OVERVIEW OF THE CURRENT SEISMIC CODES IN CENTRAL AND SOUTH AMERICA

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ABSTRACT

This paper presents an overview of the current (2011) seismic codes in Central and South America. The main aspects of the various seismic provisions of the local model building codes used in the region are presented and briefly discussed. The issues presented include code development, site characterization, building classification, design response spectra, seismic forces and reduction factor, design considerations, construction practice and code enforcement.

BACKGROUND

Many areas of Central and South America are noted for their high seismicity. Recognizing the seismic activity in the region, earthquake-resistant design of structures is a must in these countries. As such, each country has developed their own seismic codes based on their experience and laws. The codes also follow aspects of the 1997 Uniform Building Code (UBC-97) and the 2009 International Building Code (IBC-2009).

The traditional design philosophy of most codes in Central and South America is to maintain Life Safety by avoiding collapse during severe earthquakes. Although different earthquake activity levels may be used (see Table 1) the design basis earthquake is typically an event with a 475 year return period used in UBC-97.

Table 1. Earthquake Event Levels

Earthquake	Probability of exceedance	Period of Interest (years)	Return Period (years)
Frequent	50%	50	72
Occasional	20%	50	225
Rare	10%	50	475
Very Rare	2%	50	2475

The method of assigning levels of seismicity utilized by most codes in Central and South America is characterized by dividing a country into various seismic zones, similar to that used in the United States prior to 2000. However, Mexico has recently adopted a new building code which has shifted to the concept of seismic acceleration maps instead of seismic zones (similar to the concept used in USA since 2000). There are other countries (i.e. Peru), which have begun to develop their own acceleration maps, but these have not yet been introduced into their current codes.

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SEISMIC CODE DEVELOPMENT

Most countries in Central and South America have published, enforced and updated their seismic codes over a period of years. The first application of some sort of earthquake regulations goes back to 1914 in Costa Rica, 1935 in Chile, 1939 in Venezuela, and 1942 in Mexico. However, the first application of what are considered to be modern seismic codes in most countries goes back to the 1970's and followed the recommendations for seismic requirements published by the Structural Engineering Association of California (SEAOC) in 1961. Other countries, such as Bolivia, have a much shorter history of seismic codes development.

Table 2 lists the current seismic codes in Central and South America (ordered by latitude, from North to South). Earlier editions of these codes are also noted in this list. Countries and territories of the Caribbean are not included in this list due to the report space limitations. Paraguay, Uruguay and Brazil in South America are also not included, since they are located in zones of low seismicity.

Table 2. List of Central and South American Countries and their Seismic Codes

Country	Current Seismic Code	Year Published	Previous Modern Codes
USA [1]	IBC-2009	2009	IBC-2006, IBC-2003, IBC-2000, UBC-97 to UBC 1967 (modified every three years), UBC-1964 to UBC-1927.
Mexico [2]	MOC-2008	2008	MOC-1993, MOC-1982, MOC-1969
Mexico City	NTCDS-2004	2004	NTCDS-2004, NTCDS-1994, NTCDS-1987, NTCDS-1985, NTCDS-1976
Guatemala [3]	NR-1	2002	NR-1 1996
El Salvador	NTDS	1997	1994, 1989, 1965
Honduras [4]	None	None	None
Nicaragua [5]	RNC	1983	Not available
Costa Rica	CRSC-2002	2002	CRSC-1986, CRSC-1974
Panama	REP-2004	2004	REP-1994
Venezuela	COVENIN 1756	2001	COVENIN 1756:98, COVENIN 1756:87, NP-MOP 1967
Colombia	NSR-10	2010	NSR-98, CCCSR-84
Ecuador	INEN-5	2001	Not available
Peru	E.030	2003	E.030-1997, 1977, 1970
Bolivia	NBDS	2006	None
Chile [6]	Nch433.of96	2009Mod	Nch2545.Of2003 (industrial facilities), Nch433.96, NCh433.Of93, Nch433.Of72
Argentina	CISROC-103	2005	CISROC-103.1991, CIRSOC-1983, NAA 1980, CONCAR 1972

1 USA code is included as reference.
2 The Manual de Obras Civiles (Manual of Civil Works) is discussed in this paper instead of the Mexico City Building Code. Both Codes are applicable in Mexico.
3 New provisions have been published in 2010 in Guatemala (these are based on combining the UBC-97 and IBC-2009). However, these new provisions are not included in this paper.
4 The author does not have knowledge of a seismic code in Honduras.
5 The author does not have knowledge of an update of the 1983 seismic code in Nicaragua.
6 The modified version of the Nch433.of96 Mod 2009 was actually published in 2010 after the 2010 Maui Chile earthquake.

SITE CHARACTERIZATION

Seismic zones are used in all Latin-American countries, with the exception Mexico, to characterize their local seismic hazards. Ground accelerations (effective peak ground acceleration, acceleration coefficient) associated with each seismic zone varies from 0.04g to 0.50g, depending of each country and region. Three to four seismic zones are defined in most countries. Exceptions to this rule are Venezuela having 8 seismic zones (0 to 7), Colombia having 10 seismic zones (1 to 10), and Bolivia having 8 seismic zones (1 to 8). The ground acceleration in high seismic zones is approximately 0.4g in most countries. The ground accelerations of boundary regions between countries are generally not the same.

Soil type is an important component used in the definition of site hazard within the local building codes. In most countries site soils are classified as soil types S1, S2, S3 and S4. This classification is similar to the soil classification used in the Uniform Building Code (UBC-97). Panama and Colombia use the soil classification A to F, which corresponds to the IBC soil classification. Chile adopted a soil classification based on soil types I to IV. Besides the different notations used to define the soil types there is no consistency with the approach each country uses to define the soil types. In some cases shear wave velocities are used, whereas in other cases the standard penetration resistance, N, or the specific soil description is used for soil classification purposes. Some countries provide better soil type definitions than others.

Table 3 lists the seismic zones adopted in each country as well as the different soil types. An attempt has been made in this table to group the seismic zones based on the level of seismicity and similarity between the different soil types. The peak ground acceleration, effective peak ground acceleration and zone acceleration coefficient was used for this purpose.

Table 3. Seismic Zoning and Soil Characteristics

Country	**Seismicity**								**Soil Classification**					
	Seismic Zone				**Ground Acceleration (g)**				Hard Rock	Rock	Soft Rock	Stiff Soil	Soft Soil	Special
USA	Not defined				Use spectral acceleration				A	B	C	D	E	F
Mexico	Not defined				Use spectral acceleration				-	S1	S2	S3	S4	-
Guatemala	2	3		4	0.15	0.15-0.40		0.40	-	S1	S2	S3	-	-
El Salvador	-	-	2	1	-	-	0.30	0.40	-	S1	S2	S3	S4	-
Costa Rica [1]	-	II	III	IV	-	0.20-0.34	0.30-0.36	0.40-0.44	-	S1	S2	S3	S4	-
Panama	Not defined. Acc Coef given by city				Aa vary from 0.14 to 0.25 Av vary from 0.14 to 0.34				A	B	C	D	E	F
Venezuela [1,2]	0-2	3-4	5	6-7	0.10-0.15	0.20-0.25	0.30	0.35-0.40	-	S1	S2	S3	S4	-
Colombia	1-3	4-5	6-7	8-10	0-0.15	0.20-0.25	0.30-0.35	0.40-0.50	A	B	C	D	E	F
Ecuador	I	II	III	IV	0.15	0.25	0.30	0.40	-	S1	S2	S3	S4	-
Peru	1		2	3	0.15		0.30	0.40	-	S1	S2	S3	S4	S4
Chile		1	2	3		0.20	0.30	0.40	-	I	II	III	IV	-
Bolivia [1]	1-8	-	-	-	0.04-0.12	-	-	-	-	-	S1	S2	S3	-
Argentina [1]	0-1	2	3	4	0.04-0.10	0.16-0.18	0.25	0.35	-	I	II		III	-

1. Ground acceleration varies with soil type.
2. Spectral shapes (S1 to S4) instead of soil types are used to define the response spectrum.

BUILDING CLASSIFICATION AND IMPORTANCE FACTOR (I)

Buildings are classified based on their occupancy and their structural type (besides their configuration). Building occupancy categories, although different nomenclatures are used in each country, are consistently defined in all codes as: essential, important, common and minor structures. Buildings containing hazardous materials are included in most codes within the essential category with few exceptions. The basic structural types account for the construction configuration used, i.e. frame, shear wall, etc. Table 4 shows occupancy categories, importance factors (I), and structure types used by the various codes.

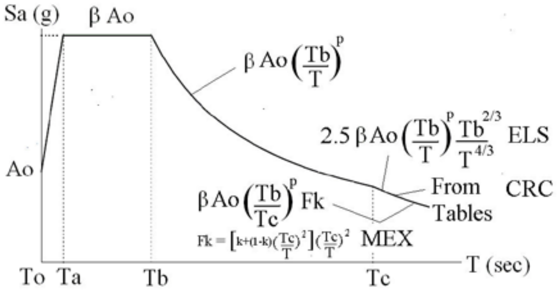
Table 4. Building Classification & Importance Factor

Country	Occupancy Category				Importance Factor [1]				Structural Category
	Essential	Important	Common	Minor	Essential	Important	Common	Minor	Basic Structural System
USA	IV	III	II	I	1.5	1.15	1	1	Buildings and non-building structures
Mexico [2]	A+	A	B	-	1.5	1.5	1	-	Type 1 to 13 including buildings, bridges, tanks, dams, industrial facilities, etc
Guatemala	I,II	III	IV	V	NA	NA	NA	NA	NA
El Salvador	I	II	III	-	1.5	1.2	1.0	-	Frames, dual, wall, others
Costa Rica	A,B	C	D	E	1.5	1.0	1.0	0.75	Frame, dual, wall, cantilever and others. Bridges, dams not included
Panama [3]	IV	III	II	I	1.0	1.0	1.0	1.0	Bearing, frame, dual, cantilever, others
Venezuela	A	B1	B2	C	1.3	1.15	1.0	NA	Type I (frames), type II (dual systems), type III (walls and braced systems), IV
Colombia [4]	IV	II	I	-	1.5	1.1	1.0	-	Frame, dual, shear wall, others
Ecuador	A	B	C	-	1.5	1.3	1.0	-	Frame, dual, shear wall, others
Peru	A	B	C	D	1.5	1.3	1.0	NA	Frame, dual, shear wall, others
Bolivia	A	B	C	D	1.4	1.2	1.0	0	Frame, dual, shear wall, others
Chile [5]	IV	III	II	I	1.2	1.2	1.0	0.6	Frames, shear walls, braced, and others
Argentina	A0	A	B	C	1.4	1.3	1.0	NA	Frame, dual, wall, others

1 Importance factor for minor building structures is left to the designer criteria, and in many cases these minor structures are not required to be designed for seismic forces.
2 The Mexico code uses an importance factor of 1.5 for important structures (A). For essential buildings (A+), the code is not explicit, but a factor of 1.5 is assumed.
3 The Panama code does not provide an importance factor for seismic actions (an importance factor is provided for wind actions only). A factor of 1 is assumed for seismic actions.
4 The Colombia code incorporates group III for important community structures with I=1.25.
5 Building categories for Chile (I to IV) have been renamed in the modified code. The Nch433.of96 code listed the buildings as category A to C instead.

DESIGN RESPONSE SPECTRA (Sa)

The design acceleration response spectrum represents the site characteristics (seismicity and soil type). Some of the codes include the importance factor in the definition of the elastic response spectrum. Other codes (i.e., Costa Rica) also include the building characteristics and directly define the inelastic (design) response spectrum. Figures 1 to 5 show (in no particular order) the response spectrum shapes of the various codes (for 5% damping). For comparison purposes, only the elastic spectrum is presented in all cases (without including the importance factor or any reduction factor). The notation, in some cases, has also been modified (from the original codes) in order to compare the various codes.

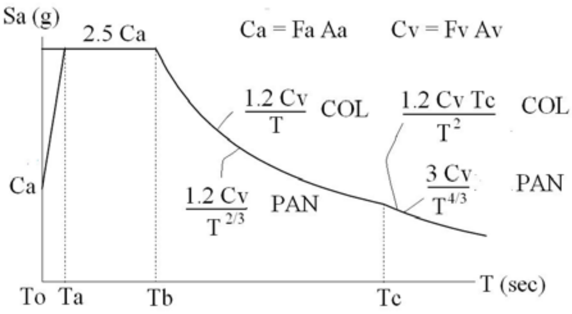


	Mexico	El Salvador	Costa Rica
Ao (acc) =	Use software PRODISIS	See Table 3	See Table 3
β =	2.5 in rock	2.5 to 3	2.5
p =	0.5 to 1	2/3	1
To =	0	0	0
Ta =	NA	0.10	0.03
Tb =	NA	0.3 to 0.9	0.4 to 1.07
Tc =	<= 2sec	4 sec	2.6 to 5

Note: The spectrum equations for Mexico are valid for a damping of 5%. The k factor in the Mexico code is equal to 2 for rock.

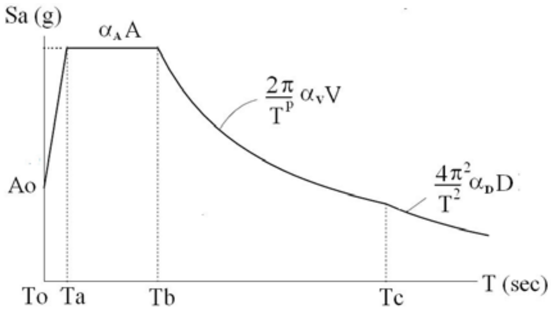
Note. Elastic and inelastic spectral acceleration plots (in logarithm scale) are given in the Costa Rica code. The valúes shown are for the elastic response spectrum

Figure 1. Elastic Design Spectrum for Mexico, El Salvador and Costa Rica



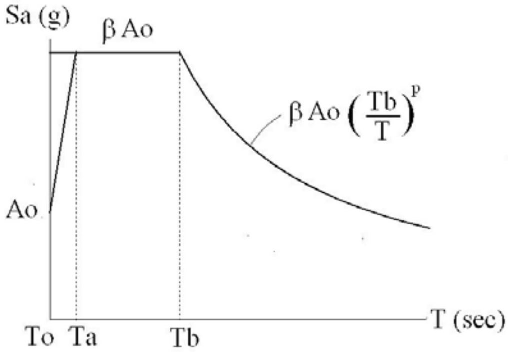
	Colombia	Panama
Aa = acceleration =	See Table 3	See Table 3
Av = acceleration =	Aa	See Table 3
Fa = f(soil type, Aa) =	1 (soil B)	1 (soil B)
Fv = f(soil type, Av) =	1 (soil B)	1 (soil B)
To =	0	0
Ta =	0.10 Cv/Ca	0
Tb =	0.48 Cv/Ca	$(0.48Cv/Ca)^{1.5}$
Tc =	2.4 Fv	4 sec

Figure 2. Elastic Design Spectrum for Colombia and Panama



Ao = ground acceleration (in Table 3)
$\alpha_A A$, $\alpha_V V$, $\alpha_D D$ = f(soil type, seismic zone)
$\alpha_A A$ = 1.10Ao (for soil type I, seismic zone 3)
p = 0.8 to 0.6 (larger value for soil type I)
To = 0 (all cases)
Ta = 0.13 to 0.37 (larger value for soil type I)
Tb = 0.22 to 0.68 (larger value for soil type l)
Tc = 1.53 to 1.75 (smaller value for soil type I)

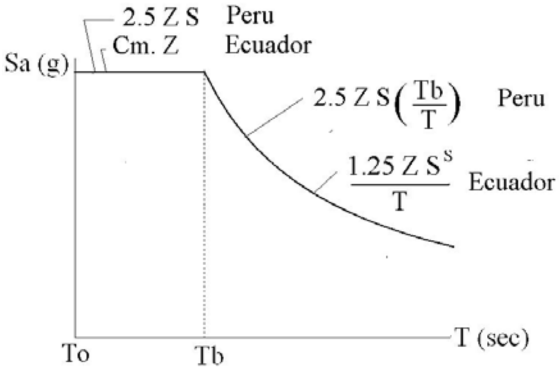
Figure 3. Elastic Design Spectrum for Chile



	Guatemala	Venezuela	Bolivia	Argentina
Ao =	See Table 3	See Table 3	See Table 3	See Table 3
β =	2.5	2.4 to 3	2.5	3.0
p =	2/3	1 to 0.8	0.5 to 1	2/3
To =	0	0	0	0
Ta =	0.12	Tb/4	0.4 to 0.8	0.1 to 0.4
Tb =	0.4 to 1.0	0.4 to 1.3	1.0 to 3.0	0.35 to 1.6

Note. The acceleration values in the Venezuela code need further to be modified by a correction factor, ϕ. This factor varies between 0.65 to 0.85 for seismic zones 1 to 4 and between 0.7 to 1.0 for seismic zones 5 to 7.

Figure 4. Elastic Design Spectrum for Guatemala, Venezuela, Bolivia, Argentina



	Ecuador	Peru
Z (zone factor) =	See Table 3	See Table 3
Cm = f (soil type, seismic zone) =	2.5 to 3	N.A.
S (soil factor) =	1 (soil S1) 1.5 (soil S3)	1 (soil S1) 1.4 (soil S3)
To =	0	0
Tb =	0.5 to 0.82 for soil S1 to S3 2.0 for soil S4	0.4 to 0.9 for soil S1 to S3

Figure 5. Elastic Design Spectrum for Ecuador and Peru

SEISMIC DESIGN FORCE AND REDUCTION FACTOR (R)

The design seismic forces (V) are calculated as the product of the seismic coefficient (Cs) times the seismic weight (W)

$$V = Cs.\ W$$

The seismic coefficients in the various countries are expressed by different equations and notations. However, in all cases the following ratio can be used to determine the seismic forces.

$$Cs = Sa / (R/I)$$

The R value is the reduction factor used by the codes to decrease the elastic seismic forces. This factor accounts for (a) the global ductility capacity of the lateral force resisting system, and (b) the over-strength inherent in the lateral force resisting system. The R factor is also a function of the structural system and the expected design level or design category.

The definition and application of the "R" factor varies between the various codes, as follows:

- In most codes the R factor is a single and constant value used to reduce the elastic forces in a constant manner, regardless of the period of the structure.
- In countries such as Venezuela the elastic forces are reduced in a non-uniform manner. The R factor is modified with the period of the structure.
- In some countries, including Costa Rica and Argentina, a global ductility concept is used instead of the typical R factor.
- Colombia and Ecuador use an additional reduction factor, Φ (always <1) to account for any structure irregularities.

There appears to be good agreement between codes with the reduction factors for concrete and masonry structures, a building type common in Central and South America. However there is little consistency among the local seismic codes in the use of the R factor for steel structures. Some codes, like the recent NSR-10 (Colombia), include a large variety of steel structural systems and associated reduction values. Other countries, such as Ecuador and Peru, use one or two group types to define all steel structures. For instance, ordinary concentric brace frames (OCBF) have a value of R=3.25 in the IBC-2009 and there are height limitations in their use. The same structure according to the Peruvian code has a value of R=6 with no height limitations. Note also that the 2009 modified Nch433 code (Chile) appears to indicate an R value of 3 for OCBF compared to a value of 7 used in the previous edition of this code. It may be desirable that more consistent structural systems and R values be defined in new versions of the local codes.

DESIGN CONSIDERATIONS

The majority of codes in Central and South America make reference or are based on the provisions of the Building Code Requirements ACI-318, and the American Institute of Steel Construction (AISC) for the design of reinforced concrete and steel structures, respectively. There are some exceptions, such as the CIRSOC (Argentina) that has based concrete design on a different approach; however, the new edition of this CIRSOC has been adjusted to also follow ACI-318. Masonry design (reinforced masonry and confined masonry) typically follows the local practices in the various countries.

Attention should be paid to the following issues:

- Load combinations in the various codes are not consistent. Many codes use LRDF-type load combinations, but other codes still have their own particular set of load combinations. It is important to keep this in mind when comparing seismic effects between local codes and international codes.
- Seismic detailing is important. Some countries make exceptions to ACI-318 detailing requirements based on their own experience. For instance, the previous edition of the Nch433 (Chile) permitted designers to not satisfy ACI requirements for boundary elements in structural walls. This may have contributed to the damage to concrete structures during the 2010 Chile earthquake. The modified version of Nch433 appears to have corrected this issue.
- Application of the current versions of the seismic codes is important. Local (country) codes require satisfying the available versions of the ACI and AISC standards at the time the local code was issued. This creates a gap with current ACI and AISC codes which are mostly revised every three years.

CONSTRUCTION PRACTICE AND CODE ENFORCEMENT

The codes, in general, require that construction documents (calculations, drawings, and specifications) need to be submitted for approval to the local authorities. However the review and approval practices vary from country to country and from city to city. Some countries, like Chile, require that the construction documents regarding public utility buildings (schools, hospitals, police stations, fire fighting stations, communication centers, etc.) and residential buildings of more than 5 stories need to also be approved by an independent reviewer. Peer-review approach is not applied in all countries.

Inspection during construction is another issue that may be different in each country. There is no guarantee that a well designed project is executed as per design intent if adequate inspection is not performed during construction. Lack of inspection is also not uncommon, especially in housing construction.

The most recent codes (i.e., Colombia, Mexico) appear to put greater emphasis on the necessity of proper construction documents review and inspection during construction that includes providing instrumentation for building monitoring for future earthquakes.

CONCLUSIONS

A general overview of the provisions of the various seismic codes utilized in Central and South America was presented. Since the seismicity and local site conditions differ from country to country, it may be not possible to find a common ground to develop similar design spectra for all countries.

However, it may be desirable to make an effort to provide for greater uniformity of some aspects of the codes, such as definition of structure types, used in all countries. The inclusion of non-building structures in the codes is also desirable. Construction quality control (inspection) requirements are another issue that may be improved in current codes.

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