Revista Ingeniería de Construcción RIC
Vol 38 Nº1 2023 www.ricuc.cl
DOI: 10.7764/RIC.00057.21

Seismic response for a reinforced concrete residential building according to South American standards in the Pacific zone

Respuesta sísmica para una edificación residencial de concreto armado acorde a las normas sudamericanas de la zona del Pacifico

J.A. Alvarado Mamani*[1] https://orcid.org/0000-0002-7541-6225
H.A. Aguilar Chuquimia * https://orcid.org/0000-0003-1373-2027

*Universidad Peruana Unión, Lima, PERU

Fecha de Recepción: 22/11/2022
Fecha de Aceptación: 10/02/2023
Fecha de Publicación: 02/04/2023
PAG: 126-143

Abstract

In the present work, the seismic response of a reinforced concrete building representative of modern multi-family residences of medium height in the southern zone of Peru was estimated. This region was considered because we can find growing urban areas with a variety of altitudes and consequently different seismic conditions, which can be found in the three countries of the case study, in accordance with the seismic standards of the Pacific area corresponding to the current official directives of Peru (E.030, 2018), Chile (NCh433, 2012) and Ecuador (NEC, 2015), using spectral modal analysis with the purpose of highlighting the most relevant aspects in the standards and identifying possible missing parameters that prominently influence the structural demand. The analysis included the estimation of shear forces, spectral acceleration and relative inter-story displacement, including variables such as seismic zoning, soil typology, category of use, structural system, among others; considering the approach of a uniform scheme for the comparison of limits between the relative inter-story displacement established in each standard. The process was carried out from numerical models of a 10-story reinforced concrete building consisting of frames and structural walls; finding, among others, that the highest acceleration demand at surface level in coastal regions for a rocky soil (Vs ≥ 900 m/s) corresponds to Peru, followed by Ecuador and Chile. It is concluded in general, that the highest demands and the most restrictive limits for different seismic zones and different soil conditions correspond to the regulatory provisions of Peru.
Keywords: *Seismic analysis; basal shear; lateral displacement; spectral acceleration; seismic response.*

Resumen

En el presente trabajo se realizó la estimación de la respuesta sísmica de una edificación de concreto armado representativa de residencias multifamiliares modernas de mediana altura de la zona sur del Perú, en concordancia con las normas sísmicas de la zona del pacifico correspondientes a las directivas oficiales vigente del Perú (E.030,2018), Chile (NCh433, 2012) y Ecuador (NEC, 2015), empleando para ello el análisis modal espectral con el propósito de destacar los aspectos más relevantes en las normas e identificar posibles parámetros ausentes que influyen de forma destacada sobre la demanda estructural. El análisis contempló la estimación de las fuerzas cortantes, la aceleración espectral y el desplazamiento relativo de entrepiso abarcando variables cómo la zonificación sísmica, tipología de suelos, categoría de úso, sistema estructural, entre otros; contemplando el planteamiento de un esquema uniforme para la comparación de límites entre los desplazamientos relativos de entrepiso establecidos en cada norma. El proceso se realizó a partir de modelos numéricos de un edificio de concreto armado de 10 niveles constituido por pórticos y muros estructurales; encontrándose, entre otros, que la mayor demanda de aceleración a nivel de superficie en las regiones costeras para un suelo rocoso (Vs ≥ 900 m/s) corresponde al Perú, seguida de Ecuador y Chile. Se concluye en general, que las mayores demandas y los limites más restrictivos para las diferentes zonas sísmicas y diferentes condiciones de suelo corresponden a las disposiciones reglamentarias de Perú.
Palabras clave: Análisis sísmico; cortante basal; desplazamiento lateral; aceleración spectral; respuesta sísmica.

1 Corresponding author:
Universidad Peruana Unión, Lima, PERU
E-mail: juan.am@upeu.edu.pe

1. Introduction

During the twentieth century worldwide there have been more than 1,100 violent earthquakes that have caused more than 1.5 million victims (Moreno and Bairán, 2012), being one of the most affected regions the South American coastal strip with important recent seismic events such as Chile 2010 and Ecuador 2016 (Ruiz and Madariaga, 2018),(Jiménez et al., 2021); one of the most relevant aspects, for the Peruvian case is the population increase and the disordered urban development of cities (Tavera, 2014), it is remarkable the informality in the engineering and construction stages of a building, being the structural design phase a critical stage in regions with low percentage of structural specialists, highlighting the cities with lower per capita income (Riesco et al., 2021) such as the southern region of Peru, which includes cities such as Tacna, Juliaca and Puerto Maldonado, comprising coastal, mountain and jungle areas with a similar construction trend.

The demands on buildings are a growing concern given that an adequate level of structural safety is sought in engineering projects, therefore it is necessary to ensure that the most relevant parameters and the most appropriate restrictions are contemplated for buildings that could be projected in the different geographical areas of the countries of the South American Pacific zone and that have been identified and expressed in, among others, in Chilean, Peruvian and Ecuadorian regulations, which together cover a wide range of seismic sources, characteristic of the South American Pacific region contemplating latitudes such as the coast, highlands and jungle presenting a constant seismic zoning with the seismicity of growing cities located in the southern region of Peru, a geographic area that presents a progressive advance in the presence of modern medium height building projects.

Given the influence of the Pacific Ring of Fire on the different population latitudes and the scarce number of seismic records in this part of the continent, it is essential that the level of probable accelerations according to the multiple studies of seismic sources in a region of similar nature and embodied in the standards of the countries be adequately contemplated and compared in the general response of buildings (El-Kholy et al., 2018)(Fenwick et al., 2002)(Doğangü and Livaoğlu, 2006)(Pong et al., 2007)(Giri et al., 2018)(Faizian and Ishiyama, 2004)(Khose et al., 2012)(Nahhas, 2011).

2. Methodology

The structural response arose from the numerical evaluation of a representative structural model of a modern reinforced concrete building considered in the southern area of Peru. The building considers 10 levels of mezzanine, 3000 m^2 of projected construction area, 2.8 m of mezzanine height, a mixed structural system (portal frames and structural walls), a common use category for multifamily housing and regulatory architectural provisions according to the current Peruvian standards (A.010, 2021; EM.070, 2019 y A.120, 2019). The numerical model was processed in Revit Structural 2021 and Robot Structural Analysis Pro software 2021, using spectral modal analysis to estimate the seismic response of the building.

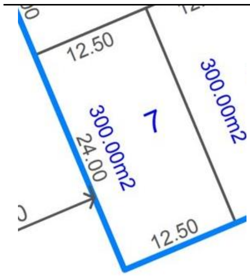
The process contemplated the choice of a configuration at architectural and structural level considering gravity loads consistent with Peruvian regulations, however the seismic actions were established according to the current standards of Peru (E.030, 2018), Chile (NCh433, 2012) and Ecuador (NEC, 2015), covering the different zones and different soil profiles according to each standard, establishing ranges of comparison based on common values such as shear wave velocities and acceleration levels in rock according to similar geographical regions (coastal, mountain and jungle areas).

2.1. Architectural configuration

The representative architectural distribution was obtained from the review of building projects of some of the most distinctive cities of southern Peru (Tacna, Juliaca and Puerto Maldonado), covering regions such as the coast, highlands and jungle in accordance with the location of many cities in the South American Pacific, considering a building corresponding to a project in an area of urban expansion of the city of Juliaca (highland area of the Peruvian highlands) see (Table 1) and (Figure 1).

Revista Ingeniería de Construcción RIC
Vol 38 Nº1 2023 www.ricuc.cl
DOI: 10.7764/RIC.00057.21

Table 1. *Justification of the representative architectural configuration for the analysis.*

			
Typical lot area of highlands	*Coastal Building (Tacna City)*	*Highland Building (Juliaca City)*	*Jungle Building (Puerto Maldonado City)*

Note: The table presents a typical land area in urban sprawl zones and representative modern buildings for multi-family or similar housing use.

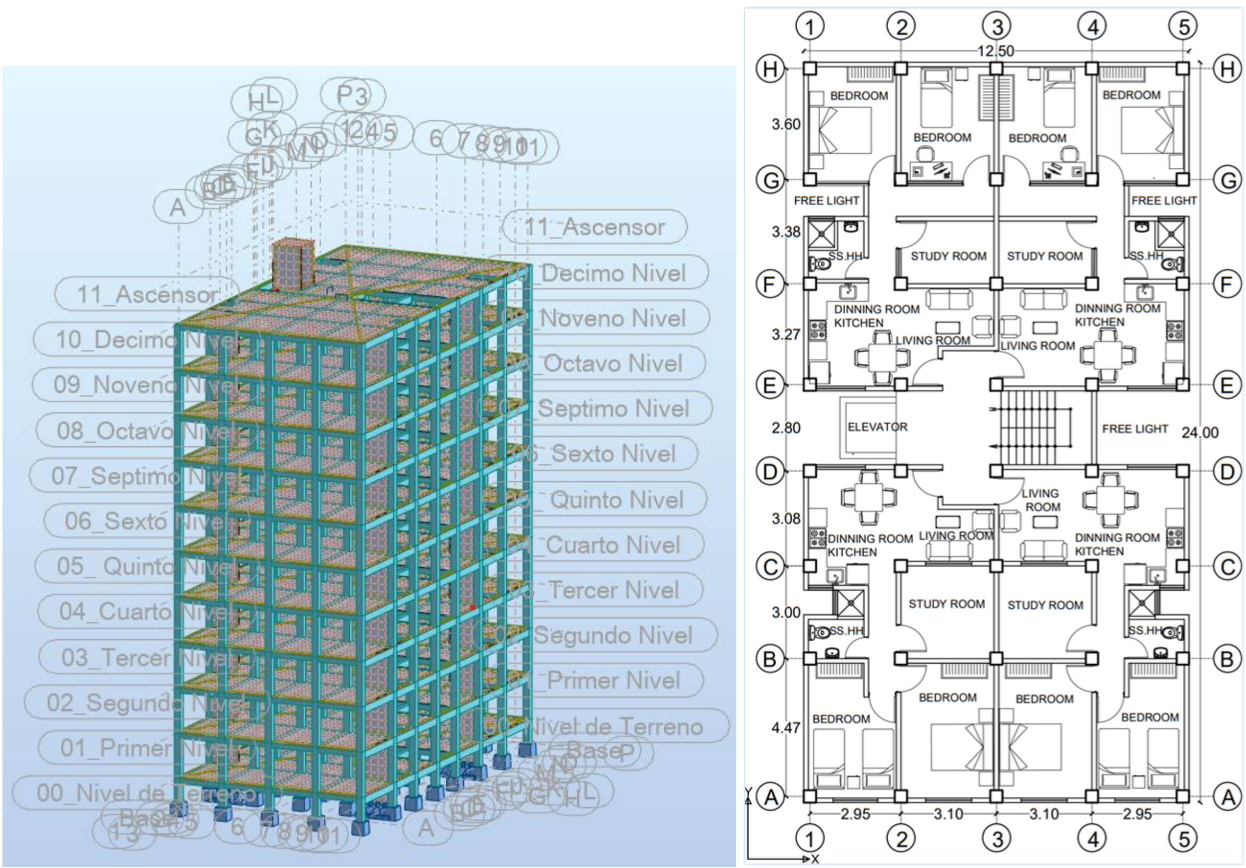


Figure 1. *Perspective view (left) and typical plan (right); dimensions in meters (m).*

2.2. Structural configuration

The dimensions of the structural elements (columns, beams, slabs, structural walls, elevator and stairwell) of the project were established mainly based on Peruvian bibliography related to the pre-dimensioning of buildings according to (Blanco, 1994), (Morales, 2006), (Delgado, 2011), draft NTP (E.060, 2009), presented in (Table 2).

Table 2. *Dimensions of structural elements.*

Columns	*0.40 x 0.40 m2*
Beams	*0.30 x 0.45 m2 and 0.30 x 0.30 m2*
Mezzanine slabs	*0.17 m*
Structural walls (inc. elevator box)	*0.20 m*
Thickness of stair slab	*0.15 m*

2.3. Mechanical properties, gravity loads and seismic weight.

The mechanical properties of the materials were considered according to the Peruvian standard (E.060, 2009) of reinforced concrete design see (Table 3), the gravity loads were established according to the Peruvian load standard (E.020, 2006) and the seismic weight was considered according to the provisions of each standard considering for Peru 100% of the dead load plus 25% of the live load, for Ecuador 100% of the dead load, for Chile 100% of the dead load plus 25% of the live load (excluding the live load of the roof).

Table 3. *Mechanical properties of materials.*

Compressive strength, f´c	*28 MPa*
Volumetric weight	*24 kN/m3*
Modulus of elasticity, E´c	*25099.8 MPa*
Shear modulus, Gc	*10913 MPa*
Poisson's modulus	*0.20*

2.4. Seismic Zoning and Soil Profiles

For comparative purposes, it was proposed to make compatible the different normative dispositions for the different seismic zones and different soil profiles according to each country, as shown in (Table 4) and (Table 5), using as a comparison parameter the shear wave velocity according to the soil profiles established in each normativity.

Table 4. *Comparative proposal for treatment of results according to seismic zoning and geographic region.*

Peru		***Chile***		***Ecuador***		***Common geographical region***
Zone	***Factor of Zone Z***	***Seismic zone***	***Effective acceleration Ao***	***Seismic zone***	***Z-Factor***	
1	*0.10g*			*I*	*0.15g*	*Jungle*
2	*0.25g*	*1*	*0.20g*	*II*	*0.25g*	*High Jungle / Highlands*
3	*0.35g*	*2*	*0.30g*	*III* *IV*	*0.30g* *0.35g*	*Highlands*
4	*0.45g*	*3*	*0.40g*	*V* *VI*	*0.40g* *0.50g*	*Coastal Strip*

Note: The table presents a proposal for comparison between the different geographical regions.

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Revista Ingeniería de Construcción RIC
Vol 38 Nº1 2023 www.ricuc.cl
DOI: 10.7764/RIC.00057.21

Tabla 5. *Comparative proposal for treatment of results according to soil profiles.*

Peru		***Chile***		***Ecuador***		***Range of comparison***
Profile	***Vs (m/s)***	***Soil Type***	***Vs (m/s)***	***Profile***	***Vs (m/s)***	***Vs (m/s)***
So	*>1500*	*A*	*≥ 900*	*A*	*>1500*	*>900 (Hard rock)*
S1	*500-1500*	*B*	*≥ 500*	*B*	*1500>Vs≥760*	*>760 (Rock or very dense soils)*
S2	*180-500*	*C D*	*≥ 350 ≥ 180*	*C D*	*760>Vs≥360 360>Vs≥180*	*>350 (Firm or intermediate ground)*
S3	*<180*	*E*	*< 180*	*E*	*< 180*	*< 180 (soft ground)*
S4	*Classification based on the EMS*	*F*	*Special Floors*	*F*	*Site evaluation*	

Note: The table presents a proposal for the comparison between different soil profiles.

2.5. Regulatory scopes

For comparative purposes it was proposed to use the different dispositions regarding the spectral acceleration in the different seismic zones and different soil profiles, involving the following parameters as the importance, seismic zoning, soil factor, dynamic amplification factor and seismic force reduction factor, as shown in (Table 6).

Table 6. *Normative spectral pseudo-acceleration for the building under study.*

	Peru	***Chile***	***Ecuador***
Spectral Acceleration (Sa)	$S_a = \frac{ZUCS}{Rp} g$	$S_a = \frac{SAo \propto}{(\frac{R^*}{I})}$	$Sa = \frac{ISa(Ta)}{R\emptyset p\emptyset e} g$ *(Adapted for uniform representation)*
Building category (U, I)	*Category C* *U=1 (Table 5)*	*Category II* *I=1 (Table 4.3, 6.1)*	*Category: other structures* *I=1 (Table 6)*
Seismic force reduction factor (Rp, R*, R)	$Rop = \begin{Bmatrix} 7\ (Dual) \\ 8\ (Porche) \end{Bmatrix}$ *(Table 7)* *Ia=1 (Table 8)* *Ip=0.75 (Table 9)* *Rp=Rop.Ia.Ip*	*Ro=11 (Table 5.1)* $T^* = \begin{Bmatrix} 0.79s\ (Dir.X) \\ 0.71s\ (Dir.Y) \end{Bmatrix}$ *To (Table 6.3)* $R^* = 1 + \frac{T^*}{0.10T_o + \frac{T^*}{R_o}}$	*R=8 (Table 15)* *∅p=0.9 (Table 13)* *∅e=1 (Table 14)*
Amplification factor (*) ***(C, α, various)*** *(*) adapted for comparative purposes*	$\begin{cases} C = 2.5,\ T < Tp \\ C = 2.5\left(\frac{Tp}{T}\right),\ Tp < T < \\ C = 2.5\left(\frac{Tp*TL}{T^2}\right),\ Tp < T < \end{cases}$ *"Tp" y "TL" (Table 4)* *(Soil-dependent)*	$\propto = \frac{1+4.5(\frac{T_n}{T_o})^p}{1+(\frac{T_n}{T_o})^3}$ *"To" (Table 6.3)* *"p" (Table 6.3)* *(Soil-dependent)*	$\begin{cases} Fa\left[1 + (n-1)\frac{T}{Toe}\right], & T \leq \\ Fa, & 0 \leq T \leq Tc \\ Fa(\frac{Tc}{T})^r, & T > Tc \end{cases}$ *"n", "Toe", "Tc" (Art. 3.3.1)* *(Dependent on soil and zoning)*
Factor of soil (S, Fa, Fd, Fs)	*"S" (Table 3)* *"Tp" and "TL" (Including in the factor of amplification)*	*"S" (Table 6.3)* *"To" y "p" (Including in the factor of amplification)*	*"Fa" (Table 3)* *"Fd" (Tabla 4)* *"Fs" (Tabla 5)* *(Including in the factor of amplification)*

DOI: 10.7764/RIC.00057.21

Note: The references are in accordance with the provisions of each standard. In addition, the meaning of each factor indicated: "Z" and "Ao" Seismic zonation, "Ia" and "Øe" Irregularity in height, "Ip" and "Øp" Irregularity in plan (with presence of torsional irregularity), "T" Period with higher translational mass in the direction of analysis, "Rop" Basic seismic forces reduction coefficient, "Ro" Structural response modification factor, "Rp" Seismic force reduction coefficient, "R*" reduction factor, "R" response reduction factor, "Fa" Basic seismic forces reduction coefficient, "Fd" amplification of the ordinates of the elastic displacement response spectrum for rock design, "Fs " nonlinear behavior of soils, "p" and "To" parameter depending on the soil type, "n" spectral amplification, "T" and "Tn" period of vibration of the nth mode.*

(Figure 2) shows a comparative graph of the seismic amplification factor, (Figure 3), (Figure 4), (Figure 5) and (Figure 6) show the normative spectra of each country according to the different soil profiles, seismic zoning and type of building (structural system, period, importance, seismic reduction factor and seismic amplification factor). For the presentation of the graphs, Peru has been identified with "(P)", Chile "(Ch)" and Ecuador "(E)"; directionality with "X" and "Y"; the seismic zoning for Peru with "Z1", "Z2", "Z3" and "Z4", for Chile with "Ao1", "Ao2", "Ao3", for Ecuador with "Z1", "Z2", "Z3" , "Z4", "Z5" and "Z6", the soil profiles for Peru with "So", "S1", "S2" and "S3", for Chile and Ecuador with "A", "B", " C ", "D" and "E".

The normative spectra were studied with respect to several parameters involved as detailed in (Table 6), highlighting among them the amplification factor of accelerations, which involves variables strongly associated to the soil profile as the Peruvian and Chilean case presenting a single amplification diagram for each type of soil in all its seismic zones, however the Ecuadorian case also involves variables associated to the seismic zoning presenting six amplification diagrams for each type of soil as we can evidence, for example, plotting the amplification factors for a soft soil (S3, E) in the different seismic zones of each country (Figure 2).

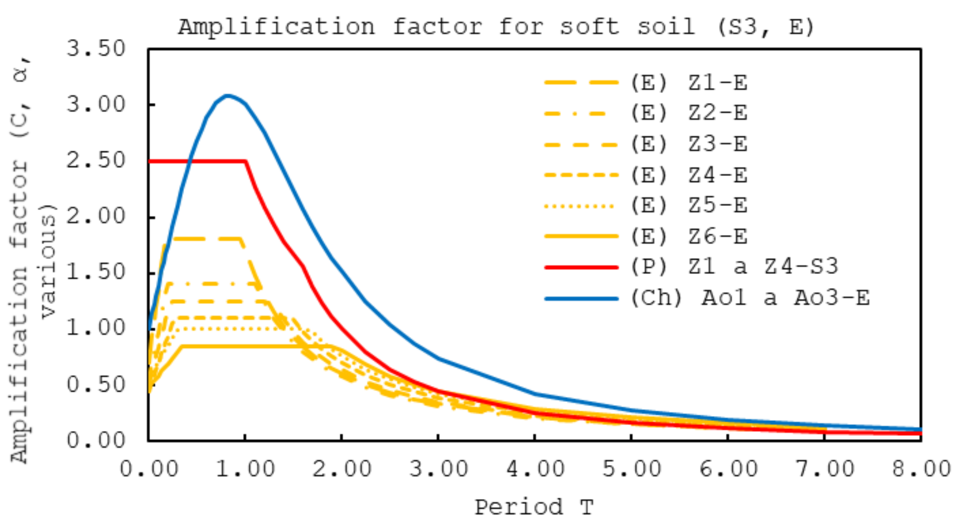

***Figure 2.** Amplification factor for soft soil (S3, E).*

2.5.1. Spectral ordinates for short periods

The ranges of comparison between zones and soils were established according to (Table 4) and (Table 5), finding in the region of short periods that for hard rock type soils, very dense soils, and very dense soils, the following are found. The predominant spectral ordinates in descending order correspond in general to Peru, Ecuador and Chile, and in some cases to Peru, Chile and Ecuador, with percentage values that vary between 47% and 85% for Ecuador with respect to Peru and between 51% and 64% for Chile with respect to Peru, see (Figure 3), (Figure 4) and (Figure 5).

However, for short periods in soft soils (S3, E) in all zones (coast, highlands and highlands/high jungle), the highest spectral values are presented for Chile followed alternatively by Peru and Ecuador, with ratios that vary between 32% and 94% with respect to Chile, see Figure 6.

DOI: 10.7764/RIC.00057.21

For short periods in areas classified as jungle, the ranges of comparison correspond, due to their geographical region, to Ecuador and Peru, finding ratios that vary between 78% and 100% for Peru with respect to Ecuador, see (Figure 3); (Figure 4); (Figure 5) and (Figure 6).

2.5.2. Spectral ordinates for fundamental period (Tx=0.79)

For the fundamental period of the building in the "X" direction in hard rock type soil (So, A) in the coastal, highland and highland/high jungle zones, the highest spectral values are presented for Peru followed alternatively by Ecuador and Chile, with ratios that vary between 36% and 96% with respect to Peru (Figure 3). For very dense soils and firm soil, and for the different coastal, highland and highland/high jungle zones, the highest spectral ordinates correspond in general to Peru, Ecuador and Chile, and in some cases to Peru, Chile and Ecuador, with percentage values that vary between 48% and 78% for Ecuador with respect to Peru and between 40% and 50% for Chile with respect to Peru (Figure 4) and (Figure 5). For soft soils (S3, E) in the coastal, highland and highland/high jungle zones, the highest spectral values are found for Chile, followed alternately by Peru and Ecuador with ratios varying between 32% and 94% with respect to Chile (Figure 6).

For the period under study in the jungle region (Ecuador and Peru) and in hard rock, very dense soils and soft soils, the percentage values vary between 57% and 98% for Peru with respect to Ecuador. However, for intermediate soils (S2, C and D) in the same area the percentage is 75% for Ecuador with respect to Peru.

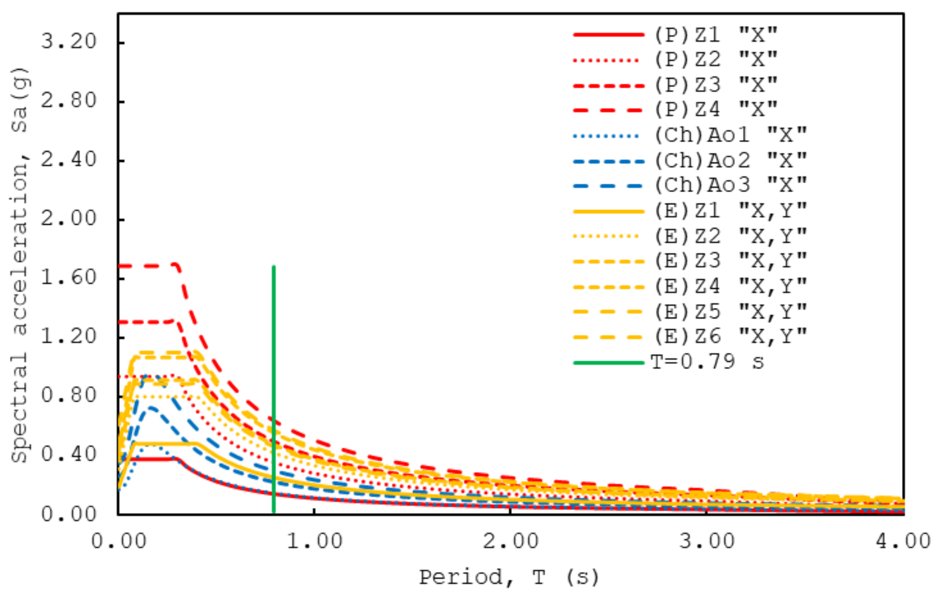

Figure 3. *Spectral acceleration in hard rock (So, A).*

Revista Ingeniería de Construcción RIC
Vol 38 Nº1 2023 www.ricuc.cl
DOI: 10.7764/RIC.00057.21

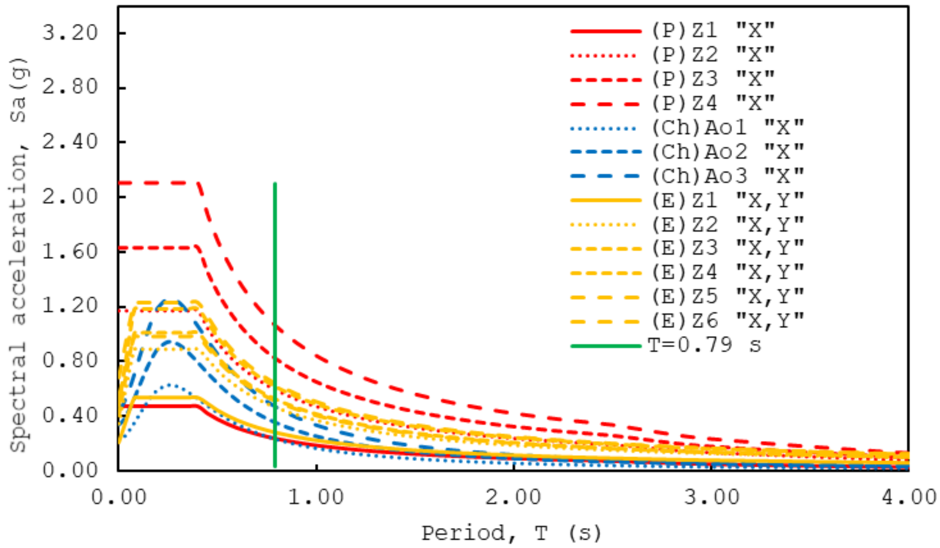

Figure 4. *Spectral acceleration in very dense soils (S1, B).*

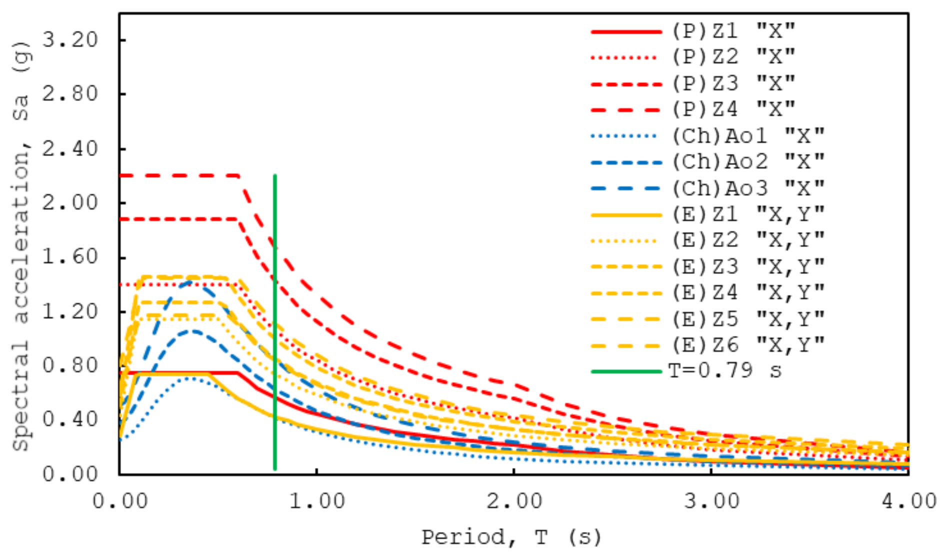

Figure 5. *Spectral acceleration on solid ground (S2, C y D).*

DOI: 10.7764/RIC.00057.21

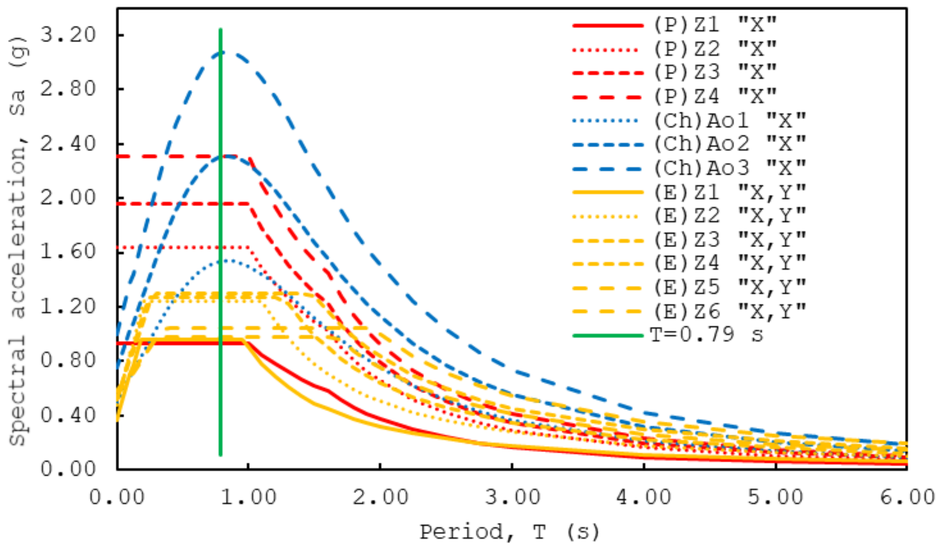

Figure 6. *Spectral acceleration on soft soil (S3, E).*

3. Results and discussion

The results of the shear force at the base and the relative displacements according to each seismic zonation and soil type were determined by means of the dynamic modal spectral analysis according to each normative. The graphical results were presented using the symbology indicated in the section corresponding to the normative spectra.

3.1. Treatment of displacements and regulatory limits

The limits established in the standards were made compatible in a proposal that contemplates equivalent values with respect to the maximum displacements as shown in (Table 7), covering the study of regular and irregular cases of the torsional type (result of the analysis process of the building under study).

Tabla 7. *Conditioned normative limits for the evaluation of permissible displacements.*

	Peru	Chile	Ecuador
Limit normative	*0.007* *E.030/Table 11* $\Delta_i = \delta_e \binom{0.75R}{0.85R}$ *vs 0.007h*	*0.002* *Nch433/Art. 5.9* $\Delta_{e_{cm}} = \delta_{e_{cm}}$ *vs 0.002h* $\Delta_e = \delta_e$ *vs* *0.002h+0.001h*	*0.02* *Nec/Art. 6.3.9* $\Delta_i = \delta_e\,(0.75R)$ *vs 0.02h*
Displacements sides relative comparable	$(\frac{\delta_e}{h_i}) = \frac{0.007}{0.75R} = 0.00133$ *(Eq.1)* $(\frac{\delta_e}{h_i}) = \frac{0.007}{0.85R} = 0.00157$ *(Eq.2)* $(\frac{\delta_e}{h_i}) = \frac{0.007}{0.75R} = 0.00117$ *(Eq.3)* $(\frac{\delta_e}{h_i}) = \frac{0.007}{0.85R} = 0.00137$ *(Eq.4)*	$:\Delta_{E\,cm} = \left(\frac{\delta_e}{h_i}\right)_{cm} =$ 0.002 $\Delta_{E_{max}} = \left(\frac{\delta_e}{h_i}\right)_{cm} +$ $0.001 =$ *0.003 (Eq.5)*	$(\frac{\delta_e}{h_i}) = \frac{0.02}{0.75R} = 0.0033$ *(Eq.6)*

Note: The references are in accordance with the provisions of each standard. Additionally, the meaning of each indicated factor is indicated: δ_e : Lateral displacement of mezzanine with reduced seismic actions, $\delta_{e_{cm}}$: Maximum relative displacement between two consecutive floors measured at the center of mass, Δ_i: Inelastic lateral displacement, Δ_e: Elastic lateral displacement, h: Height of story. Peru with dual system (Regular structures R=7 (Equation.1), Irregular structures R=5.25 (Equation.2)) and with gantry system (Regular structures R=8 (Equation 3); Irregular structures R=6 (Equation 4)). Chile with mixed systems (walls and frames) (Equation 5), Ecuador with dual systems and frames for regular and irregular structures R=8 (Equation 6).

DOI: 10.7764/RIC.00057.21

3.2. Base shear force

The results, by shear force, are coherent with what was found for the spectral ordinates in the period under study (item 2.5.2), the magnitudes of the basal force are found in (Figure 7), (Figure 8) , (Figure 9) and (Figure 10), the shears have been obtained from the spectral modal dynamic analysis, and for comparative effects any type of scaling for design purposes has been disregarded, highlighting that for a profile classified as hard rock the minimum shear corresponds to Peru for the jungle zone with a basal coefficient of 1.4% (shear force / weight of the building), and for the coastal zone in the same soil profile, the maximum basal coefficient is 6.5%, also corresponding to Peru (see Figure 7).

It can be affirmed that the general tendency in the profiles catalogued as very dense soils and firm soil (according to the proposal given in (Table 5) is basically the same as the hard rock profile, with the minimum and maximum values corresponding to Peru, finding basal coefficients between 2.4% and 17.1% as shown in (Figure 8) and (Figure 9). However, for the soil profile catalogued as soft, the minimum values correspond to Peru and Ecuador, and the maximum corresponds to Chile with percentages that vary between 9.5% and 18.2% (see Figure 10).

In general, the shear magnitudes range from 300 kN to 6395 kN for all soils, for all zones and for all countries, being the lowest of all for the jungle zone and the highest of all for the coastal region, in "hard rock" and "soft soil" respectively.

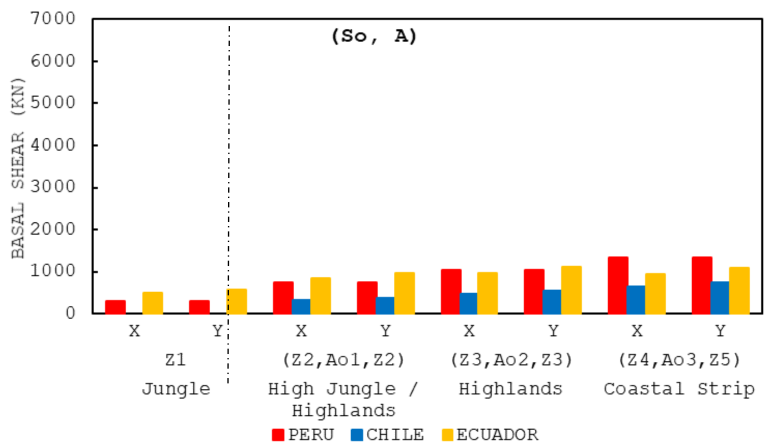

***Figure 7.** Basal shear in hard rock (So, A).*

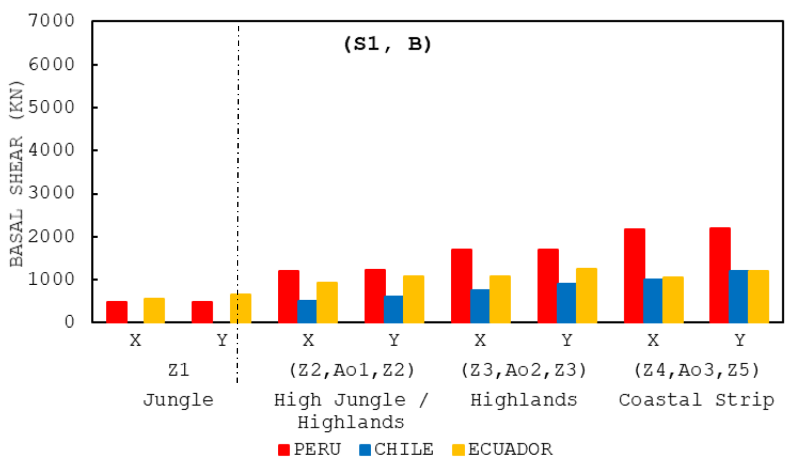

***Figure 8.** Basal shear in very dense soils (S1, B).*

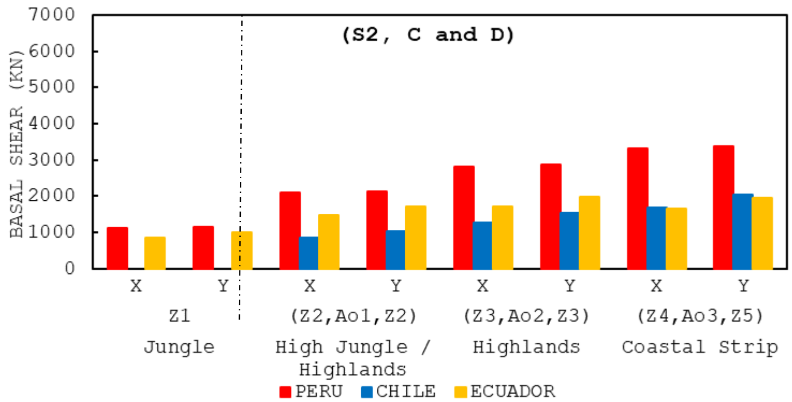

Figure 9. *Basal shear on firm soil (S2, C and D).*

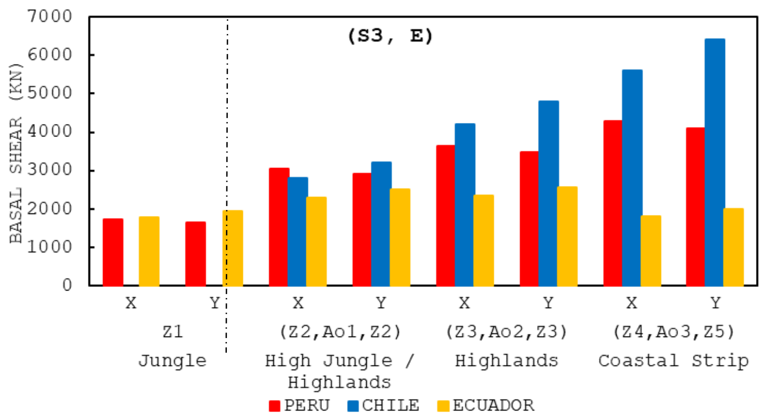

Figure 10. *Basal shear in soft soil (S3, E).*

3.3. Relative displacement due to reduced seismic forces

The displacements have been estimated for reduced seismic demands, making the results obtained for the different standards comparable according to the proposals established in (Table 4), (Table 5), (Table 6) and (Table 7).

Given the abundance of results and in favor of highlighting the most relevant ones, (Table 8) presents the relationships between the relative displacements of inter-story for the different seismic zones with respect to the most demanded zone with soft soil profile. The same (Table 8) identifies, for example for Chile, as 100% to the maximum displacements estimated in that country and as 5% to the minimum ones, being these percentage relations with respect to the maximum displacement of the country; in the same way values are presented for Peru and Ecuador.

Table 8. *Displacement relationships for different soil types and zones.*

Displacement "i"/ maximum displacement for Peru					
Zone	***Type of soil***				***Geographical region***
	So	***S1***	***S2***	***S3***	
Z1	*6%*	*11%*	*26%*	*40%*	*Jungle*
Z2	*16%*	*27%*	*49%*	*71%*	*High Jungle / Highlands*
Z3	*23%*	*38%*	*66%*	*85%*	*Highlands*
Z4	*29%*	*49%*	*77%*	*100%*	*Coastal Strip*
Displacement "i"/ maximum displacement for Chile					
Zone	***Type of soil***				***Geographical region***
	A	***B***	***C y D***	***E***	
Ao1	*5%*	*8%*	*15%*	*50%*	*High Jungle / Highlands*

DOI: 10.7764/RIC.00057.21

Ao2	*8%*	*13%*	*22%*	*75%*	*Highlands*
Ao3	*10%*	*17%*	*29%*	*100%*	*Coastal Strip*
Displacement "i"/ maximum displacement for Ecuador					
Zone	***Type of soil***				***Geographical region***
	A	***B***	***C y D***	***E***	
Z1	*20%*	*23%*	*35%*	*74%*	*Jungle*
Z2	*34%*	*38%*	*61%*	*96%*	*High Jungle / Highlands*
Z3	*39%*	*43%*	*70%*	*98%*	*Highlands*
Z4	*45%*	*51%*	*82%*	*100%*	
Z5	*38%*	*42%*	*69%*	*75%*	*Coastal Strip*
Z6	*47%*	*52%*	*91%*	*80%*	

Note: For Direction "X"; Z(i) and Ao(i)= Seismic zone, Soil type= So, S1, S2, S3, A, B, C, D and E.

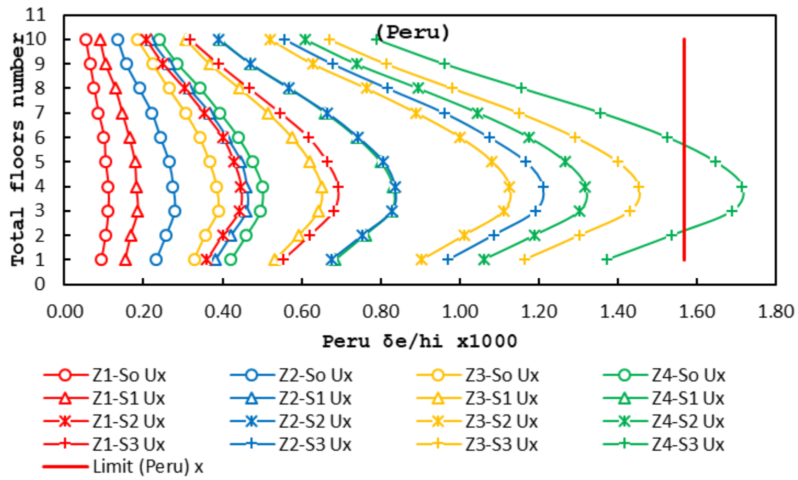

Figure 11. *Relative displacement by reduced seismic forces for the Peruvian standard E.030.*

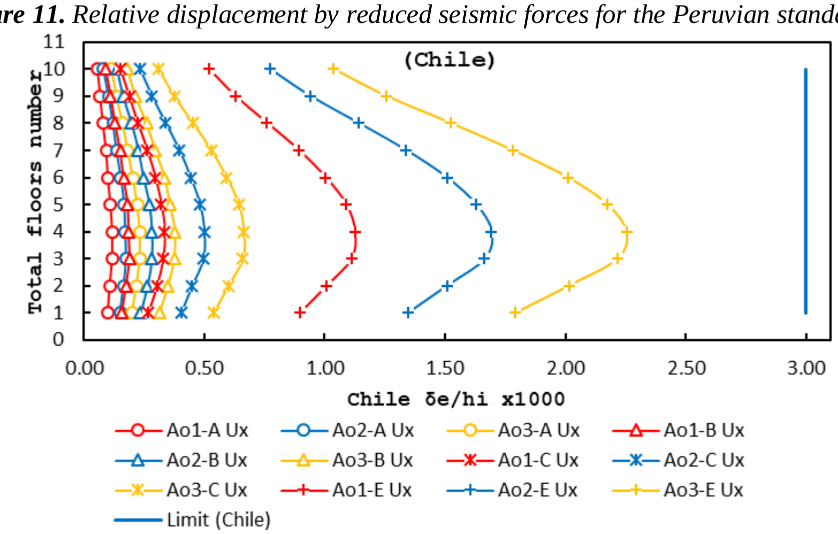

Figure 12. *Relative displacement by reduced seismic forces for Chilean standard Nch433.*

DOI: 10.7764/RIC.00057.21

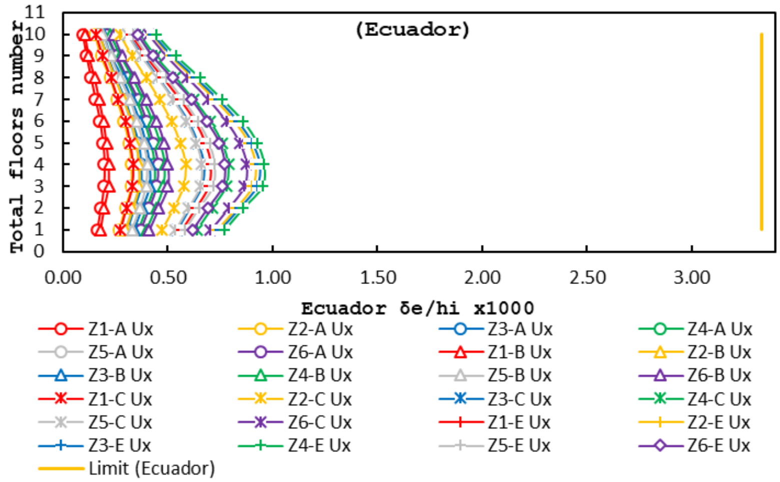

Figure 13. *Relative displacement by reduced seismic forces for the Ecuadorian NEC standard.*

(Table 9) shows the maximum results for the "X" direction, obtained according to each standard and for the building under study, finding that the maximum relative displacements, in a hard rock type profile are: for Peru 0.00050 (<0.00157), for Chile 0.00023(<0.00300), and for Ecuador 0.00045(<0.00333). In the same sense, for a soft soil profile the results are: for Peru 0.00171(>0.00157), for Chile 0.00225(<0.00300), and for Ecuador 0.00077(<0.00333); noting that the most restrictive limit has been surpassed in the Peruvian case (according to the comparative proposal in (Table 7)), the detail of the results is presented numerically in (Table 9) and graphically in (Figure 14), (Figure 15), (Figure 16) and (Figure 17).

Table 9. *Maximum relative displacements.*

Maximum relative displacement (dimensionless)						
Hard rock profile (So, A)						
Peru		***Chile***		***Ecuador***		***Geographical region***
Zone	*X (o/oo)*	***Zone***	*X (o/oo)*	***Zone***	*X (o/oo)*	
Z1(0.10g)	*0.111*			*Z1(0.15g)*	*0.196*	*Jungle*
Z2(0.25g)	*0.279*	*Ao1(0.20g)*	*0.118*	*Z2(0.25g)*	*0.325*	*High Jungle / Highlands*
Z3(0.35g)	*0.389*	*Ao2(0.30g)*	*0.175*	*Z3(0.30g)*	*0.371*	*Highlands*
				Z4(0.35g)	*0.436*	
Z4(0.45g)	*0.500*	*Ao3(0.40g)*	*0.232*	*Z5(0.40g)*	*0.361*	*Coastal Strip*
				Z6(0.50g)	*0.454*	
Very dense soil profile (S1, B)						
Peru		***Chile***		***Ecuador***		***Geographical region***
Zone	*X (o/oo)*	***Zone***	*X (o/oo)*	***Zone***	*X (o/oo)*	
Z1(0.10g)	*0.186*			*Z1(0.15g)*	*0.218*	*Jungle*
Z2(0.25g)	*0.461*	*Ao1(0.20g)*	*0.189*	*Z2(0.25g)*	*0.361*	*High Jungle / Highlands*
Z3(0.35g)	*0.650*	*Ao2(0.30g)*	*0.282*	*Z3(0.30g)*	*0.414*	*Highlands*
				Z4(0.35g)	*0.486*	
Z4(0.45g)	*0.832*	*Ao3(0.40g)*	*0.379*	*Z5(0.40g)*	*0.404*	*Coastal Strip*
				Z6(0.50g)	*0.500*	
Firm ground profile (S2, C and D)						
Peru		***Chile***		***Ecuador***		***Geographical region***
Zone	*X*	***Zone***	*X*	***Zone***	*X*	

	(o/oo)		(o/oo)		(o/oo)	
Z1(0.10g)	*0.446*			*Z1(0.15g)*	*0.336*	*Jungle*
Z2(0.25g)	*0.836*	*Ao1(0.20g)*	*0.336*	*Z2(0.25g)*	*0.586*	*High Jungle / Highlands*
Z3(0.35g)	*1.125*	*Ao2(0.30g)*	*0.500*	*Z3(0.30g)*	*0.675*	*Highlands*
				Z4(0.35g)	*0.789*	
Z4(0.45g)	*1.318*	*Ao3(0.40g)*	*0.664*	*Z5(0.40g)*	*0.661*	*Coastal Strip*
				Z6(0.50g)	*0.875*	
			soft soil profile (S3, E)			
Peru		***Chile***		***Ecuador***		***Geographical region***
Zone	*X (o/oo)*	***Zone***	*X (o/oo)*	***Zone***	*X (o/oo)*	
Z1(0.10g)	*0.693*			*Z1(0.15g)*	*0.707*	*Jungle*
Z2(0.25g)	*1.211*	*Ao1(0.20g)*	*1.125*	*Z2(0.25g)*	*0.918*	*High Jungle / Highlands*
Z3(0.35g)	*1.454*	*Ao2(0.30g)*	*1.693*	*Z3(0.30g)*	*0.939*	*Highlands*
				Z4(0.35g)	*0.961*	
Z4(0.45g)	*1.714*	*Ao3 (0.3g)*	*2.254*	*Z5(0.40g)*	*0.725*	*Coastal Strip*
				Z6(0.50g)	*0.771*	

Nota: X= Direction "X"; Z(i)= Seismic zone.

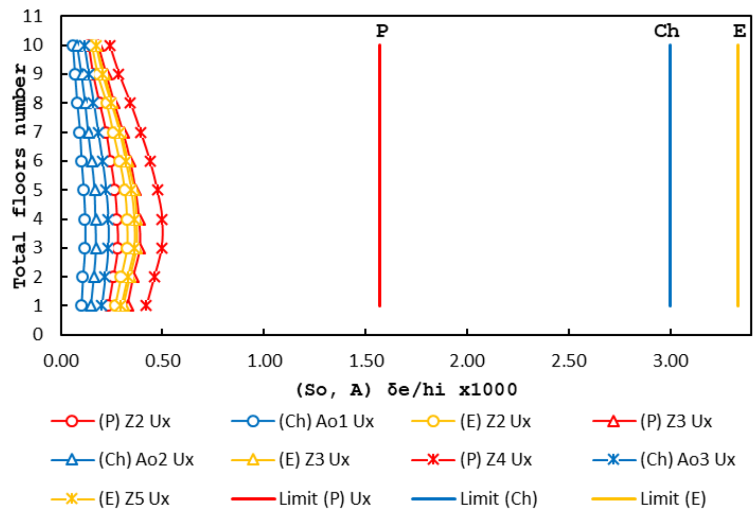

Figure 14. *Maximum relative displacement in hard rock (So, A).*

Revista Ingeniería de Construcción RIC
Vol 38 Nº1 2023 www.ricuc.cl
DOI: 10.7764/RIC.00057.21

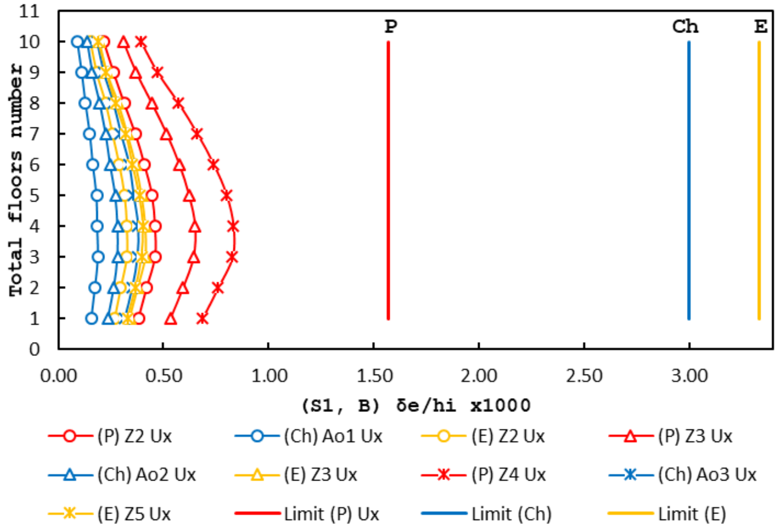

Figure 15. *Maximum relative displacement in very dense soils (S1, B).*

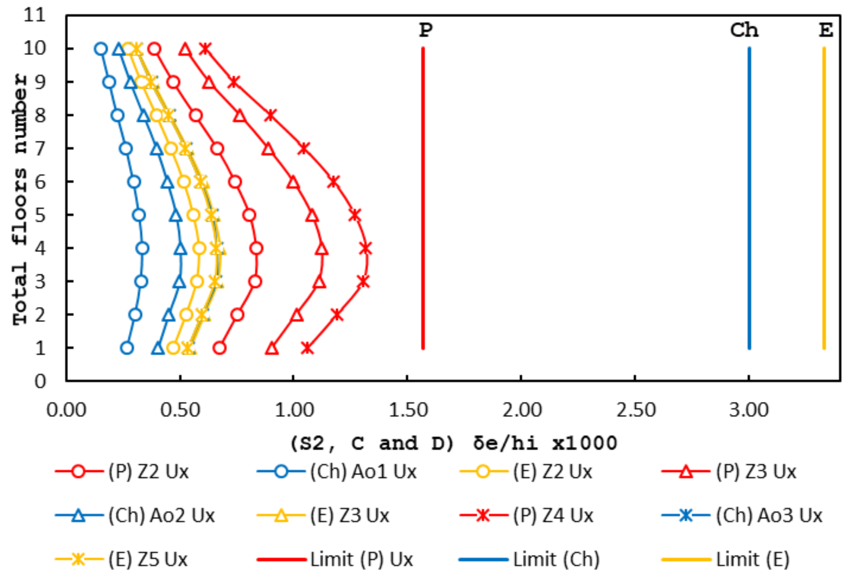

Figure 16*. Maximum relative displacement on firm soil (S2, C and D).*

DOI: 10.7764/RIC.00057.21

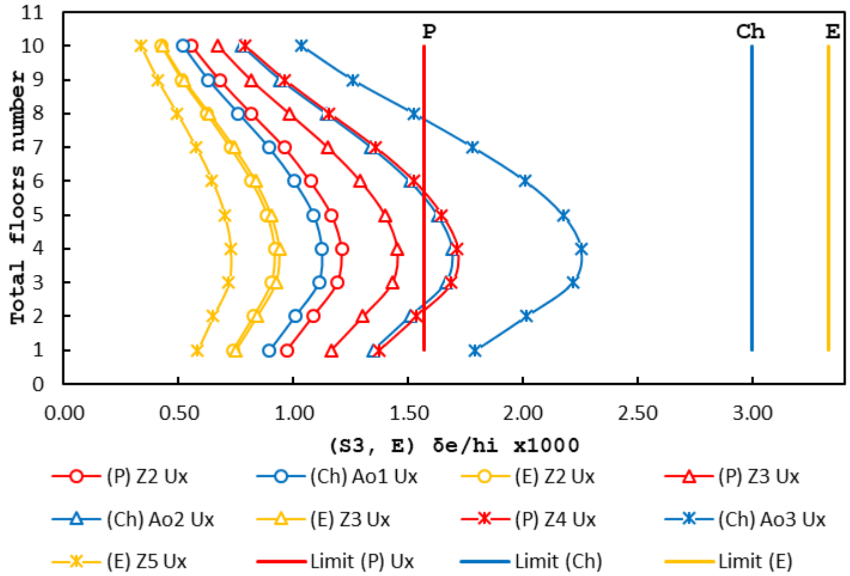

Figure 17. *Maximum relative displacement on Soft soil (S3, E).*

4. Conclusiones

The seismic response of a reinforced concrete building representative of modern multifamily residences in southern Peru, have been evaluated in accordance with the current South American seismic standards of Peru (E0.30, 2018), Chile (NCh433, 2012) and Ecuador (NEC, 2015), using the spectral modal analysis and with a uniform treatment of results, for this purpose, four groups of compatible soils have been generated, the seismic zones have been grouped in four according to compatible geographical regions, a uniform treatment of the relative displacements in the elastic range has been proposed and the limits established in each standard have been made compatible. It has been found that the maximum displacements in the "soft soil" and most demanded seismic zone correspond to Chile, however, in the rest of seismic zones and soil profiles the maximum values correspond to Peru.

The shear forces at the base for the fundamental periods of the building under study in the different seismic zones and for the different soil profiles present diverse values, finding that these oscillate between 1.4% and 18.2% of the weight of the building. In relation to the spectra, the seismic force reduction factors for the soft soil type present calculated values for Peru Rp=5.25, for Chile R=5.118 and for Ecuador RØeØp =7.2, however, R* is a different value in each type of soil, therefore, it has been found that the highest demands correspond in general to Peru, however, the maximum spectral ordinates established for the "soft soil" and the most demanded seismic zone corresponds to Chile, with a maximum spectral value of 3.1g, in the same sense it has been found that for the same zone and soil in Ecuador there is 1.0g and in Peru 2.3g.*

The maximum relative displacements for the building under study and considering all the standards, have been produced for Peru in the most demanded seismic zone and in the "soft ground" with calculated values in the elastic range of 1.71 (o/oo) (equivalent to 7.6 (o/oo) in the inelastic range), exceeding the limit established according to the Peruvian standard of 7.0 (o/oo) (equivalent to 1.57 (o/oo) in the elastic range for a building with torsional irregularity). The above has been proposed in the context of a uniform treatment of results considering in detail the different variables and limits established in the current standards of Peru, Chile and Ecuador. Additionally, it has been found, among others, that the maximum relative elastic displacements in the coastal zones of each country and considering a soil profile classified as very dense, correspond to 0.832 (o/oo) for Peru, 0.379 (o/oo) for Chile and 0.404 (o/oo) for Ecuador. Likewise, in relation to the permissible regulatory limits, it is found that these vary in the elastic range between 1.372 (o/oo) and 3.333 (o/oo) for Perú, Chile and Ecuador, finding that the most restrictive limits, in reinforced concrete buildings, correspond to Peru.

It is finally concluded that this type of studies are very important in order to identify the diverse variables associated to the seismic response of a building, considering compatible seismic regions and uniform soil profiles, so it allows to contribute in the improvement in which it is seen the differences between each norm of the South American seismic norms under a continental approach given the similar seismic source genes present in the studied countries.

5. References

A.010. (2021). *Norma Tecnica A.010 "Condiciones generales de diseño" del reglamento nacional de edificaciones.* Ministerio de vivienda, construccion y saneamieto.

A.120. (2019). *Norma Tecnica A.120 "Accesibilidad Universal en Edificaciones"del reglamento de edificaciones*. Ministerio de vivienda, construccion y saneamieto.

Blanco, A. (1994). *Estructuración y Diseño de Edificaciones de Concreto Armado*. Consejo Departamental de Lima.

Delgado, G. (2011). *Diseño Estructuras Aporticadas de Concreto Armado* (Novena Edi). EDICIVIL S.R.Ltda.

Doğangü, A., and Livaoğlu, R. (2006). A comparative study of the design spectra defined by Eurocode 8, UBC, IBC and Turkish Earthquake Code on R/C sample buildings. *Journal of Seismology*, *10*(3), 335–351. https://doi.org/10.1007/S10950-006-9020-4

E.020. (2006). *Norma Tecnica E.020 "Cargas" del reglamento nacional de edificaciones*. Ministerio de vivienda, construccion y saneamieto.

E.030. (2018). *Norma Técnica E.030 "Diseño Sismorresistente" del reglamento nacional de edificaciones*. Ministerio de vivienda, construccion y saneamieto.

E.060. (2009). *Norma Tecnica E.060 "Concreto Armado" del reglamento nacional de edificaciones*. Ministerio de vivienda, construccion y saneamieto.

El-Kholy, A. M., Sayed, H., and Shaheen, A. A. (2018). Comparison of Egyptian Code 2012 with Eurocode 8-2013, IBC 2015 and UBC 1997 for seismic analysis of residential shear-walls RC buildings in Egypt. *Ain Shams Engineering Journal*, *9*(4), 3425–3436. https://doi.org/10.1016/J.ASEJ.2018.07.004

EM.070. (2019). *Norma Tecnica EM.070 "Transporte mecánico" del reglamento nacional de edificaciones*. Ministerio de vivienda, construccion y saneamieto.

Faizian, M., and Ishiyama, Y. (2004). *COMPARISON OF SEISMIC CODES OF 1981 JAPAN (BSLJ), 2000 USA (IBC) AND 1999 IRAN (ICS)*. The Thailand Research Fund (TRF). http://www.thaiseismic.com/comparison-of-seismic-codes-of-1981-japan-bslj-2000-usa-ibc-and-1999-iran-ics/

Fenwick, R., Lau, D., and Davidson, B. (2002). A comparison of the seismic design requirements in the New Zealand loadings standard with other major design codes. *Bulletin of the New Zealand Society for Earthquake Engineering*, *35*(3), 190–203. https://doi.org/10.5459/BNZSEE.35.3.190-203

Giri, P., Bhatt, A. D., Gautam, D., and Chaulagain, H. (2018). Comparison between the seismic codes of Nepal, India, Japan, and EU. *Asian Journal of Civil Engineering*, 20(2), 301–312. https://doi.org/10.1007/S42107-018-0102-8

Jiménez, C., Saavedra J., and Moreno, N. (2021). Seismic source characteristics of the 2016 Pedernales-Ecuador earthquake (Mw 7.8). *Physics of the Earth and Planetary Interiors*, *312*(June 2020). https://doi.org/10.1016/j.pepi.2021.106670

Khose, V. N., Singh, Y., and Lang, D. H. (2012). A Comparative Study of Design Base Shear for RC Buildings in Selected Seismic Design Codes: *Earthquake Spectra*, 28(3), 1047–1070. https://doi.org/10.1193/1.4000057

Morales, R. (2006). *Diseño en Concreto Armado*. Instituto de la Construccion y Gerencia.

Moreno, R., and Bairán, J. (2012). Evaluación sísmica de los edificios de mampostería típicos de Barcelona aplicando la metodología Risk-UE. *Revista Internacional de Metodos Numericos Para Calculo y Diseno En Ingenieria*, *28*(3), 161–169. https://doi.org/10.1016/j.rimni.2012.03.007

Nahhas, T. M. (2011). A comparison of IBC with 1997 UBC for modal response spectrum analysis in standard-occupancy buildings. *Earthquake Engineering and Engineering Vibration*, *10*(1), 99–113. https://doi.org/10.1007/S11803-011-0050-8

NCh433. (2012). *NCh 433. of1996 modificada en 2012"Diseño sísmico de edificios"*. Instituto nacional de normalizacion.

NEC. (2015). *La Norma ecuatoriana de la construcción NEC 2015, Codigo NEC-SE-DS: "Peligro Sísmico, diseño sísmo resistente."* Ministerio de desarrollo urbano y vivienda.

Pong, W., Gannon, G. A., and Lee, Z. H. (2007). A comparative study of seismic provisions between the international building code 2003 and Mexico's manual of civil works 1993. *Advances in Structural Engineering*, *10*(2), 153–170. https://doi.org/10.1260/136943307780429699

Riesco, G., Arela, R., and Malaver, L. (2021). *Presupuesto público en el sur del Perú : Indicadores en el Bicentenario*. Universidad Católica San Pablo. https://ucsp.edu.pe/wp-

DOI: 10.7764/RIC.00057.21

content/uploads/2021/06/Presupuesto-publico-en-el-sur-del-Peru.pdf
Ruiz, S., and Madariaga, R. (2018). Historical and recent large megathrust earthquakes in Chile. *Tectonophysics*, *733*, 37–56. https://doi.org/10.1016/j.tecto.2018.01.015
Tavera, H. (2014). *Evaluacion del peligro asociado a los sismos y efectos secundrios en Perú*. Instituto Geofisico del Perú.