabilistic MCE earthquake is intended to have a probability of exceedance of 2% in 50 years (2475 year return period), while the DBE represents 10% in 50 years (475 year return period). The maps give spectral values at 0.2 second and 1 second respectively. The USGS maps are prepared by computing the seismic hazard at a large number of grid points covering the entire United States. The maps are prepared considering both deterministic and probabilistic hazard spectra.

Once the spectral values at 0.2 and 1 second are obtained from the seismic maps, these spectral values are used to define a response spectrum curve that is representative of a typical site on firm soil (site class B), using rules defined in Chapter 11 of ASCE-7. The spectrum is further modified by using soil modification factors (Site coefficients  $F_a$  and  $F_v$ ). The resulting spectrum represents the MCE. The DBE spectrum, which is the design basis for the majority of buildings, is computed as  $2/3 * MCE$ . When using the equivalent lateral static procedure, which is allowed for regular buildings below a certain height, the seismic design forces for a structure are determined from the design spectrum based on the structure's first mode period. The design forces are further modified by various factors including the importance factor (I), and response modification factor (R) which is a function of the lateral force system and material used.

## 2.2 Attenuation Relationships

The USGS uses attenuation relationships for various regions of the United States including those developed by the NGA (“Next Generation of Ground-Motion Attenuation Models”) project primarily for shallow crustal regions which covers the western United States (Chiou and Youngs, Bozorgnia and Campbell, and Boore & Atkinson) [5]. The NGA relationships are developed for the “geomean” (geometric mean) of the two horizontal components (GMIRot50, see [5]). However, the next edition of codes (ASCE-7 2010, NEHRP 2009) will use the maximum rotated component of the ground motion. Also, in the new code, when the site is close to fault, directionality will need to be considered in site specific ground motions by rotating the ground motion to Fault Normal (FN) and Fault Parallel (FP) components.

## 2.3 Site Specific (SS) Response Spectra

A site specific response spectrum is allowed to be developed for all sites and is required for soft soil sites and for certain types of buildings (base-isolated or with supplemental damping). The site specific MCE spectrum is developed by taking the minimum of the probabilistic response spectrum computed using probabilistic seismic hazard analysis of the site (2% in 50 years), and 150% of the deterministic spectrum for the largest possible magnitude on the governing fault for the site. The resulting site specific spectrum shall not be smaller than 80% of that obtained using the code maps. In areas of very high seismicity, such as California, the resulting MCE earthquake may have a return period that can sometimes be significantly less than 2475 years, because the deterministic upper limit typically controls. After the MCE is obtained, the DBE is computed as 2/3 times the MCE.

## 2.4 Code Requirements for Selection and Scaling of Ground Motion Records

Chapter 16 of ASCE-7 specifies the criteria by which records are selected and scaled. A minimum of three records or pairs of record components (for three-dimensional analysis), with magnitude and distance similar to the event controlling the hazard at the site are required for dynamic analysis. For two-dimensional analysis, single ground motion components should be selected such that the average spectrum of all selected motions does not fall below the code design spectrum (typically the DBE) at any period over the required matching period range. For three-dimensional analysis, pairs of ground motion components should be selected such that the spectrum representing the average of the SRSS spectra of all of the pairs does not fall below 1.3 times the design spectrum by more than 10%, at any period over the required matching period range. The selection of the ground motions may be performed by either scaling or spectral matching of the records to the target spectrum.

The matching of the spectrum is performed over a period range extending from  $0.2T_1$  to  $1.5T_1$ , where  $T_1$  is the building’s period in the first mode. Different matching period ranges apply for base isolated buildings and buildings with supplemental damping.

## 2.5 Methods of Ground Motion Selection and Scaling

While the code specifies the acceptance criteria for the selected records, the details of the method of selection are left to the user. A number of different methods for the selection and scaling of ground motion records have been proposed over the years, some of which may

not be in full agreement with code criteria. The methods vary from scaling the ground motion to a single period on the target spectrum, to average matching over a period range [3], to more complex operations involving more advanced selection algorithms and/or modification of the ground motion records to match a target spectrum. Recently, a number of selection methods were proposed and evaluated by a group of researchers working through the Pacific Earthquake Engineering Research Center (PEER) [6]. Another approach to selection of ground motions involves the modification of recorded or simulated ground motion records to match a target design spectrum. The transformation can be performed in the time domain [7] or in the frequency domain [8], with the former being preferred because it introduces less artificial frequencies, and results in ground motion records that appear to be more realistic. Other than fault normal and fault parallel (in the future code), records are generally not required to be rotated, although some engineers choose to apply pairs of ground motion records at two or more different rotations.

## 2.6 Number of Motions and Interpretation of Analysis Results

A minimum of three ground motions is required for dynamic analysis. The structure is analyzed for the suite of ground motions and designed for the maximum response to all records in the suite. If seven or more ground motions are used in the analysis, the average of the response of all motions can be used instead. However, some components need to be designed for the maximum value, and some designers choose to design for higher values in some cases even when not required by code. For example, some designers use values higher than the mean (84 percentile, 150% or other) when designing for critical modes of behavior, such as designing for higher shear forces in reinforced concrete shear walls in order to prevent shear failures [9].

## 2.7 Current Practice and Future Trends

A limited survey of recently designed high-rise buildings using Performance Based Design methodologies revealed that spectral matching, where the frequency content of the ground motion is modified to match the target spectrum, is more widely used than simple scaling [9]. The national regulations including ASCE-7 (2010 edition) are currently undergoing some major changes that affect seismic force levels and the selection and use of ground motions, including the move to risk targeted design spectra, and the specification of maximum rotated accelerations as opposed to currently used geometric based accelerations.

# 3. SEISMIC DESIGN AND GROUND MOTION USE IN CHINA

## 3.1 Earthquake Return Periods

The design earthquake return periods specified by GB50011-2001 “Code for Seismic Design of Buildings” [10] are as follows:

**Minor earthquake (return period: 50 years):** The structure shall continue to be in service without damage and will not require any repair.

**Moderate earthquake (return period: 475 years):** The structure shall continue to be usable with minor damage. It may require a simple repair or may not need any repair.

**Major earthquake (return period: 2000 years):** The structure shall not collapse or experience severe failure.

### 3.2 Site effects

A comprehensive evaluation of seismic, geological and seismo-geological conditions should be performed to identify the site as suitable, not suitable or hazardous. Factors such as topography, vicinity to active faults, landslide potential, liquefaction and subsidence should be included in the evaluation.

### 3.3 Design Earthquake

In GB50011-2001, the design earthquake parameters  $\alpha_{max}$  and peak ground acceleration  $A_g$  are functions of the seismic intensity  $I$  and characteristic period of the soil  $T_g$ , and are determined from the “Seismic Ground Motion Parameter Zonation Map of China (2001)” or by the authorized seismic microzonation maps.

Earthquake microzonation is based on hazard studies of the region. Several important factors, such as the seismicity, seismogeology and attenuation laws of ground motion should be taken into account. The seismic intensity, as well as the effective peak acceleration  $A_g$  and the characteristic period  $T_g$  of response spectra are used by GB50011.

### 3.4 Response Spectra For Seismic Design

The response spectra adopted by GB50011 are shown in Figure 1 and described with:

$$\gamma = 0.9 + \frac{0.05 - \zeta}{0.5 + 5\zeta} \quad (1)$$

$$\eta_1 = 0.02 + (0.05 - \zeta) / 8 \quad (2)$$

$$\eta_2 = 1 + \frac{0.05 - \zeta}{0.06 + 1.7\zeta} \quad (3)$$

Where  $\gamma$  is the factor that describes the descending ratio of the spectral curve between  $T_g$  and  $5 T_g$ ,  $\eta_1$  is the slope of the straight line of the response spectral curve in the periods of  $5 T_g$  to  $6.0s$ ,  $\eta_2$  is the adjustment factor for a given damping ratio  $\zeta$ . The values of  $\alpha_{max}$  and  $A_g$  are provided in the code for the minor earthquake as given in Table 1 below:

Table 1: The Intensity  $I$ , Peak Acceleration  $A_g$  and Earthquake coefficient  $\alpha_{max}$

Seismic Intensity $I$	6	7		8		9
Earthquake Zone	I	II <sub>a</sub>	II <sub>b</sub>	III <sub>a</sub>	III <sub>b</sub>	IV
Peak Acceleration $A_g(g)$	0.018	0.036	0.056	0.071	0.112	0.143
Earthquake Coefficient $\alpha_{max}$	0.04	0.08	0.12	0.16	0.24	0.32

The characteristic period  $T_g$  of response spectra is related to the site condition and epicentral distance of earthquake, and may influence the calculated seismic effects of structures with longer natural periods.

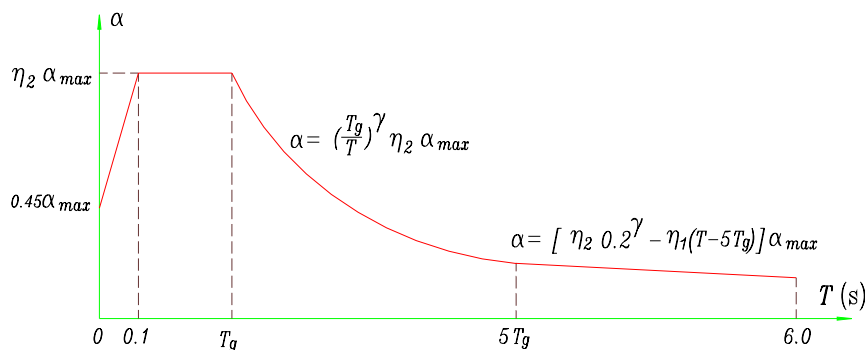


Figure 1: Response Spectra suggested by GB50011-2001

### 3.5 Time History Analysis

Time history analysis should be performed for high-rise buildings, buildings with high performance demands, and structures with very irregular configurations as well, to evaluate structural capacity of strength and deformation for the minor earthquake level and to calculate the nonlinear deformation for the major earthquake. It is recommended that for base-isolated buildings, the time history analysis be applied by using the simplified lumped mass shear model.

### 3.6 Earthquake Ground Motions for Time History Analysis

In GB50011-2001, at least two measured earthquake ground motion records and one simulated ground motion are generally required as earthquake inputs for time history analyses. The selection of real earthquake records and the simulation of ground motion should be applicable to the local site condition, seismic intensity and environment of the site. For time history analysis, the average of the spectra of the ground motions used should be statistically compatible with the design spectrum specified by the code. It is required that the ordinates of the response spectrum of each selected record shall not be 10% below the design spectrum at three fundamental periods of the target structure. Besides, for the elastic time history analysis, the base shear force calculated with an individual acceleration history shall be above 65% of that calculated by the code response spectrum analysis; the average base shear force calculated from the selected and simulated earthquake inputs shall be above 80% of that calculated by the code response spectrum analysis.

For super high rise and very irregular buildings, 2-D or 3-D structural models should be adopted and at least 5 real earthquake records and 2 simulated time histories of the ground motion should be used as the input for time history analyses

## 4. SEISMIC DESIGN AND GROUND MOTION USE IN NEW ZEALAND

In New Zealand, the guiding document for the seismic design of structures is NZS 1170.5:2004 [15], which defines site hazard spectra based on seismic hazard mapping obtained from a probabilistic hazard model.

### 4.1 Code Design Response Spectrum and Probabilistic Seismic Hazard Model

The elastic site spectra for New Zealand have been derived from results of a probabilistic seismic hazard model [17]. The seismic-source component of the model incorporates 305 active faults and a grid of distributed-seismicity sources with parameters estimated from a catalogue of historical earthquakes. This has been used in conjunction with attenuation expressions for crustal earthquakes and for subduction zone earthquakes that have been modified from overseas models, to better fit New Zealand strong-motion earthquake data [12].

The elastic site spectrum for horizontal loading,  $C(T)$ , is defined as:

$$C(T) = C_h(T) Z R N(T, D) \quad (4)$$

Where,  $C_h(T)$  corresponds to the spectral shape factors for each of the site subsoil classes, that are normalized by the codified peak ground acceleration for rock. The hazard factor  $Z$  is a mapped quantity calculated using the probabilistic seismic hazard model that when multiplied by  $C_h(T)$  produces the code representation of the 500-year spectrum for the location and site conditions, neglecting near-fault effects. The return period factors  $R$  are the multiplication factors required to produce the code representations of the spectra for return periods other than 500 years, as required for the serviceability limit state or for the ultimate limit state for various combinations of function category and design working life. The near fault factor,  $N(T, D)$ , accounts for systematic near-fault effects that may modify the long-period spectral ordinates, and are not included in the standard hazard analysis used to derive the  $Z$  and  $C_h(T)$ . The  $N(T, D)$  factor takes a value different from 1 only when the shortest distance ( $D$ ) from the site to one of New Zealand's most active faults listed in the Standard is less than 20 km, and then only for periods ( $T$ ) greater than 1.5 s [16].

### 4.2 Selection and Scaling of Ground Motion Records

NZS 1170.5:2004 specifies that ground motion record selection for time-history analysis should use actual records having a seismological signature the same as (or reasonably consistent with) the signature of the events that significantly contributed to the target design spectra of the site over the period range of interest. The ground motion is to have been recorded by an instrument located at a site, the soil conditions of which are the same as (or reasonably consistent with) the soil conditions at the site. NZS 1170.5:2004 also requires that at least three records must be considered for time-history analysis, and the most disadvantageous response must be considered for design. NZS 1170.5:2004 uses two scaling factors: the record scale factor ( $k_1$ ) and the family scale factor ( $k_2$ ). The record scale factor ( $k_1$ ) minimizes the difference between recorded and target response spectrum in a least mean square sense over the period range between  $0.4 T_1$  and  $1.3 T_1$ . The family scale

factor ( $k_2$ ) is applied to ensure that the energy in the spectrum of at least one record of the set exceeds the energy of the target spectrum.

### 4.3 Current Practice and Future Trends

Currently each project that considers time-history analysis requires a specific study to define the most appropriate set of records for the particular seismological signature at this location. Recently a criterion was developed [14] for the selection of ground motion records for time-history analysis of buildings, a seismic hazard zonation was defined based on this selection, and specific suites of records for the different zones and soil classes were recommended. Five zones in the North Island and six zones in the South Island of New Zealand were defined. Sets of seven records were selected and in all zones, the selection of more than one record from a single earthquake was avoided. The reason for selecting seven records instead of the three records recommended in NZS 1170.5:2004 was related to recent studies ([11], [13]) that revealed that the option of using the average response of seven records instead of the maximum response of three records improves the performance of the method, because it eliminates the influence of specific ground motions and offers a lower dispersion of the response parameters used for design.

## 5. SEISMIC DESIGN AND GROUND MOTION USE IN EUROPE

In Europe, the national standards of all CEN (European Committee for Standardization) member states are based on the European standard Eurocode 8: Design of structures for earthquake resistance. Eurocode 8 is one standard within the family of nine Eurocode standards which represent a set of harmonized technical rules for the design of construction works. The National Standard Organizations of the following countries are bound to implement all Eurocode standards: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom. In all countries, Eurocodes shall be given the status of National Standards, either by publication of an identical text or by endorsement, and conflicting national standards shall be withdrawn at latest by March 2010. The following discussion will focus on the requirements of Eurocode 8, which has 6 parts. Ground motion is defined in Part 1: General rules, seismic actions and rules for buildings [18].

### 5.1 Code Design Response Spectrum

The hazard is described in terms of the reference peak ground acceleration on type A ground,  $a_{gR}$ . This value may be derived from zonation maps found in the country's national Annex. The reference peak ground acceleration, chosen by the National Authorities for each seismic zone, corresponds to the reference return period  $T_{NCR}$  of the seismic action for the no-collapse requirement (or equivalently the reference probability of exceedance in 50 years,  $P_{NCR}$ ) chosen by the National Authorities. The recommended values are  $P_{NCR} = 10\%$  and  $T_{NCR} = 475$  years. An importance factor  $\gamma$  equal to 1 is assigned to this reference return period. For return periods other than the reference, the design ground acceleration on type



A ground  $a_g$  is equal to  $a_{gR}$  times the importance factor  $\gamma_I$ . For the damage limitation limit state, the recommended values are  $P_{DLR} = 10\%$  (in 10 years) and  $T_{DLR} = 95$  years.

The earthquake motion at a given point on the surface is represented by an elastic ground acceleration response spectrum, called “elastic response spectrum”. The absolute spectral values are controlled by the design ground acceleration. The shape of the elastic response spectrum is taken as being the same for the no-collapse requirement (ultimate limit state – design seismic action) and for the damage limitation requirement. In Eurocode 8, expressions are provided for the shape of the elastic response spectrum  $S_e(T)$  both for the horizontal and vertical components of the seismic action. The values of the parameters describing the shape of the elastic response spectrum depend upon the ground type. These values are provided in National Annexes. Two types of spectra are recommended, depending on the magnitudes of earthquakes that contribute most to the seismic hazard defined for the site. Recommended values for all parameters for both types of spectra for different ground types are provided In Eurocode 8.

The design spectrum is obtained from the elastic response spectrum based on no collapse by using the reduction factor  $q$ , which is in Eurocode 8 called “behaviour factor”.

## 5.2 Attenuation Relationships

No specific attenuation relationships (recently called also GMPEs – Ground Motion Prediction Equations) are prescribed or recommended in Eurocode 8. The European ground motion database [19] is still relatively small. Some GMPEs based on European database exist. One of the most recent ones was proposed by Akkar and Bommer [20]. There are some indications ([21], [22]) that the new NGA GMPEs can be used also in Europe.

## 5.3 Site Specific (SS) Response Spectra

Depending on the importance class of the structure and the particular conditions of the project, ground investigations and/or geological studies should be performed to determine the seismic action. The conditions under which ground investigations additional to those necessary for design for non-seismic actions may be omitted and default ground classification may be used are specified in National Annexes.

## 5.4 Ground Motion Records

The seismic motion may also be represented in terms of ground acceleration time-histories and related quantities (velocity and displacement). When a spatial model of the structure is required, the seismic motion shall consist of three simultaneously acting accelerograms. The same accelerogram may not be used simultaneously along both horizontal directions.

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. Artificial accelerograms shall be generated so as to match the elastic response spectra for 5% viscous damping. The duration of the accelerograms shall be consistent with the magnitude and the other relevant features of the

seismic event underlying the establishment of  $a_g$ . When site-specific data are not available, the minimum duration  $T_s$  of the stationary part of the accelerograms should be equal to 10 s. Recorded accelerograms, or accelerograms generated through a physical simulation of source and travel path mechanisms, may be used, provided that the samples used are adequately qualified with regard to the seismogenic features of the sources and to the soil conditions appropriate to the site, and their values are scaled to the value of  $a_g.S$  for the zone under consideration.

The suite of accelerograms should observe the following rules:

- a) a minimum of 3 accelerograms should be used;
- b) the mean of the zero period spectral response acceleration values (calculated from the individual time histories) should not be smaller than the value of  $a_g.S$  for the site;
- c) in the range 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% damped code elastic response spectrum.

While the code specifies the acceptance criteria for the selected records, the details of the method of selection and of the interpretation of results are left to the user.

### **5.5 Current Practice and Future Trends**

Time-history analyses, where the accelerograms are needed, are rarely used in practice, with exception of very important structures. Spectral matching, where the frequency content of the recorded ground motion is modified to match the target spectrum, appears to be the most widely used approach for the determination of accelerograms. Sets of recorded accelerograms are also used. The author is not aware of applications of artificial or generated accelerograms.

## **6. SEISMIC DESIGN AND GROUND MOTION USE IN TAIWAN**

The current 2005 edition of the seismic building code in Taiwan (Code'05) [23] tabulates the spectral values at 0.2 and 1 seconds for both the MCE (2%/50yrs) and DBE (10%/50yrs) for all the townships. These values are determined from the probability procedures, and require further modifications for a given site by considering the site soil condition and the near fault factors determined from the deterministic procedures. Then, similar to the procedure described in Section 2.1 of this paper, 5% damped smooth MCE or DBE design response spectrum can be constructed. When using the static lateral force procedure, the design base shear is determined from response spectrum based on the structure's fundamental vibration period in the considered direction. The design forces are further modified by a response modification factor which is a function of lateral force resisting system, the level of excitations (DBE or MCE) and the aforementioned vibration period [24]. In addition to the equivalent static force procedure, the use of SRSS or CQC rule in the response spectrum method in determining the seismic design forces are rather common. In this approach, the aforementioned modified DBE or MCE spectra are often used and the

elastic dynamic responses are scaled accordingly to a level that the dynamic base shear is equal to 90% of the equivalent static base shear for a regular structure. Nonlinear response history analysis is not specifically required in the current Code'05 for fix-based building structures. However, it has been frequently adopted to evaluate the system performance and the possible nonlinear demands on members or connections of the structures under the DBE or MCE as exemplified in the reference [25].

### **6.1 Selection and Scaling of Ground Motion Records**

The Chapter 3 of Code'05 outlines the criteria on how ground motion records are selected and scaled. No fewer than three response history analyses shall be performed. Each input ground motion record is required to have a magnitude, fault distance, and source mechanisms that are consistent with the controlling design earthquake. The final selections of the ground motions may be adopted by either scaling or spectral matching of the records to the aforementioned DBE or MCE smoothed design spectrum [25]. The most common scaling method is as follows. If  $T_1$  is the fundamental vibration period of the building in the considered direction, the historical ground motions shall be scaled such that the associated 5% damped spectral accelerations between the period range from  $0.2T_1$  to  $1.5T_1$  satisfy: (1) any spectral acceleration of the given ground motion shall be greater than 0.9 times that of the design response spectrum; and (2) the average of response spectrum from the scaled motion does not fall below the target design response spectrum. Each selected ground motion shall be applied along each considered direction. In the current Code'05, there is no clear requirement on performing the horizontal bi-directional response history analysis. In addition, there is no separate ground motion selection or scaling procedure for base isolated buildings and buildings with supplemental damping. In Taiwan, special building structures are subjected to review. The review committee usually recommends the selection of ground motions that include scaled historical ground motions, and not just simulated ground motions matching the smooth design spectrum.

## **7. COMPARISON AND SUMMARY**

Seismic design criteria and ground motion selection methods from five different world regions were presented and compared. An examination of the different code requirements uncovers some interesting similarities as well as differences. Table 2 summarizes various requirements and observations from the different codes.

From the following table and the prior discussions, it appears that while there are some obvious differences, particularly in the way design forces and response spectra are defined, the approaches for selection and usage of ground motion records follow a common methodology, with some minor differences. Response-history analysis is rarely used in practice, so the code provisions for this type of analysis are sometimes vague and some decisions are occasionally left to the designer. The codes in all 5 regions require a minimum of 3 ground motion records, and use similar selection and scaling requirements.

The period range for matching varies slightly with the European code having the strictest fitting requirement and New Zealand having the least restrictive. All codes seem to allow ground motion modification using spectral matching, and simulated ground motions appear to be generally accepted.

Table 2: Comparison of seismic requirements in different world regions

Criteria	USA	China	Europe	New Zealand	Taiwan
Minor Earthquake		50 years	95 years		30 years
Moderate Earthquake	475 years	475 years	475 years	500 years	475 years
Major Earthquake (MCE)	2475 years	2000 years		2500 years	2475 years
Seismic Design Basis Spectrum	DBE = (2/3)*MCE	50 years	475 years	500 years	475 years
Response Modification Factor (R, q, etc)	R	-	q	R, N, Z	R
Minimum Base Shear from linear dynamic analysis	85%	65% for individual gm; 80% for avg of all gm	No provision	80%	90%
Minimum Number of ground motions	3	3 (5 for special structures)	3	3	3
Interpretation of dynamic analysis results	Average response if $\geq 7$ records, otherwise peak	Average response if $\geq 7$ records, otherwise peak	No guidelines	Maximum response of 3 records or more	Maximum response of 3 records or more
Matching single-component	$S_{a_{avg}}$ for all gm > target	$S_a$ for each gm > $0.9*target$	$S_{a_{avg}}$ for all gm > $0.9*target$	Minimize difference between each gm and target	$S_a$ for each gm > $0.9*target$ . $S_{a_{avg}}$ for all gm > target
Matching two-horizontal components	Average of all gm SRSS > $0.9*1.3*target$ over matching periods	Match each component individually	Match each component individually	Match each component individually	Match each component individually
Matching Periods	$0.2T_1-1.5T_1$	$T_1, T_2, T_3$	$0.2T_1-2T_1$	$0.4T_1-1.3T_1$	$0.2T_1-1.5T_1$
Artificial Records Allowed	Yes	Yes	Yes	No	Yes
Spectral Matching Allowed	Yes	Yes	Yes	Yes	Yes

The period range for matching varies slightly with the European code having the strictest fitting requirement and New Zealand having the least restrictive. All codes seem to allow ground motion modification using spectral matching, and simulated ground motions appear to be generally accepted. This is particularly important in regions where the availability of ground motion records may be limited. Consideration of bi-directional effects is not uniformly stated in all codes, and the maximum considered earthquake (MCE) is missing from the European code. Additionally, near fault effects are generally not addressed, with the exception of the US and New Zealand codes.

While the design response spectrum definitions vary slightly between the considered codes, the response spectrum approach is still the main approach in all codes worldwide, and most use a design-basis ground motion with a return period of around 500 years. There are also many similarities in the requirements for ground motion selection among the various codes. Hence, there appears to be an incentive for further harmonization between the various codes, and the authors encourage a move towards a more uniform approach in ground motion selection and scaling.

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