Proceedings of the 10th International Conference on Civil Structural and Transportation Engineering (ICCSTE 2025)
July, 2025 | Imperial College London Conference Center, London, United Kingdom
Paper No. 358
DOI: 10.11159/iccste25.358

Seismic Performance Evaluation of a 10-Story Structural Wall Building under Severe Earthquakes in Lima, 2025.

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Abstract **-** This research aims to contribute to the study of seismic behaviour by evaluating the seismic performance of reinforced concrete wall structures through the development of a representative archetype. This archetype was elaborated based on the analysis and systematisation of ten structural plans of real buildings that share similar characteristics. The methodology followed includes the non-linear static analysis to determine the data that will help to plot the capacity curve of the structure. This process is carried out with the Stera 3D software that provides the data of the capacity curve, then the demand curves or demand spectra are elaborated according to the indications of the vision 2000 committee. Subsequently, the structural performance point is determined through the intersection between the capacity curve and the demand curves, which makes it possible to identify the level of performance achieved. The results obtained show that the archetype analysed achieves a different performance level for each earthquake that generates a different demand curve. This approach allows a more accurate understanding of the seismic behaviour of similar buildings, providing useful tools for decision making in structural design and seismic strengthening.

Keywords**:** Seismic performance-derivatives-seismic hazard-structural walls-capacity curve

1. Introduction

Globally, buildings present a wide diversity in terms of shapes, dimensions and functions, reflecting the dynamism and constant evolution of the construction sector. This industry, essential for urban and social development, is continuously facing new technical challenges, especially with regard to ensuring the functionality and structural safety of buildings in the face of external events. In particular, earthquakes represent one of the main threats to the integrity of buildings, as they can induce damage of varying severity, ranging from minor damage to total collapse, depending on the quality of design and construction execution.

The occurrence of large earthquakes not only puts the lives of thousands of people at risk but also generates substantial economic losses. A recent and devastating example was the double earthquake in Turkey on 6 February 2023, with magnitudes of 7.8 and 7.5 MW, separated by just nine hours, which caused the collapse of numerous buildings and plunged the population into a critical situation of emergency and widespread destruction. Due to the great problem of self-construction between 2007 and 2014, approximately 68.55 % of the houses built in Metropolitan Lima were the product of informal self-construction processes, which significantly increases the structural vulnerability of the urban environment [1]. This situation casts doubt on the response capacity of many buildings in the event of a major seismic event.

Faced with this problem, it is essential to investigate and evaluate the seismic performance of different structural systems in areas of high seismicity, as is the case of the city of Lima, particularly those based on structural walls, which due to their characteristics offer greater stiffness and energy dissipation capacity.

2. Methodology

In order to carry out this research work, it is necessary to develop the following stages:

a. Selection of 10 plans of buildings with a structural wall system.
b. Review the structural details of each of the 10 plans.
c. Obtain the archetype model from the sample of plans.
d. Model the structure.
e. Perform the non-linear static analysis of the structure.
f. Obtain and elaborate the capacity curve or spectrum.
g. Constructing Inelastic Demand Spectra from Elastic Spectra
h. Determine the performance points for each demand curve.
i. Verify the seismic performance level of the structure.

Tools:

- Architectural and structural drawings of buildings
- Microsoft Excel
- AutoCAD
- Stera 3D software

Flowchart.

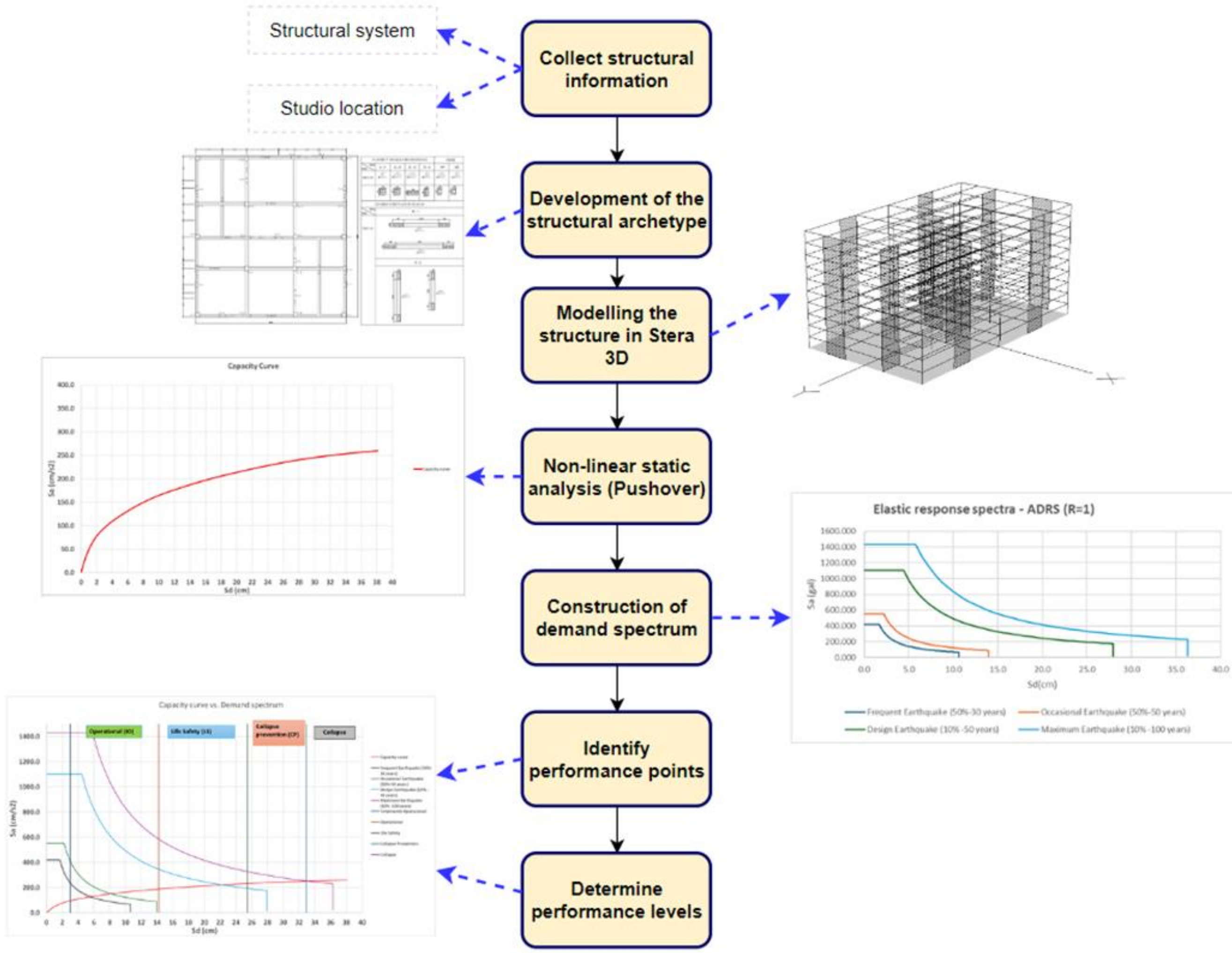

Fig. 1: Process flowchart.

3. Results

The results were obtained by intersecting the seismic demand curves and the capacity spectrum of the structure. For this purpose, Stera 3D software was used, which allowed a non-linear static (pushover) analysis to be performed on the structural modelling, thus obtaining the data necessary to construct the idealised capacity curve.

The elaboration of the demand curves was based on the design spectrum defined by the Peruvian Technical Standard E.030, considering a response reduction coefficient equal to R = 1 to represent an elastic behaviour. Additionally, according to the guidelines of the Vision 2000 Committee, three additional reduced demand spectra were generated, corresponding to different levels of seismic hazard, defined according to their probability of exceedance and return period (frequent, occasional, rare and very rare earthquake).

Finally, the intersection of the capacity curve with each of the demand spectra made it possible to identify the structural performance points, from which the level of performance achieved by the structure in each seismic scenario was evaluated.

3.1 Elaboración del arquetipo y modelado

The Fema P695 standard provides a guide and support for the development of an archetype of structural systems, the archetype is the representative of a set of structures, from which the average, mode, maximum or minimum values, etc. of the elements of the structures are determined, to use these values in the creation of the structural archetype in order to obtain a representative structure that will be subjected to a seismic-resistant analysis [2].

The structural archetype used for the modelling in this research was developed from the evaluation of ten plans belonging to existing buildings in the city of Lima with more than six levels and all of them with a structural wall system. From this review, relevant data was rigorously extracted and systematised through a detailed analysis of the structural and architectural plans. This process made it possible to determine values such as the average number of floors, the area of the structure in plan, the height of the mezzanines, the precise measurement of the concrete area, the quantity and distribution of the reinforcing steel, the geometric dimensions, as well as the quantity and amounts of steel of the main structural elements: columns, beams and structural walls.

With the information obtained, representative averages of the structural parameters were calculated, which allowed the definition of a representative archetype reflecting the predominant characteristics of the buildings analysed. This representative model is used as a basis for comparative analyses and structural design in the framework of the seismic performance study.

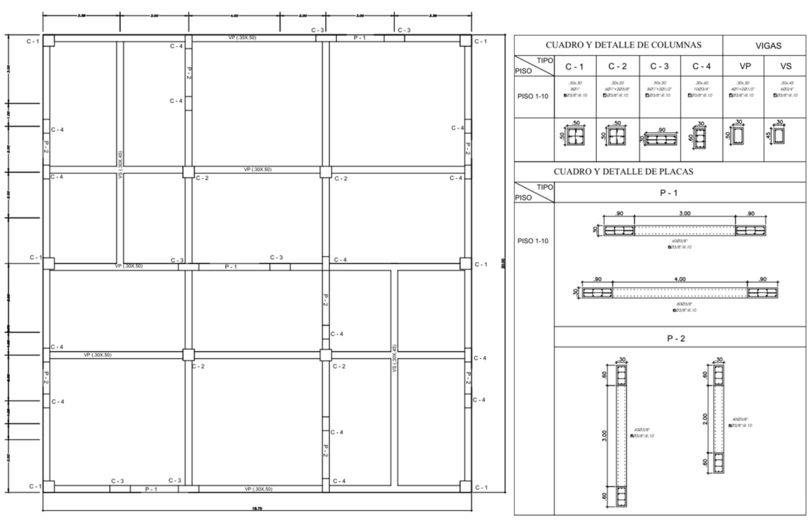

Fig. 2: Structural archetype

The modelling of the structural archetype in Stera 3D is elaborated according to the functions that the programme allows and requests, starting by creating the axes where the structural elements will be located and indicating the number of floors of the building, from there the structural elements are located and the values of the dimensions, steel, f'c and fy are entered to finally have the 3D model.

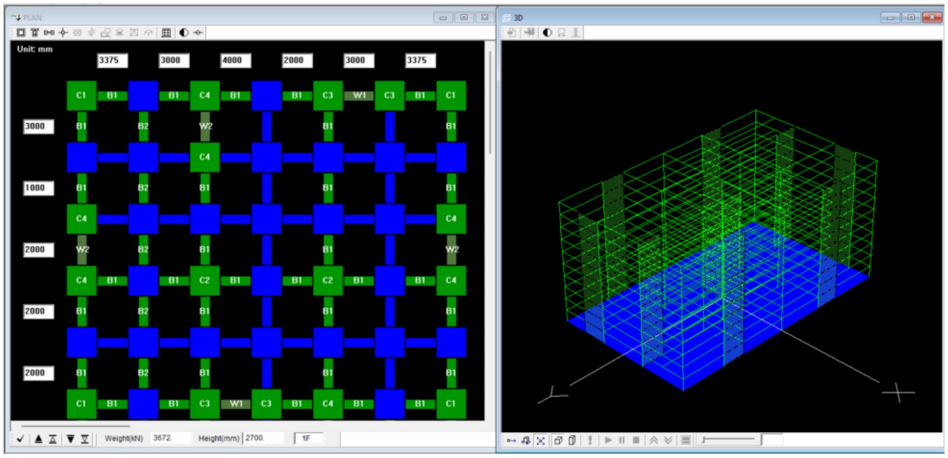

Fig. 3: Archetype modelled in STERA 3D

3.2 Curva o espectro de capacidad.

The structural capacity curve was generated using Stera 3D software, from the detailed modelling of the proposed archetype. Once the model was completed, a non-linear static (pushover) analysis was performed to obtain the progressive response of the structure to incremental lateral loads. The numerical results obtained were exported in Excel format, which facilitated their processing and the graphical representation of the capacity curve, as illustrated in Figure 3. This procedure is essential to evaluate the non-linear behaviour of the building and to determine its critical seismic performance points.

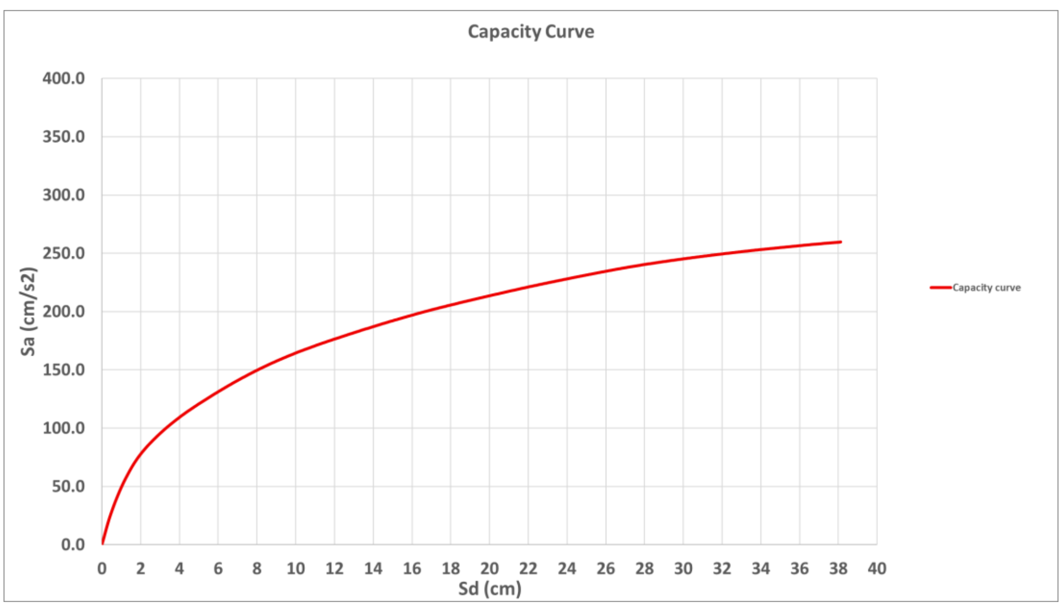

Fig. 4: Capacity curves of the structure

3.3 Espectros de demanda.

The demand spectra are developed from the design spectrum established by the Peruvian Technical Standard E.030, which provides the seismic parameters as a function of geographical location and site conditions. In the present study, the city of Metropolitan Lima has been considered as the scope of analysis, classified within seismic zone 4, with a seismic coefficient $Z_4 = 0.45$.

According to the seismic microzonation of the city, the soil type identified corresponds to category S1 (soil type 1). For this classification and the value of Z_4, the following site parameters are adopted: soil amplification factor S = 1, transition period $T_p = 0.4$ s and platform period T_L = 2.5 s. From these data, the values of the seismic amplification coefficient (C) are calculated for different intervals of the structural period (T), as stated in equations (1), (2) and (3) of the standard.

$$C = 2.5 \rightarrow T < T_P \tag{1}$$

$$C = 2.5 \times \left(\frac{T_P}{T_L}\right) \rightarrow T_P < T < T_L \tag{2}$$

$$C = 2.5 \times \left(\frac{T_P \times T_L}{T^2}\right) \rightarrow T > T_L \tag{3}$$

Likewise, it is established that the building analysed corresponds to category C, according to the classification of use established in NTP E.030, as it is a representative archetype of multi-family dwellings, which are considered to be of common use. Consequently, a use factor U = 1 is assigned, which corresponds to this building category. Finally, for the generation of the elastic design spectrum, a response reduction factor R= 1 is adopted, which implies that the spectrum represents the seismic demand without considering inelastic dissipation capacity.

Tabla 1. Part of the data obtained for the design spectrum.

T (seg)	**C**	**Sa(cm/s2)**
0	2.5	1102.50
0.1	2.5	1102.50
0.2	2.5	1102.50
0.3	2.5	1102.50
0.4	2.5	1102.50
0.5	2	882.00
0.6	1.66666667	735.00
0.7	1.42857143	630.00
…	**…**	**…**

In addition, in accordance with the guidelines established by the Vision 2000 document, the preparation of the demand spectra is based on the design spectrum defined in accordance with the regulations in force. For this process, a conversion factor (CF) is applied, the magnitude of which varies according to the level of seismic hazard, which allows the intensity of the spectrum to be adjusted according to the probability of exceedance and the corresponding return period. The values of CF used are defined in Table 2, allowing to adequately represent frequent, occasional, rare and very rare earthquakes in the framework of the structural performance analysis.

Tabla 2. Conversion factors for each earthquake.

Earthquake	**Exceedance probability**	**Return period**	**FC**
Frequent	50% in 30 years	44	0.38

Service (Occasional)	50% in 50 years	73	0.5
Design (Rare)	10% in 50 years	475	1
Maximum (Very rare)	10% in 100 years	950	1.3

With the application of these conversion factors, it is possible to determine the spectral pseudo-acceleration values corresponding to each seismic scenario. These values allow the demand spectra associated with the different hazard levels to be plotted, which will subsequently be used for their intersection with the capacity curve of the structure, within the framework of the performance analysis.

Tabla 3. Part of the acceleration values for each earthquake.

Period (sec)	**Sa (gal)**			
	S. Frequent (50%-30 years)	**S. Occasional (50%-50years)**	**S. Design (10% -50 years)**	**S. Maximum (10% -100 years)**
0.00	418.950	551.250	1102.50	1433.250
0.10	418.950	551.250	1102.50	1433.250
0.20	418.950	551.250	1102.50	1433.250
0.30	418.950	551.250	1102.50	1433.250
0.40	418.950	551.250	1102.50	1433.250
0.50	335.160	441.000	882.00	1146.600
0.60	279.300	367.500	735.00	955.500
0.70	239.400	315.000	630.00	819.000
…	…	…	…	…

The information obtained allowed the construction of the corresponding demand curves, which were developed according to the occurrence of the earthquake.

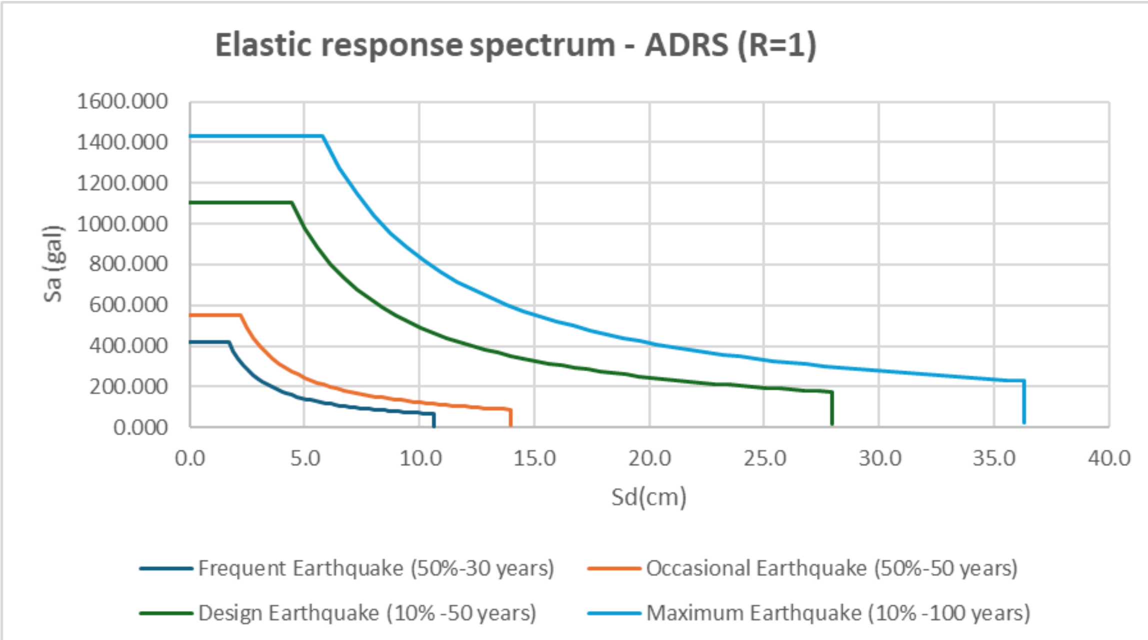

Figura 5. Demand curves or spectra for each earthquake.

3.4 Punto de desempeño

The following procedure consists of determining the structural performance points through the intersection between the capacity curve and the demand spectra corresponding to the four evaluated earthquake levels. This intersection makes it possible to identify the inelastic displacement(ΔP) associated with each level of seismic demand. In this context, the Vision 2000 document provides a graphical guide for the interpretation of structural behaviour by defining performance ranges based on the inelastic displacement capacity. These ranges are classified into five levels: Fully Operational, Immediate Operational or Occupancy (IO), Life Safety (LS), Collapse Prevention (CP) and Collapse, which allow a qualitative assessment of structural damage. This information is illustratively represented in Figure 5, thus facilitating the classification of the performance status achieved by the analysed structure.

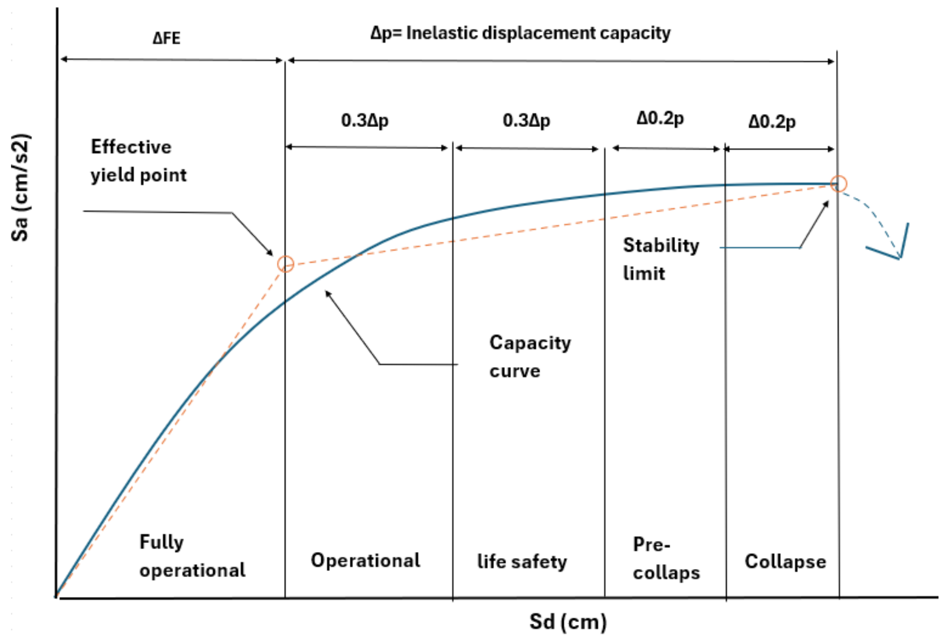

Figura 6. Performance levels for the capacity curve according to vision 2000

For the classification of the performance levels it is necessary to calculate the inelastic displacement capacity (Δp), whose value depends on the effective yield point (ΔFE) and the stability limit; these values are obtained based on the bilinearisation methodology for the capacity curve and the maximum displacement value provided by Stera 3D when performing a linear static analysis. These values are shown in table 4.

Tabla 4. Intervals to determine the performance level

Performance level	**Maximum permissible displacement (cm)**
fully operational	< 3.0
Operational	≥3.0 but < 14.23
Life Safety	≥14.23 but < 25.46
Collapse Prevention	≥25.46 but < 32.94
Collapse	≥32.94

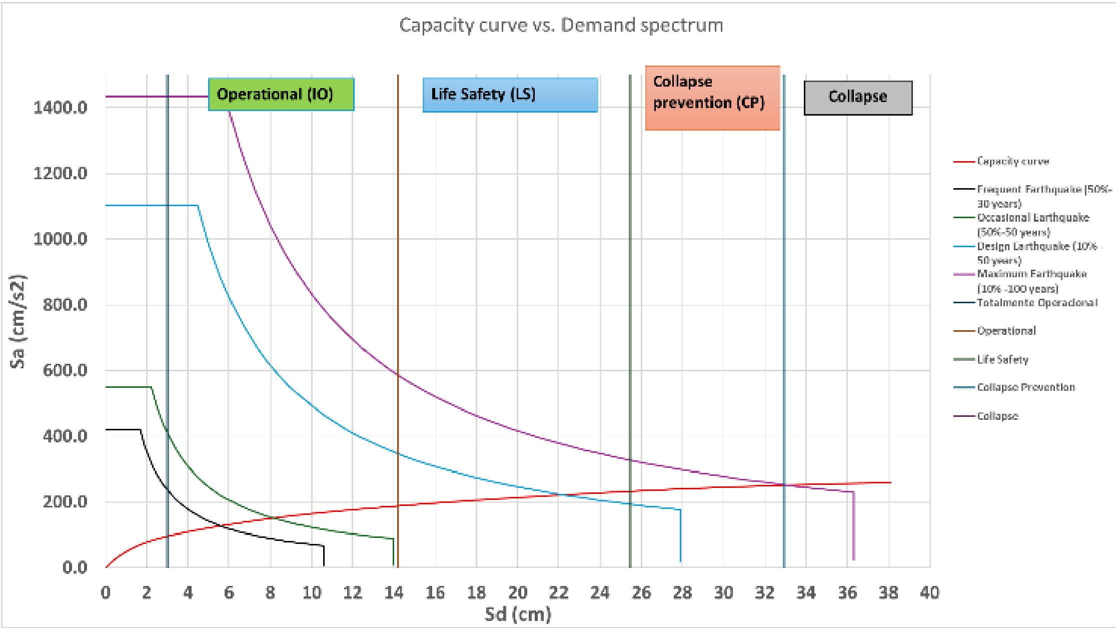

Fig. 7: Seismic performance points and levels of the structure for the 4 earthquakes

4. Conclusion

From the joint analysis between the demand curves and the capacity curve, it is possible to determine the seismic performance level of the evaluated structural archetype. The performance points obtained for each seismic scenario are located at the following coordinates of the spectral plane (Sd; Sa): for the frequent earthquake, at (5.73; 124.13); for the occasional earthquake, at (8.10; 152.10); for the rare or design earthquake, at (22.34; 220.50); and for the very rare or maximum earthquake, at (32.67; 254.80).

Each of these points has been evaluated with respect to the inelastic displacement intervals defined by the Vision 2000 Committee, which allows identifying their correspondence with the structural performance levels. In this sense, it is concluded that, for the frequent and occasional earthquakes, the behaviour of the structure is located at the Immediate Occupancy (IO) level; for the design earthquake, at the Life Safety (LS) level; and for the maximum or very rare earthquake, the structural response reaches the limit level between Collapse Prevention (CP) and Collapse (C). These results are illustrated in Figure 6.

Acknowledgments

We express our gratitude to the Peruvian University of Applied Sciences for its commitment to promoting and supporting scientific research, contributing to the strengthening and advancement of engineering in Peru.

To the Research Directorate of the Peruvian University of Applied Sciences for the support provided to carry out this research work through the UPC-EXPOST-2025-1 incentive

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