EQUIPMENT DEMAND SPECTRUM FOR ESSENTIAL BUILDING APPLICATIONS

J. Gatscher(1), S. Littler(2)

(1) *Fellow Engineer, Schneider Electric, Power Products Division, jeff.gatscher@se.com*
(2) *Principal Technical Expert, Schneider Electric, Energy Management Business, scott.littler@se.com*

Abstract

Every country or regional building code that contains earthquake protection provisions will include an earthquake design response spectrum option for building structure design. This building design spectrum (BDS) is used when designing infrastructure to resist earthquake demands and is the foundation for creating equipment testing requirements. The goal of this paper is to introduce the concept of a nonstructural equipment demand spectrum (EDS) that is used to establish seismic qualification requirements for equipment for any regional code or seismic design standard that contains BDS requirements for structures. A generic EDS is developed based on common elements contained in codes and standards that include earthquake protection provisions for building structures.

The generic EDS is constructed considering peak response and zero period response from country/region-specific building code BDS shape profiles. Code defined BDS soil classifications are utilized in the assessment. In addition, the EDS must consider the default code assumptions regarding earthquake hazard map probability of exceedance. Lastly, the EDS must include provisions to account for building amplification effects for equipment installations located above grade elevation. The net result is a broadband EDS shape profile that is directly linked with individual country/region code provisions. The EDS spectrum is applied during shake-table testing using random, multifrequency excitation to account for the random nature of earthquake demands. The EDS is equivalent to a generic building floor spectrum. To demonstrate the concept, EDS shape profiles are constructed for ten country/region code provisions including, Argentina, Australia, Canada, Chile, Europe, Japan, New Zealand, Peru, Taiwan and United States of America.

There is a compelling need to standardize equipment qualification practices for essential building applications such that equipment capacity can be a transparent metric universally applied. Constructing a generic EDS using common elements of regional BDS shape profiles will establish the needed objective measure for nonstructural equipment qualification. It is believed that with a clear understanding of the principles involved, there will be a well-defined path forward to establish consensus guidelines that can be globally implemented.

Keywords: nonstructural equipment testing; building floor spectrum, seismic certification; global earthquake demands

1. Introduction

Nonstructural equipment installations are composed of two design elements: (1) equipment supports and attachments and (2) equipment items. Fig. 1 displays a pictorial diagram representing typical equipment installations highlighting the distinction between supports, attachments and equipment items.

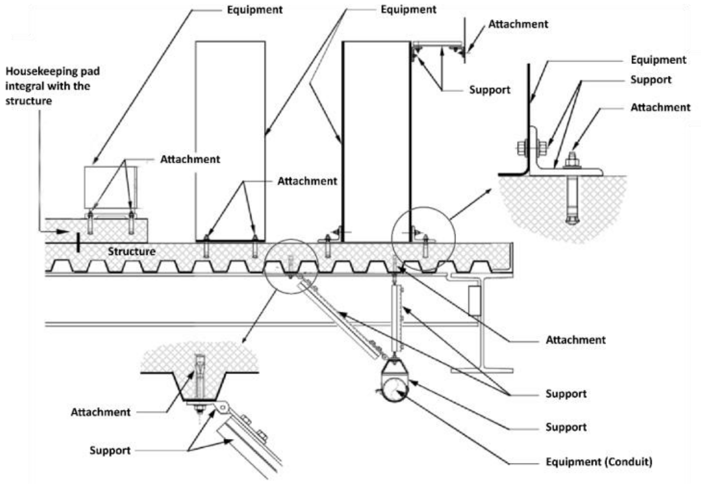

Fig. 1 – Pictorial of equipment elements comprising typical equipment installations

Country-specific and regional building codes establish minimum earthquake protection requirements for building structures and the mechanical and electrical equipment that service buildings to make a building functional. Certain buildings are classified as essential infrastructure and thus require a higher level of performance to resist earthquake demands. The mechanical and electrical systems servicing essential buildings have a higher level of conformance expectations compared to the systems contained in non-essential infrastructure. Building codes use the concept of an equipment importance factor to designate which equipment inherit a higher level of performance requirements to resist earthquake demands. The modern-day trend for seismic conformance of equipment items in designated seismic systems is qualification via shake-table testing to validate post earthquake equipment functionality.

Modern-day code provisions provide both a base shear force equation and response spectrum option for building structure design. Today, however, building codes do not include a response spectrum option for equipment qualification testing and only include lateral and vertical force equations that are used to properly size equipment supports and attachments. Thus, the need is to establish a generic equipment demand spectrum (EDS) that is used for equipment item qualification via the seismic shake-table testing method.

On the surface, country and regional codes appear quite different and thus the premise has been these codes must be inherently different, which makes conformance assessment a task relegated to local experts on a country-by-country basis. Fundamentally, all seismic design codes and standards that contain provisions for earthquake resistance are formulated using the same earthquake engineering principles. There is great similarity between regional codes and standards, and this similarity provides the impetus to construct an equipment qualification methodology that can be universally applied.

Every country building code or seismic standard that contains an earthquake response spectrum for essential infrastructure can be used to develop an equipment demand spectrum (EDS) for qualification testing of equipment. The EDS is an objective measuring stick used to transform seemingly disparate regional requirements into transparent equipment test requirements that ties the codes together. Using regional code building design spectra, soil type classification factors, and building amplification we arrive at a seismic EDS level for a given code's prescribed earthquake hazard. The net result is generation of well-defined EDS compliance profiles for country-specific and regional building codes. Table 1 identifies the building codes reviewed herein.

Table 1 – List of Country/Region Building Codes and Seismic Standards

Country / Region	Code Reference ID	Code Revision Year
Argentina	INPRES-CIRSOC103	1991 [1]
Australia	AS 1170.4-2007 (R2018)	2018 [2]
Canada	2015 NBCC	2015 [3]
Chile	NCh 433.Of1996	2012 [4]
Europe	Eurocode 8 EN1998-1	2004 [5]
Japan	Building Standard Law	2016 [6]
New Zealand	NZS 1170.5:2004+A1	2016 [7]
Peru	N.T.E. - E.030	2016 [8]
Taiwan	CPA 2011 Seismic Design Code	2011 [9]
USA	ASCE/SEI 7-10	2010 [10]

2. Building Design Spectra

The building design response spectrum shape is typically defined in terms of seismic factors related to ground motion intensity and soil classification parameters. In some cases, there may be other factors used that are not related to ground motion. The other factors might include building importance factor or building structure response modification factor. The key is to isolate the factors that control ground motion intensity. Ground motion factors are associated with each code's earthquake hazard map. Fig. 2 highlights several building design response spectrum plots for different countries' building codes. The factors influencing these ground motion spectra plots need to be explored.

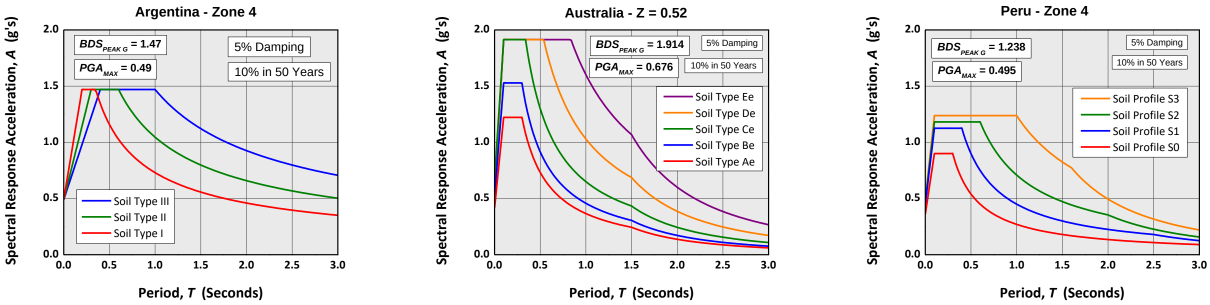

Fig. 2 – Building design response spectrum plots from various country-specific building codes

2.1 Prescribed Hazard Maps

The study of earthquake induced ground motion has evolved into a sophisticated science with the core objective to provide hazard maps that associate geographic location with earthquake hazard risk. In the generation of hazard maps, there are theoretical uncertainties that get adopted and geopolitical considerations that are applied as well. Thus, as earthquake science evolves and improves the hazard maps are revised to reflect current state knowledge. The resulting byproduct is a geographic hazard map that relates the probability of earthquake ground motion intensity with geographic location.

The most common type of earthquake hazard map implemented globally is a uniform hazard map, also known as a zonal system map. Zonal system maps break down a country's geography into a limited number of "seismic zones." Typically, the number of discrete zones ranges from three to six zones depending on the size and relative seismicity of the country. Within each seismic zone a uniform seismic ground motion intensity factor is assigned, and thus all geographic locations within the zone boundary will all assume the same seismic factor value.

Areas within a country that experience greater seismic events are assigned a higher factor inside a seismic zone boundary. Areas within a country that experience less seismicity are assigned a lower factor. The primary drawback of a zonal map is there is no distinction between geographic locations within the zone boundary. Thus, the entire zone is assigned a uniform hazard value, irrespective of a location's proximity to known sources of seismicity.

As an improvement to the zone system, the concept of PSHA (probabilistic seismic hazard analysis) was developed to implement better attenuation relationships by considering the influence of proximity to known sources of seismicity and the probability of occurrence. The byproduct of PSHA is a continuously variable earthquake ground motion intensity factor that is dependent on geographic coordinates (i.e., latitude-longitude coordinates). Every geographic location within a country or region has a unique hazard value. Fig. 3 displays the PSHA hazard maps for the U.S., Canada and Europe. Continuously variable PSHA maps require the use of databases of the hazard parameters based on a grid of latitude-longitude coordinates. The PSHA method can also be used to support micro-zonation maps that define hazard levels for municipalities and regions within a given country. This later method of prescribing the earthquake hazard at the municipality level is typically done by referencing a table that lists municipality and prescribed hazard value.

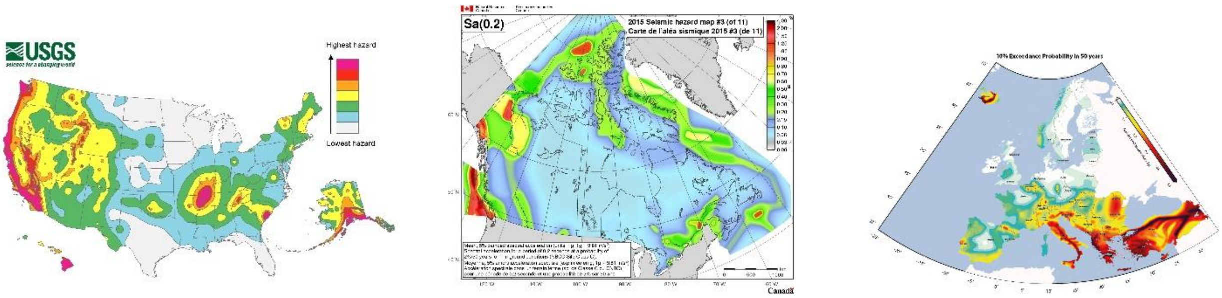

Fig. 3 – Seismic hazard maps using PSHA lat/lon discretization from regional building codes.

All ground motion hazard maps are related to a defined level of earthquake probability of exceedance. Since not all hazard maps are using the same probability level, this concept needs to be reviewed such that all stakeholders are clear on a code's default assumptions.

2.2 Probability of Exceedance

Whether the earthquake hazard map is defined using zonal boundaries, micro-zones or is continuously variable, the concept of exceedance probability and earthquake return period are key concepts that influence code prescribed hazard levels. For any given hazard map, the geoscientists calculate the ground motion effect (peak acceleration) at a geographic site for all the earthquake locations and magnitudes believed possible in the vicinity of the site. Each of these magnitude-location pairs is believed to happen at some average probability per year. Small ground motions are relatively likely, large ground motions are very unlikely. Beginning with the largest ground motions and proceeding to smaller, the probabilities are added up until arriving at a total probability corresponding to a given probability, *P*, in a particular period of time, *T*.

The probability *P* comes from ground motions larger than the ground motion at which they stopped adding. The corresponding ground motion (peak acceleration) is said to have a *P* probability of exceedance in *T* years. The map contours or zonal boundaries are the ground motions corresponding to this probability at all the sites for a given hazard map. Thus, a given hazard map is not actually a probability map, but rather a ground motion hazard map at a given level of probability.

The following are the most common combinations of probabilities and periods of exceedance implemented in global seismic codes:

1.) *2% Probability of Exceedance in 50 Years* – This is used to define a more conservative hazard map compared to the other probability of exceedance levels. This equates to approximately a 0.000404 probability of exceedance per annum. The associated earthquake return rate is defined as one over the probability of exceedance per annum. Thus, the earthquake return rate is 2,475 years. Which is defined as the ground motion intensity with a uniform probability of being exceeded at least once in 2,475 years.

2.) *5% Probability of Exceedance in 50 Years* – This equates to approximately a 0.001 probability of exceedance per annum. Thus, the earthquake return rate is 1,000 years. Which is defined as the ground motion intensity with a uniform probability of being exceeded at least once in 1,000 years.

3.) *10% Probability of Exceedance in 50 Years* – This equates to approximately a 0.0021 probability of exceedance per annum. Thus, the earthquake return rate is 476 years. Which is defined as the ground motion intensity with a uniform probability of being exceeded at least once in 476 years.

4.) *40% Probability of Exceedance in 50 Years* – This equates to approximately a 0.010 probability of exceedance per annum. Thus, the earthquake return rate is 100 years. Which is defined as the ground motion intensity with a uniform probability of being exceeded at least once in 100 years.

The key point is that each code's hazard map is defined using a baseline default probability of exceedance, typically employing one of the four levels described above. Conformance assessments must identify the probability of exceedance level that was used, such that all stakeholders understand the underlying assumptions. There may be equipment applications that require conformance assessment at a more conservative level than the code's default. In such cases, adjustment multipliers need to be applied to the hazard map acceleration intensities to account for the difference between exceedance probability levels.

2.3 Ground Motion and Site Soils

The mechanics of earthquake events can be grossly simplified as a mechanical induced energy wave that is traveling from the seismic rupture source (i.e. faulting mechanism of the earthquake) within the earth's crust to a surface location where there may be constructed infrastructure. In this simplified sense, this energy shock wave imparts a ground motion input as a complex, multi-frequency, vibratory motion, which has both horizontal and vertical components, to the base foundation of the buildings that are in its path. The building foundation will respond to this base input, and the building structure will begin to shake. How the building responds to the earthquake input is dependent on numerous factors, including: the construction site rock/soil properties, building structure dynamic characteristics and the input characteristics of the earthquake shock wave.

These factors contribute to make the earthquake shaking of a building and all the equipment attached to (or nearby) the building more of a stochastic than a deterministic event. This implies that no two buildings that are subjected to the same earthquake will respond in the same way. Thus, even if the exact same equipment are contained within each building in an affected area, the input energy characteristics that the various equipment may see will be different. Fig. 4 illustrates this simplified concept of the earthquake input to a building foundation and building structure input into the attached equipment within the building.

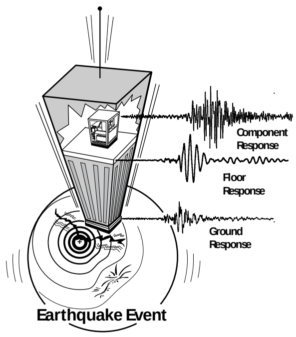

Fig. 4 – Earthquake demand perspective from geotechnical source input to building structure and from building input to equipment items. Source taken from [11].

The properties of the rock and/or soil at a building site will affect the input shock wave as it travels from the seismic rupture source to the building foundation. Some locations may contain softer soils and other building locations may consist of harder soils or of bedrock. The site characteristics or soil category of a building location is one of the common elements that can be found in codes that contain provisions for earthquake protection.

Typically, there will be three to five rock/soil type categories and each type will affect the input shock wave differently. The softer soil types will tend to attenuate the shock wave and the harder bedrocks will tend to amplify the shock wave. Thus, the earthquake hazard maps need to account for the different soil/rock types by using site class adjustment factors that get applied to the seismic hazard values. These adjustment factors are directly included in the building design response spectrum formulas.

3. Equipment Demand Spectra

The BDS defined in Section 2, which is used to design buildings to resist earthquake demands, defines the maximum responses at ground level for equipment applications. The building design spectrum is a ground-level spectrum and provides direct input into formation of equipment demand spectra.

Since we need to consider all site classes, we need to identify the maximum response ($BDS_{PEAK\,G}$) for all soil types contained in a given building code's earthquake BDS. Next, we need to identify the maximum ZPA (zero period acceleration) for all soil types. This is the response acceleration magnitude at zero period (T = 0) on the BDS. This point on the BDS is commonly referred to as the PGA or peak ground acceleration. Fig. 5 highlights the difference between maximum response acceleration ($BDS_{PEAK\,G}$) and PGA_{MAX} on typical building design spectra.

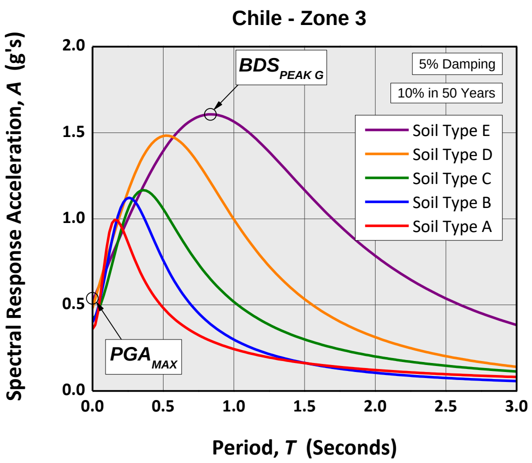

Fig. 5 – Typical building design spectrum showing difference between $BDS_{PEAK\,G}$ and PGA_{MAX}.

Next, the ratio of maximum BDS response ($BDS_{PEAK\,G}$) over PGA_{MAX} is calculated and is defined in Eq. (1) as the BDS response ratio (BDS_{RATIO}). This ratio is used in constructing the generic EDS shape profiles. The EDS is the equipment item seismic test requirement for a given building code. The concept is to construct a generic equipment demand spectrum (EDS) used for equipment qualification for essential building applications. The EDS is equivalent to a generic floor response spectrum.

$$BDS_{RATIO} = \frac{BDS_{PEAK\,G}}{PGA_{MAX}} \tag{1}$$

3.1 Building Amplification

The type of building construction will affect the input shock wave as it travels from the building foundation, up the building structure, to a location where equipment may be attached. Some buildings are short and stiff and other buildings are taller and more flexible. Some buildings are constructed using moment resisting frames and others are constructed using shear wall construction. Every unique building type will respond differently to the input shock wave resulting from seismic events. Equipment installed at building roof elevation will likely experience an amplified input as compared to equipment installed at ground level. Building amplification effects need to be included when constructing an equipment demand spectrum used for equipment qualification.

Over the last five years there has been considerable research [12, 13] surrounding the topic of in-structure building amplification and building response reductions (floor spectra assessments). With minor-to-moderate earth shaking intensity, the building structure may remain linear elastic, and the resulting building amplification at roof elevation would likely be on the order of 3 to 4 times (or greater) the base input for long period structures. With moderate-to-severe shaking intensity, most building structures are designed to have a nonlinear response and will likely experience inelastic response reductions. In this case, the resulting building amplification at roof elevation would likely be on the order of 1 to 2.5 times the base input for long period structures [12].

The primary goal in equipment qualification testing is to demonstrate the maximum seismic withstand capacity for a given product line. This implies the ground motion target for equipment qualification is not for minor-to-moderate earth shaking intensity, but to cover moderate-to-severe earthquake events. A conservative building amplification factor at roof elevation would therefore be on the order of 1.5 to 2 times the base input when considering moderate-to-severe earthquake events.

The use of a 2x limit factor has been recommended in recent ATC-120 research findings [12] and is adopted herein for those building codes that do not contain explicit building amplification limit factors. For example, a 2x building amplification limit factor is greater than the 1.6x limit factor used today in equipment testing to satisfy the American ASCE/SEI 7 earthquake demands for equipment qualification (AC156 test protocol). The AC156 test protocol [14] has been in use since 2000 and increasing the building amplification limit factor to be greater than 1.6x is a conservative change in equipment qualification practices for essential building applications.

3.2 EDS Development

Let us summarize the influence factors that affect earthquake inputs into equipment installed in essential infrastructure. The earthquake itself is a highly random event that can only be quantified based on probable risk of exposure via earthquake hazard maps. We know some geographies are more prone to experience seismic events than others. We learn new lessons in the aftermath of damaging earthquakes, and we adjust our earthquake protection strategies accordingly to reflect current state knowledge.

We know the seismic shock wave is impacted by the type of bedrock and soils present at the location of constructed infrastructure. We know the building structure will respond to the seismic shock wave as it becomes input to the building foundation. How the building responds is dependent on the building structural design and on the magnitude, location, and faulting mechanism of the earthquake, but it is also affected by wave propagation, input direction, velocity, frequency content and duration of motion. We know the equipment item will respond to the seismic input from building structure. How the equipment responds is dependent on equipment dynamic characteristics such as natural period, damping, ductility, and reserve strength.

The bottom line is that it is not possible to pre-determine the dynamic characteristics of the earthquake shock wave that becomes input into installed equipment for any building type at any site location on the globe. A deterministic approach to equipment seismic qualification is simply not feasible, nor even possible. The only realistic approach is to apply stochastic principles as the basis for equipment qualification. The EDS should therefore be defined as a broadband spectrum using random multifrequency excitation to account for the random nature of earthquake demands.

This approach is very different compared to site-specific floor spectra assessments which are typically defined as narrowband spectra with the building's fundamental period acting as a vibration filter. Thus, the spectral peaks are narrow and specifically tuned to a given building's structural dynamic characteristics. However, the OEM equipment supplier does not design equipment platforms for a single building type at single geographic location. Equipment suppliers design product lines that cover all building types, at all floor elevations within a building, and for potential installation locations that span the globe. In the vast majority of cases, the OEM knows nothing about the dynamic characteristics of buildings in which equipment is to be installed.

The EDS in this sense, must be able to provide input energy content spanning over a wide frequency bandwidth to cover the wide variability in geographic locations, building structure types and earthquake characteristics. Fig. 6 presents a generic EDS profile with response acceleration defined by two variables, A_{FLX} and A_{RIG}, and frequency break points defined by five variables, f_1 thru f_5. The EDS response acceleration variables, A_{FLX} and A_{RIG}, are defined in terms of the building design spectrum (BDS) parameters and building amplification (BA) factors per Eq. (2) thru Eq. (5).

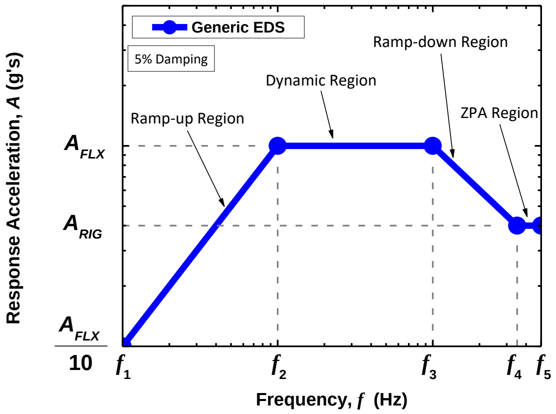

Fig. 6 – Generic broadband equipment demand spectrum used for equipment qualification.

$$A_{FLX} = BDS_{PEAK\,G}\left(BA_{FLX}\right) \tag{2}$$

$$BA_{FLX} = \left(1 + 2\frac{z}{h}\right) \rightarrow BA_{FLX}\big|_{MAX} = BAL_{FLX} \tag{3}$$

$$A_{RIG} = \frac{BDS_{PEAK\,G}}{BDS_{RATIO}}\left(BA_{RIG}\right) \tag{4}$$

$$BA_{RIG} = \left(1 + 2\frac{z}{h}\right) \rightarrow BA_{RIG}\big|_{MAX} = BAL_{RIG} \tag{5}$$

Where:

A_{FLX} = Response acceleration magnitude for the Dynamic Region of the EDS.

$BDS_{PEAK\,G}$ = Peak response acceleration taken from a given country/region building design spectrum for all rock/soil type classifications.

BA_{FLX} = Building amplification factor controlling the Dynamic Region of the EDS.

BAL_{FLX} = Building amplification limit factor controlling the maximum amplification of the Dynamic Region of the EDS.

A_{RIG} = Response acceleration magnitude for the ZPA Region of the EDS.

BDS_{RATIO} = Ratio of $BDS_{PEAK\,G}$ divided by PGA_{MAX} taken from a given country/region building design spectrum as defined in Eq. (1).

PGA_{MAX} = Maximum response acceleration at zero period (T = 0) taken from a given country/region building design spectrum for all rock/soil type classifications.

BA_{RIG} = Building amplification factor controlling the ZPA Region of the EDS.

BAL_{RIG} = Building amplification limit factor controlling the maximum amplification of the ZPA Region of the EDS.

z = Height in building structure at point of attachment of equipment item.

h = Average roof height of building structure relative to the base elevation.

It should be noted; most country building codes do not include explicit definition of a vertical building design spectrum. Thus, most vertical earthquake requirements for equipment testing will typically use a scaled version of horizontal parameters to define the vertical EDS. If applicable, the above general terms can be explicitly defined for both horizontal and vertical axes by adding -H and -V designators to the BDS and BA parameters listed above.

The Fig. 6 EDS ramp-up region is needed to increase response acceleration input from low amplitudes at very low frequency to peak response acceleration at low frequency. The dynamic region is the amplified region of the EDS spectrum and maintains a constant maximum response acceleration input over a wide spectrum bandwidth. The ramp-down region decreases response acceleration input from maximum peak levels to levels associated with PGA at high frequency.

The parameters defining the EDS shape profile include building amplification as a function of building height ratio, z/h, and building amplification limit factors to place a maximum response acceleration cap as the building height ratio nears roof elevation. Limiting building amplification over the dynamic region will harmonize the EDS with building floor spectra research that reveals roof-level inelastic response reductions for moderate-to-severe earthshaking intensity [13]. The EDS frequency break points, f_1 thru f_5, and applicable spectra building amplification and limit factors are either taken directly from existing test protocols (e.g., ICC AC156) or can be conservatively established as shown in Table 2 and Table 3.

Table 2 – Recommended Horizontal EDS Frequency Points and Building Amplification Limit Factors

Country / Region	**Code Reference ID**	**Horz. Frequency Points (Hz)**					**Horz. Limit Factors**	
		f_1	f_2	f_3	f_4	f_5	BAL_{FLX}	BAL_{RIG}
Argentina	INPRES-CIRSOC103	0.1	1	10	35	50	2	3
Australia	AS 1170.4-2007	0.1	1	10	35	50	2	3
Canada*	2015 NBCC	0.1	1.3	8.3	33.3	N/A	1.6	3
Chile	NCh 433.Of1996	0.1	1	10	35	50	2	3
Europe	Eurocode 8 EN1998-1	0.1	1	10	35	50	2	3
Japan	Building Standard Law	0.1	1	10	35	50	2	3
New Zealand	NZS 1170.5:2004+A1	0.1	1	10	35	50	2	3
Peru	N.T.E. - E.030	0.1	1	10	35	50	2	3
Taiwan	CPA 2011 Seismic Design	0.1	1	10	35	50	2	3
USA*	ASCE/SEI 7-10	0.1	1.3	8.3	33.3	N/A	1.6	3

* Defined by ICC AC156 test protocol

Table 3 – Recommended Vertical EDS Frequency Points and Building Amplification Limit Factors

Country / Region	Code Reference ID	Vert. Frequency Points (Hz)					Vert. Limiting Factors	
		f_1	f_2	f_3	f_4	f_5	BAL_{FLX}	BAL_{RIG}
Argentina	INPRES-CIRSOC103	0.1	1	10	35	50	2/3	2/3
Australia	AS 1170.4-2007	0.1	1	10	35	50	2/3	2/3
Canada*	2015 NBCC	0.1	1.3	8.3	33.3	N/A	2/3	2/3
Chile	NCh 433.Of1996	0.1	1	10	35	50	2/3	2/3
Europe	Eurocode 8 EN1998-1	0.1	1	10	35	50	2/3	2/3
Japan	Building Standard Law	0.1	1	10	35	50	2/3	2/3
New Zealand	NZS 1170.5:2004+A1	0.1	1	10	35	50	2/3	2/3
Peru	N.T.E. - E.030	0.1	1	10	35	50	2/3	2/3
Taiwan	CPA 2011 Seismic Design	0.1	1	10	35	50	2/3	2/3
USA*	ASCE/SEI 7-10	0.1	1.3	8.3	33.3	N/A	2/3	2/3

* Defined by ICC AC156 test protocol

Final EDS shape profiles are dependent on a given code's prescribed hazard level, such that A_{FLX} and A_{RIG} magnitudes can be calculated per Eq. (2) thru Eq. (5) based on the code's BDS peak response and PGA_{MAX}. Table 4 lists $A_{FLX\text{-}H}$ and BDS_{RATIO} values for the identified hazard level and probability of exceedance for the ten codes listed in Table 1. It should be noted; the listed hazard level may not be the absolute worst-case maximum for the identified code. Fig. 7 displays the resulting horizontal EDS plots for different country/region building codes using the recommended EDS parameters contained in Table 2 and the EDS demand parameters listed in Table 4.

Table 4 – $A_{FLX\text{-}H}$ and BDS_{RATIO} Parameters for Country/Region Codes

Country / Region	Code Reference ID	Reference Hazard ID	Exceedance Probability	EDS Demand	
				$A_{FLX\text{-}H}$ (g)	BDS_{RATIO}
Argentina	INPRES-CIRSOC103	Zone 4	10% in 50 yrs	1.47	3.0
Australia	AS 1170.4-2007	Z = 0.52	10% in 50 yrs	1.91	2.83
Canada*	2015 NBCC	48.4296^{O} N, 123.3621^{O} W	2% in 50 yrs	1.35	2.33
Chile	NCh 433.Of1996	Zone 3	10% in 50 yrs	1.61	3.09
Europe	Eurocode 8 EN1998-1	a_{Gr} = 0.4	10% in 50 yrs	1.80	2.5
Japan	Building Standard Law	Zone A	10% in 50 yrs	1.22	2.5
New Zealand	NZS 1170.5:2004+A1	Z = 0.6	10% in 50 yrs	1.80	2.26
Peru	N.T.E. - E.030	Zone 4	10% in 50 yrs	1.24	2.5
Taiwan**	CPA 2011 Seismic Design Code	S_S^D = 0.8, S_1^D = 0.45	10% in 50 yrs	1.20	2.5
USA*	ASCE/SEI 7-10	34.086^{O} N, 118.212^{O} W	10% in 50 yrs	1.84	2.5

* Hazard level defined by geological survey databases for identified lat-lon coordinates
** Hazard level assumes near-fault factors N_A = 1.5 and N_V = 2.0

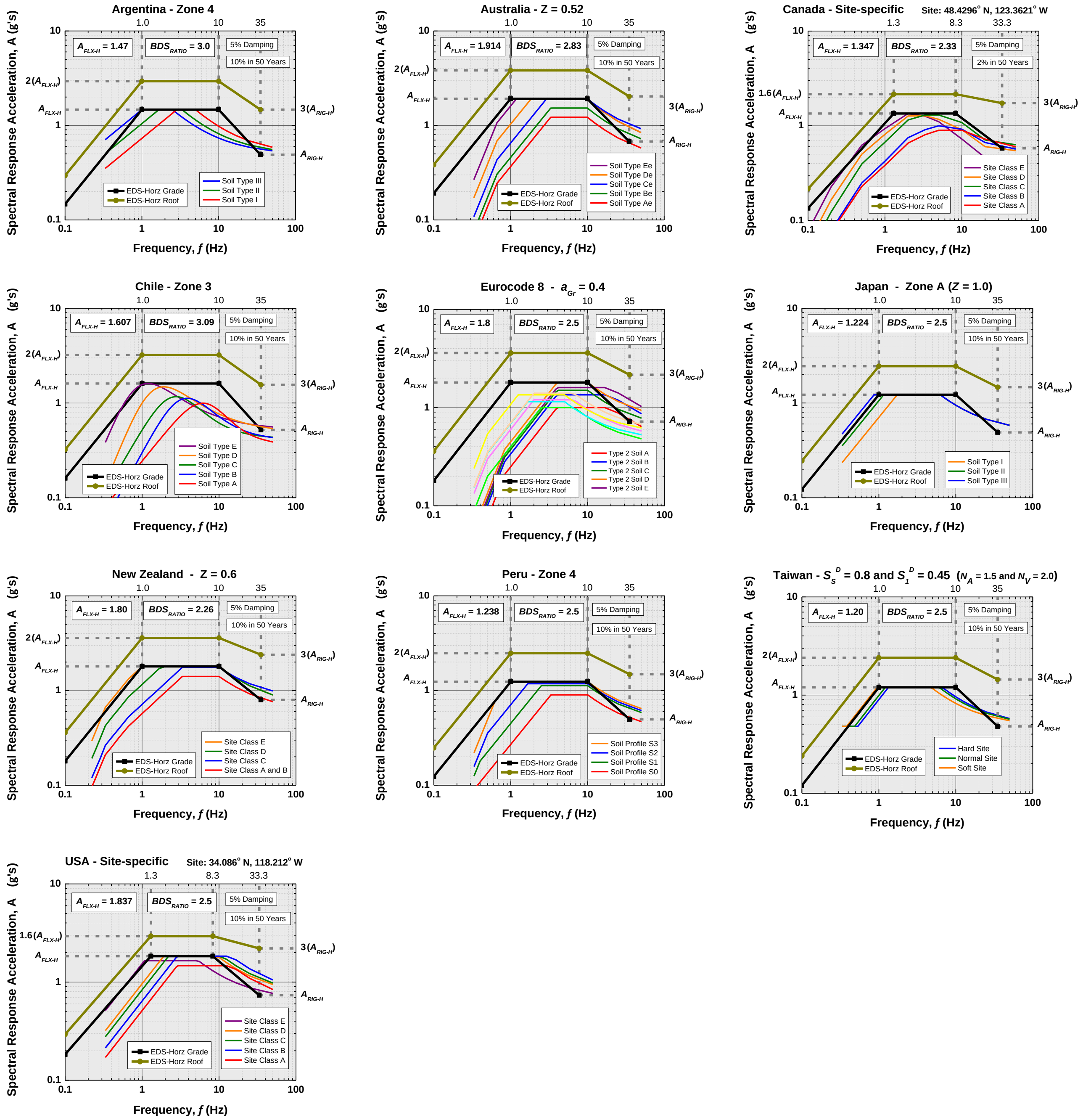

Fig. 7 – EDS profiles for ten country/regional building codes using assumed hazard values.

4. Conclusions

By using the response spectrum method to construct a generic, broadband equipment demand spectrum as described herein, a common measuring stick can be implemented across different regional codes and standards. Equipment suppliers can provide seismic certificates of conformance that address country or region-specific earthquake requirements. No building information is required, and certification levels are calculated at both grade and roof height elevations using the maximum peak response accelerations taken from country/region building design spectra based on a given hazard level. This approach results in a conservative test unit input excitation using random, multifrequency excitation. The method used to transform a country/region BDS requirement into an equipment test requirement (EDS) has been proven effective for over twenty years since adoption of ICC AC156 to address the American ASCE/SEI 7 nonstructural earthquake provisions [15]. Adopting this methodology to address other country and regional building codes/standards would render equipment qualification a transparent activity that can be objectively approached at a global level.

In addition, since the EDS shape profiles are pre-defined based on country/region-specific BDS shapes, the validation process to a given code can be automated. As marketplace needs evolve, additional countries/regions can be added to the Table 1 list. The negative side to this approach is that as individual countries/regions revise their respective codes and seismic standards, a routine maintenance activity must be conducted to ensure country/region-specific EDS profiles remain up to date and in-sync with code revisions.

5. References

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