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Seismic Analysis of a Two-Story Confined Masonry House: Comparative Study of Seismic-Resistant Standards E.030, NSR-10 and Nch433

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***Abstract* -** Earthquakes are a significant threat in countries with high seismic activity such as Peru, Chile, and Colombia, where the application of earthquake-resistant regulations is essential to ensure structural safety. The objective of this research is to determine the discrepancies in the use of criteria and designs of the earthquake-resistant regulations E.030 versus Nch433 and NSR-10, as well as how these affect loads, drifts, and accelerations. This is obtained through a comparative analysis of basal shear forces, story drifts, and spectral accelerations. Therefore, a model of a two-story confined masonry house located in San Juan de Miraflores, Lima, is made using Etabs software and complying with the minimum requirements of standard E.070. NSR-10 showed the greatest strength. basal shear with a value of 422.94 Tonf on both the "X" and "Y" axes by means of analysis Linear static. On the other hand, the highest incidence of drifts with respect to their maximum permissible drifts was obtained with the E.030 standard with a value of 4.905% by linear static analysis and the highest incidence by spectral modal analysis was obtained with the same standard with a value of 5.31%. These significant differences in shear forces at the base are mainly due to the different expressions and criteria used for calculating shear, in addition to the different considerations for the use of loads in buildings. Standards E.030 and NSR-10 for calculating shear forces at the base in linear static analysis use an expression obtained from their spectra; however, the Chilean standard NCH433 does not use an expression based on its spectrum, but rather a completely different formula.

***Keywords*:** Confined masonry, seismic analysis, drifts, basal shear force, spectral acceleration

1. Introduction

In the seismically active regions of the Pacific Ring of Fire, ensuring the structural safety of buildings is essential. In Latin America, confined masonry housing is widely used due to its low cost and ease of construction [1]. However, the criteria for the earthquake-resistant regulations governing these buildings vary across countries. In this regard, it is essential to analyze the similarities and differences between Peru's E.030 regulation, Chile's Nch433 regulation, and Colombia's NSR-10 regulation, three countries with high seismic activity and distinct regulatory approaches to structural safety.

Various investigations have analyzed the performance seismic of buildings, highlighting the differences in the regulation's earthquake-resistant [2, 1, 3]. These regulations they have evolved in answer to local experiences with earthquakes and advances technological in engineering structural [4]. In this In this sense , the evolution of regulations is highlighted in Latin America and its impact in the resistance structural of buildings [5]. In addition, the importance of updating is emphasized are regulations in function of the data seismic further recent [6].

Understanding the evolution and differences in seismic design codes allows for improved seismic classification and assessment of construction sites [4]. However, comprehensive comparisons between earthquake-resistant codes in Peru, Chile, and Colombia, especially for confined masonry housing, are still limited. This paucity of comprehensive comparative studies highlights the need for more detailed assessments to better understand the implications of each code on the structural safety of buildings under seismic events.

On the other hand, several studies have performed seismic analysis for confined masonry buildings through numerical modeling [7, 8, 9]. However, they claim that, despite the existence of numerical models to predict the seismic behavior of these structures, there is a deficiency of reliable and generalized models that can predict the behavior in these structures [10].

This highlights the importance of exploring other methods that allow a more precise and detailed analysis of the seismic performance of confined masonry.

This study proposes a comparative analysis of the Peruvian seismic code E.030, the Chilean code Nch433, and the Colombian code NSR-10. The code is applied to a representative model of a confined masonry house and uses Etabs software to simulate the structural behavior using the criteria and expressions specific to each code, but for the same soil conditions, especially the acceleration conditions, in all three codes, in order to make a truthful comparison. The parameters to be evaluated include story drifts, base shear forces, and spectral accelerations, allowing the identification of differences and similarities in the design criteria and structural resistance in each code.

This research contributes to the understanding and recognition of the similarities and differences in seismic design criteria, as well as how these affect the resulting loads, story drifts, base shear forces, and spectral acceleration in compliance with each standard. Furthermore, it aims to strengthen the literature on comparing seismic design criteria for each standard, so that future research focused on the same lines of inquiry has a basis from which to draw on this information.

2. Methodology

2.1. Development of a representative model of a confined masonry dwelling

Since our research covers countries such as Peru, Chile, and Colombia, we first compare the materials used in confined masonry dwellings in each country. We also describe the properties of the materials used, the type of soil, and other structural characteristics. We then develop a schematic plan of a confined masonry dwelling, designed according to Peruvian masonry standard E.070. Finally, load measurements are performed using Peruvian standard E.020.

2.2. Seismic analysis with earthquake-resistant regulations

To perform a seismic analysis using ETABS, the material properties are first defined, and the confined masonry structure of the house is modeled. Then, dead and live loads are assigned according to each code, and seismic parameters are configured according to codes E.030, Nch433, and NSR-10 to generate models A, B, and C, respectively. Pseudo-acceleration spectrum and load combinations for each code are also created, and finally, the linear static and modal spectral analysis is performed.

In this final stage, a comparison and evaluation will be conducted in terms of base shear, story drifts, and spectral accelerations for each of the models. The results obtained from each standard will be analyzed and compared to determine differences and similarities. The research will conclude with a comprehensive evaluation of the results, thus achieving the main objective of the study.

3. Structuring a representative model of a confined masonry dwelling

3.1. Dimensions and properties of the home

The dimensions of the structural elements are determined in accordance with Technical Standard E.070. Since laboratory tests were not performed in this study, the material properties specified in the Peruvian Confined Masonry Standard were adopted. These considerations allow for the preliminary dimensioning of the structural elements, whose characteristics and material properties are presented in Table 1.

Table 1: Dimensions of structural elements and material properties.

Dimension of structural elements			**Properties of the materials**	
	Thickness (cm)	Camber (cm)		
Columns	14	25	f'c (kg/cm^2)	210
Walls	14	-	f´b (kg/cm^2)	130
Beams	14	20	Specific weight of masonry (kg/m^3)	1800

Slab	20	-	Specific weight of concrete (kg/m ^{3})	2400

3.2. Representative model of the home

Considering the dimensions of the structure and the properties of the materials, the structural model is carried out in the Etabs software, obtaining a representative model called AC, as shown in Figure 1. This model serves as a basis for carrying out a detailed comparison of the seismic analysis with each regulation.

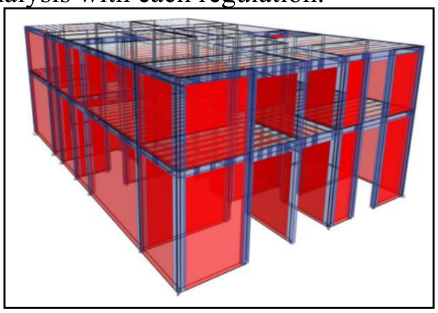

Fig. 1: Representative AC model.

3.3. Seismic parameters

For the determination of seismic parameters according to each regulation, Peruvian standard E.030 is used as a reference. It establishes the project's location in the San Juan de Miraflores district, Lima. This district consists of medium to dense sand deposits, as well as medium-consistency clays and silts [11]. Based on seismic microzonation, the soil profile corresponds to type S_2.

To maintain comparable conditions for comparing regulations, seismic zoning and soil type similar to that defined by Standard E.030 were selected for the other two regulations considered. Based on this information, the seismic parameters corresponding to each standard were determined. Table 2 presents the values adopted in each case.

Table 2: Parameters of standards E.030, NSR-10 and Nch433.

PARAMETERS / STANDARDS	**E.030**	**NSR-10**	**Nch433**
Seismic zoning (g)	0.45	0.45	0.40
Soil type	S_2 $500\ m/s > V_S \geq 180 m/s$	D $360\ m/s > V_S \geq 180\ m/s$	D $V_S \geq 180$
S	1.05	$F_a = 1.05$ $F_v = 1.55$	1.2
Importance factor (I)	1	1	1
R_0	3	2	4
Irregularity	1	0.75	No reference
R	3	1.5	$R^* = 1 + \frac{N \times R_o}{4 T_o \times R_o + N}$

3.3. Load analysis

Once the seismic parameters have been defined according to each standard, the structural analysis is performed using Etabs software. The first step in this process is to assign loads to the structural model, following the guidelines established by each national standard. Table 3 presents the load standards for each country, along with the values adopted for the analysis.

Table 3: Loads with each regulation in comparison.

Loads	E.020 (Peru)	NSR-10 (Colombia)	Nch1537 (Chile)
Live load of mezzanine	200 kg/m ^{2}	180 kg/m ^{2}	203.94 kg/m ^{2}
Roof live load	100 kg/m ^{2}	180 kg/m ^{2}	203.94 kg/m ^{2}
Dead load	Own weight + 100 kg/m ^{2}	Own weight + 320 kg/m ^{2}	Own weight + 141 kg/m ^{2}

3.4. Shear force at the base

Peruvian standard E.030 establishes that the shear force at the base of the structure (V) is determined using equation 1, ensuring that the C/R ratio is not less than 0.11. In addition, an accidental torsional moment must be considered, applying an eccentricity equal to 5% of the largest dimension in the direction analyzed.

According to the Colombian standard NSR-10 (art. A.4.3.1), the basal seismic shear (V_s) is calculated with equation 2, also considering an eccentricity of 5% of the largest perpendicular dimension, in accordance with article A.3.6.7.1.

For its part, the Chilean standard NCh433 (art. 6.2.3) determines the basal shear stress ($Q_{o)}$ using equation 3, and also requires including the accidental torsional effect, calculated as the product between the static force of each level and its respective eccentricity.

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$$V = \frac{Z \cdot U \cdot C \cdot S}{R} \cdot P \tag{1}$$

$$V_s = S_a \cdot g \cdot M \tag{2}$$

$$Q_o = C \cdot I \cdot P \tag{3}$$

From these expressions, the base shear forces of the floor are calculated with each standard. Figures 2 and 3 show the base shear forces with standards E.030, NSR-10 and Nch433 evaluated on the "X" and "Y" axes.

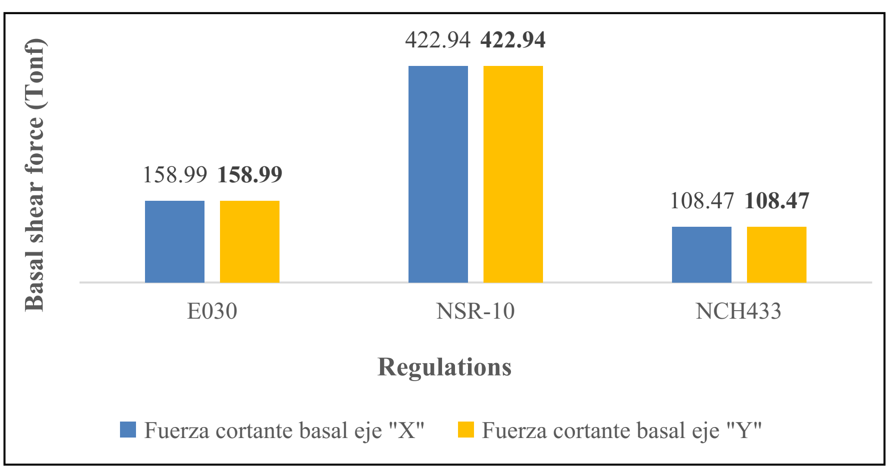

Fig. 2: Comparative graph of the basal shear force (linear static analysis)

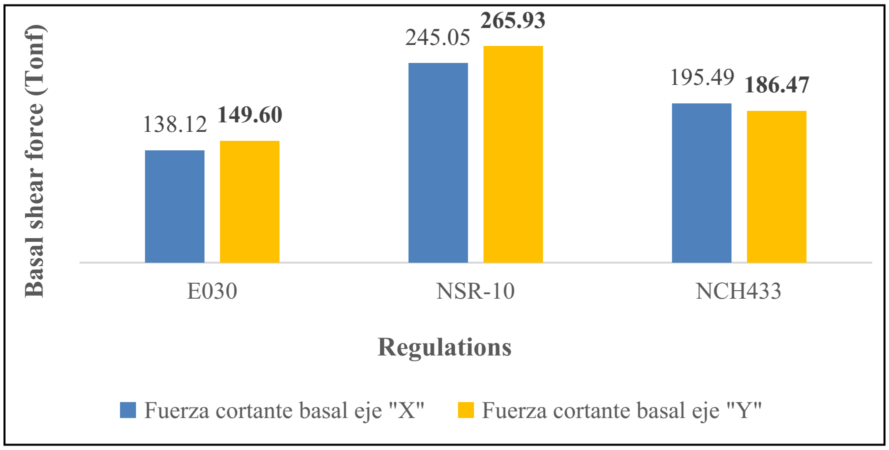

Fig. 3: Comparative graph of the basal shear force (spectral modal analysis)

Figures 2 and 3 show that the base shear forces obtained using the Colombian NSR-10 standard are significantly different, with the forces being higher than those of the other three standards. One of the main reasons is that the Colombian standard assigns greater loads to the structure and uses 100% of the dead load and 100% of the live load in buildings with a live load less than or equal to 180 kg/m^2. Therefore, it can be stated that the structure designed with the NSR-10 will withstand greater seismic loads. However, the E.030 is in third place, below the NSR-10 and the NCH433.

Likewise, it was also identified that in the Peruvian (E.030) and Colombian (NSR-10) regulations, the value of the base shear in the static seismic analysis is determined from formulas derived directly from their respective design spectra. In contrast, the Chilean regulation (NCh433) adopts a different approach, since it establishes the calculation of the base shear using its own formula, without explicitly basing it on the seismic response spectrum. On the other hand, it was not necessary to scale the dynamic shears, since all shears meet the condition that dynamic shears must be at least 80% of the static shears for regular structures.

3.5. Floor drifts

Table 4 presents the maximum permissible drift limits established by the three seismic-resistant standards under analysis, such as the Peruvian standard E.030, the Colombian standard NSR-10, and the Chilean standard NCh433. These restrictions aim to control the lateral deformation of buildings during seismic events, in order to safeguard structural integrity, minimize damage to nonstructural elements, and ensure the safety of occupants. A comparison between these standards reveals differences in the seismic design criteria adopted by each country.

Table 4: Maximum permissible drift limits.

Confined masonry structure	
E.030 (Perú)	$\frac{\Delta \mathrm{i}}{\mathrm{h_i}} = 0.005$
NSR-10 (Colombia)	$0.005h_i$
Nch433 (Chile)	$0.002h_i$

Similarly, the Etabs software calculates the floor drifts for each standard. Figures 5 and 6 show the floor drifts for each standard E.030, NSR-10, and Nch433, using linear static and spectral modal analysis, respectively.

Table 5: Inelastic drifts and permissible drifts with each regulation (linear static analysis)

Rule	Drift direction	Floor	Inelastic Drift	Permissible drift	(%) maximum drift
E.030	Earthquake X	Floor 2	0.000245	0.0050	4.905%
		Floor 1	0.000164	0.0050	3.285%
	Earthquake Y	Floor 2	0.000056	0.0050	1.125%
		Floor 1	0.000061	0.0050	1.215%
NSR-10	Earthquake X	Floor 2	0.000288	0.0125	2.304%
		Floor 1	0.000195	0.0125	1.560%
	Earthquake Y	Floor 2	0.000056	0.0125	0.450%
		Floor 1	0.000074	0.0125	0.592%
Nch433	Earthquake X	Floor 2	0.000075	0.0050	1.500%
		Floor 1	0.000050	0.0050	1.000%
	Earthquake Y	Floor 2	0.000017	0.0050	0.340%
		Floor 1	0.000019	0.0050	0.380%

Table 6: Inelastic drifts and permissible drifts with each regulation (spectral modal analysis)

Rule	Drift direction	Floor	Inelastic Drift	Permissible drift	(%) maximum drift
E.030	Earthquake X	Floor 2	0.000266	0.0050	5.310%
		Floor 1	0.000187	0.0050	3.735%
	Earthquake Y	Floor 2	0.000054	0.0050	1.080%
		Floor 1	0.000059	0.0050	1.170%
NSR-10	Earthquake X	Floor 2	0.000209	0.0125	1.672%
		Floor 1	0.000148	0.0125	1.184%
	Earthquake Y	Floor 2	0.000043	0.0125	0.344%
		Floor 1	0.000046	0.0125	0.368%
Nch433	Earthquake X	Floor 2	0.000237	0.0050	4.740%
		Floor 1	0.000167	0.0050	3.340%
	Earthquake Y	Floor 2	0.000043	0.0050	0.860%
		Floor 1	0.000046	0.0050	0.920%

Regarding drifts and their incidence, it is observed that the highest value close to the drift limit allowed by each regulation, in linear static analysis and spectral modal analysis, corresponds to the Peruvian standard E.030 as shown in Table 5 and Table 6.

On the other hand, each standard establishes different drift limits, as well as different methodologies for seismic analysis. Standards E.030 (Peru) and NCh433 (Chile) use a reduced design spectrum using a seismic reduction factor (R). In contrast, standard NSR-10 (Colombia), Title A, uses an elastic spectrum without applying this reduction factor.
There are also differences in how each standard limits drift. The Chilean and Colombian standards set limits on elastic drift, setting them at 0.2% and 0.5% of the story height, respectively. The Peruvian standard, on the other hand, limits inelastic drift, with maximum values of 0.005 for confined masonry structures.

3.6. Design spectrum

Peruvian standard E.030 establishes that, for each horizontal direction evaluated, an inelastic pseudo-acceleration spectrum (Sa) must be applied, determined using equation 4. In contrast, Colombian standard NSR-10 uses an elastic spectrum, without incorporating the response reduction factor (R) in the initial calculation; however, this factor is subsequently applied in the design of structural elements to reduce seismic forces, as indicated in article A.5.4.1. Therefore, the design spectrum in this standard is calculated using equation 5. Chilean standard NCh433 also considers an inelastic pseudo-acceleration spectrum, which is determined using equation 6.

$$S_a = \frac{Z\cdot U\cdot C\cdot S}{R}\cdot g \tag{4}$$

$$S_a = \frac{A_{a/v}\cdot I\cdot "C"\cdot F_{a/v}}{R} \tag{5}$$

$$S_a = \frac{S\cdot A_o\cdot I\cdot \alpha}{R^*} \tag{6}$$

Figure 6 presents the comparison between the response spectrum of the Peruvian standard E.030, the Colombian standard NSR-10 and the Chilean standard Nch433.

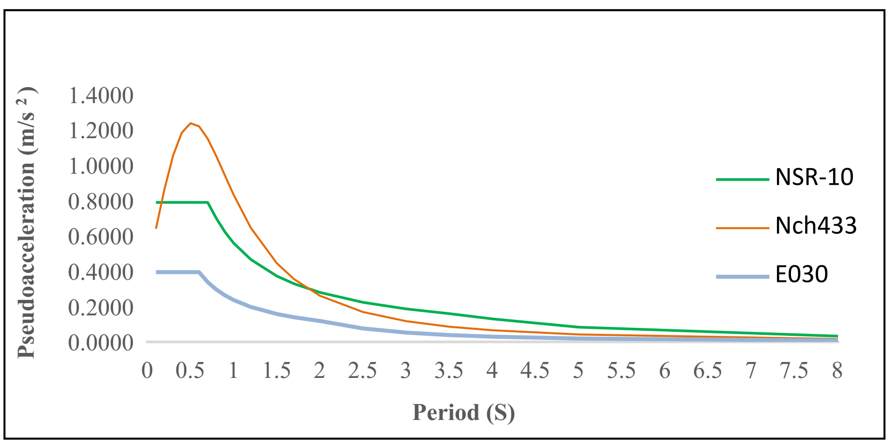

Fig. 6: Design spectrum graph of the E.030, NSR-10 and Nch433 standards.

According to Fig. 6, for short periods of less than 0.6 seconds, the E.030 (Peru) and NSR-10 (Colombia) standards present similarities, although the Colombian standard shows a higher value. This difference is explained by the fact that, in the case of confined masonry structures, the NSR-10 uses a lower response reduction factor (R = 1.5), in contrast to the value considered by the Peruvian standard (R = 3).

A key aspect of the Colombian standard: Its particular approach based on acceleration factors and effective peak horizontal velocity (A_a and A_v), which are not used by other regulations when constructing the design spectrum. These factors allow a better characterization of the seismic intensity, considering both the geographical location and the soil properties

[12]. On the other hand, the Chilean standard offers a spectrum more representative of reality, due to the shape of its curve [13], which can be seen in Fig. 6.

4. Conclusion

This comparative study has revealed significant differences in the design criteria adopted by earthquake-resistant standards E.030 (Peru), NSR-10 (Colombia), and NCh433 (Chile) for confined masonry buildings. Each standard employs specific approaches in determining the base shear force, assigning gravity and seismic loads, limiting story drifts, and formulating design spectra. NSR-10 considers all dead and live loads in low-occupancy structures, leading to significantly higher shear forces. NCh433, on the other hand, applies its own criteria for calculating base shear, without relying directly on the seismic response spectrum, and presents the most restrictive drift limits. For its part, the E.030 standard uses an inelastic spectrum with an intermediate seismic reduction factor, which results in lower seismic stresses compared to the Colombian regulations.

In this sense, this research offers a strengthening of the literature in the comparison of seismic design criteria for each regulation, so that future research focused on the same line of inquiry has a basis from which to draw on this information.

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