Comparative analysis of the seismic response of an essential and a common building using site spectra and dynamic modal spectral analysis according to South American standards

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Abstract. The buildings built on coastal soil, located on the fire belt present a high seismic risk, since there are unfavorable soil conditions and in other cases plate subduction. This has led to countries located in these areas developing seismic regulations that allow the proper design of engineering works; however, various regulations present different considerations for the design, such as the use of parameters that allow standardizing the design that often does not present the same seismic responses of the real dynamic behavior of the soil. Therefore, the present research proposes to evaluate the seismic response of two buildings, one essential and the other common, with an analysis using site spectra, a dynamic spectral modal analysis and additionally a time-history analysis taking into account soil types and use of different seismic parameters of South American standards. The main result is that the seismic response by analysis with site spectra (ES) is greater compared to the dynamic spectral modal analysis according to the magnitude of the earthquakes and the type of soil.

1. Introduction
The western coast of South America presents a constant and high seismic activity, this due to the subduction of the Nazca plate below the South American plate. In this way, the affected countries have strong institutions that analyze the tectonic behavior of these plates. The study carried out by Tavera [1] shows that in the central part of the South American west coast there are 5 zones with a high concentration of seismic energy. It is important to emphasize that in several countries of South America there has been a seismic silence for several years that increases their vulnerability.

Several authors suggest that the design spectrum for a building should be done taking into account the site parameters. Eskandarinejad et al. [2] propose that for the use of design spectra the propagation of seismic waves through the soil layers should be considered, since the spectral content and the characteristics based on the amplitude of the movements of the terrain depend on them. On the other hand, Lagaros et al. [3] consider that a series of seismic registers correctly selected for obtaining seismic capacity of the structural system through linear or non-linear seismic analysis should be taken into account. In addition, Papaspiiliou et al. [4], propose to consider soil amplification and probabilistic seismic risk calculations (PSHA) for seismic analysis with site spectra.

Finally, Sonmez et al. [5] developed a comparative study of seismic performance through a response history analysis of 3 existing structures according to European regulations and site spectra (ES). The results obtained show that the use of the site spectrum, compared to the code spectra, had a great effect on the performance of the irregular structure.
The present investigation proposes to make a comparison between an analysis with site spectra and a dynamic modal analysis in two buildings of different category of importance, mainly considering South American standards. One of the structures will be hospitable and the other a multifamily housing. The main objective of this comparative analysis is to evaluate the effect generated by site spectra on the structural seismic response.

2. Method

In the investigation that is going to be raised, the comparison of seismic responses of reinforced concrete buildings in different conditions will be carried out through seismic analysis methods such as spectral modal analysis, taking into account the importance of the building following the proposed guidelines by Peruvian seismic regulations E.030 and Chilean regulations NCh433; In addition, the other method to be used will be to perform a seismic analysis with site spectra, for which records of the earthquakes of Maule 2010 E-O, Arequipa 2001 N-S and Lima 1974 E-O will be used.

2.1. Structural modeling

The structural comparison of the structures was carried out: an essential and a common one. For this, the use of computer software for structural analysis was used and the loading conditions of the South American regulations were taken into account, however, other considerations can be taken into account, depending on where the building is carried out. The modeling was done in plan and a 3D view that helps to have a better visualization of the structures.

2.2. Design spectra according to regulations

The structural comparison of the structures was carried out: an essential and a common one. For this, the use of computer software for structural analysis was used and the loading conditions of the South American regulations were taken into account, however, other considerations can be taken into account, depending on where the building is carried out. The modeling was done in plan and a 3D view that helps to have a better visualization of the structures.

2.2.1. Peruvian standard (E.030). The design spectrum of the structures, seismic parameters were used, which were obtained based on the seismic-resistant E.030 standard. The design spectrum of Peruvian regulations is represented by the pseudo-acceleration and the period of the structure. In the investigation, 8 design spectra were used in total, since there are two degrees of importance for the type of building, two axes of analysis and two soil conditions, however only the most significant ones that are related to S2 soil are evaluated.

2.2.2. Chilean standard (NCH433). The design spectrum obtained under the conditions of NCH433, is quite similar to the previous regulations, however the graph is different because of the difference that for the soil amplification parameter ($\propto$) and the reduction factor $R^*$ is They use formulas that depend on the fundamental period of vibration of the structure and the soil conditions. The number of spectra used was the same as the previous one and in the same way only the most representative ones will be evaluated.

2.3. Site spectrum

For the development of one of the seismic analyzes, it is necessary to obtain site spectra that consider the true behavior of the soil. Alva et al. [6] developed a geotechnical study to obtain the dynamic response of the soil on the surface considering the behavior of each type of soil. For this they used the earthquakes of Maule 2010 EO, Arequipa 2001 NS and Lima 1974 EO, scaled them to a uniform hazard spectrum of 500 years and based on cutting wave speeds, degree of soil damping this record was scaled from the rock to the surface, resulting in the Site Spectrum. The Maule earthquake had a magnitude of 8.8 degrees on the Richter scale with an epicenter in the Pacific Ocean and shook the southern center of Chile, for this earthquake the EO direction was taken, the Arequipa earthquake had a magnitude mb equal to 6.9, mainly affected the city of Arequipa, for the consideration of this earthquake the NS direction was taken. As for the Lima earthquake of 1974, with intensity of 8 degrees on the Mercalli
scale and magnitude 5.6 on the Richter scale, the epicenter went to southern Lima and affected the
districts of Chorrillos, La Molina, Cercado de Lima and the Constitutional Province of Callao, the
registration at the EO address was used.

In the investigation a modal analysis was considered considering these spectra, which are in Figure 1, comparing it with spectra of the E.030 standard of the essential building, to determine the graphic difference between these spectra.

![Figure 1. Site spectrums used in an elastic range](image)

2.4. Seismic analysis
The modal spectral analysis was carried out following the guidelines of the South American regulations and following the methodology of Chopra [7]. For this, computational design and structural analysis software and the mentioned design spectra were used, as can be seen in Figure 1 with the design spectrum S2.

The Analysis with site spectra was performed following the modal analysis methodology, but considering other spectra, called site spectra (ES). For this analysis, the ES plotted in Figure 1 were used and computational software was used to obtain the seismic response of the buildings. In the present investigation the analysis of structures whose period is in 0.5 and 1 seconds has been prioritized, since it is where the ES presents a greater spectral acceleration.

3. Method
3.1. Existing structures
In order to make a comparison of structural results between ES and South American standards, a seismic analysis is carried out in a hospital building and a multi-family building with the help of the Etabs software. The seismic parameters of standard E.030 and Nch433 are taken. The structural representation of the essential and common building are shown in Figures 2 and 3, respectively.

![Figure 2. Hospital building](image)
The fundamental vibration periods of the hospital and multifamily structure are 0.71 s and 0.52 s for the X direction, respectively, 0.98 s and 0.32 s in the Y direction. As for the seismic parameters set forth in E.030 and Nch433, they will be considered the following values.

3.2. **Design spectrum**

To carry out the design spectra, the parameters present in Tables 1 and 2 were taken into account considering a type of soil S2 and D for both Peruvian and Chilean regulations. On the one hand, the design spectra for the 2 types of buildings, according to Peruvian regulations, are presented in Figure 4, where the initial values of spectral acceleration are between 0.20 g and 0.45 g. On the other hand, in Figure 5, the design spectra according to the Chilean standard are shown, which are different in shape due to the different calculation method, the initial spectral acceleration values are between 0.10 g and 0.35 g.

| Parameters                      | Characteristic      | Common building | Essential building |
|---------------------------------|---------------------|-----------------|--------------------|
| Zone Factor                     | Zone 4              | Z= 0.45         | Z= 0.45            |
| Category and use factor         | Category C and A    | U= 1.0          | U= 1.5             |
|                                  | Soil, Type S2       | S= 1.05         | S= 1.05            |
| Site Parameters                 | Periods             | T_p= 0.60       | T_p= 0.60          |
|                                  |                     | T_L= 2.00       | T_L= 2.00          |
| Basic coefficient of            | Structural system   | R_x= 5.4        | R_x= 6.3           |
| reduction of seismic forces     | Reinforced concrete | R_y= 5.4        | R_y= 4.2           |

| Parameters                      | Characteristic      | Common building | Essential building |
|---------------------------------|---------------------|-----------------|--------------------|
| Zone Factor                     | A_0                 | A_0= 0.40       | A_0= 0.40          |
| Importance factor               | Category II and IV  | U= 1.0          | U= 1.5             |
|                                  | S= 1.20             | S= 1.20         |                    |
|                                  | T_o= 0.75           | T_o= 0.75       |                    |
|                                  | T'= 0.85            | T'= 0.85        |                    |
|                                  | n= 1.80             | n= 1.80         |                    |
|                                  | p= 1.00             | p= 1.00         |                    |
| Soil factor                     | Soil type D         | R_o= 11         | R_o= 11            |
| Response Modification Factor    | Reinforced concrete | R_x= 4.10       | R_x= 4.80          |
| Dynamic Reduction Factor        | R*                  | R_y= 3.14       | R_y= 5.69          |
3.3. Drifts and comparison

In the first place, static analysis is carried out, in order to identify the various irregularities existing in both structures, identifying for the hospital the Irregularity of Torsional and Mass; and for the multifamily corner incoming.

To conclude with the seismic analysis, we proceed to perform the dynamic spectral modal analysis according to the guidelines of the standards, with which the values of the mezzanine drifts of the building are obtained.

It can be seen in Figure 6 that the drifts of the multifamily building comply with the limit of 0.007 proposed by the E.030, obtaining greater displacements in the ES of Arequipa 2001. However, the result in Figure 7 is all contrary to the hospital building, since in the drifts of the Peruvian norm it is above the ES and the Chilean norm. This demonstrates that the Use factor present in both standards has a great impact on the results.

In addition to the relative displacements, the drift relations of the buildings were also obtained to represent the effects of the local spectrum in terms of comparison with those obtained by the South American seismic norms. As shown in Table 4 for multifamily building, it was determined that the maximum drift of the ES represents 145% and 142% of the E030 and NCH433, respectively. However, according to Table 3, in hospital construction, the ES compared to the Peruvian norm represent 90% of its drifts, otherwise the Chilean norm shows where the ES represent 148% of the respective standard.
Table 3. Comparative analysis of ES / E.030 drifts in the hospital building

| Floor | ES Arequipa 2001 | ES Lima 1974 | ES Maule 2010 | Average |
|-------|------------------|--------------|---------------|---------|
| 9     | 0.91             | 0.73         | 0.76          | 0.80    |
| 8     | 0.92             | 0.73         | 0.77          | 0.80    |
| 7     | 0.93             | 0.74         | 0.78          | 0.81    |
| 6     | 0.94             | 0.75         | 0.78          | 0.82    |
| 5     | 0.95             | 0.75         | 0.79          | 0.83    |
| 4     | 0.95             | 0.76         | 0.79          | 0.83    |
| 3     | 0.95             | 0.76         | 0.79          | 0.83    |
| 2     | 0.95             | 0.75         | 0.79          | 0.83    |
| 1     | 0.94             | 0.75         | 0.79          | 0.82    |
| 0     | 0.93             | 0.74         | 0.78          | 0.82    |

Figure 6. Drift of hospital building on the y axis

Figure 7. Drift of Common building on the x axis
Table 4. Comparative analysis of ES / E.030 drifts in the common building

| Floor | ES Arequipa 2001 | ES Lima 1974 | ES Maule 2010 | Average |
|-------|------------------|--------------|---------------|---------|
| 7     | 1.42             | 1.04         | 1.04          | 1.17    |
| 6     | 1.42             | 1.04         | 1.04          | 1.17    |
| 5     | 1.43             | 1.04         | 1.05          | 1.17    |
| 4     | 1.43             | 1.04         | 1.05          | 1.17    |
| 3     | 1.43             | 1.04         | 1.05          | 1.17    |
| 2     | 1.43             | 1.04         | 1.05          | 1.17    |
| 1     | 1.42             | 1.04         | 1.04          | 1.17    |
| 0     | 1.40             | 1.02         | 1.03          | 1.15    |

4. Conclusions
The present work has as main objective to estimate the effects of the site spectra of a region, the structural seismic behavior of buildings with two types of importance: an essential and a common one, in addition to making the structural comparison of the seismic response, in this case, mainly drifts, of modal analyzes with design spectra of South American seismic codes, high probability of earthquake enzymes and analysis with site spectra of South American earthquakes, such as Maule, Arequipa and Lima.

For the essential building, in relation to the displacements it is concluded that through the modal analysis of the 3 site spectra the structure does not comply with the maximum drifts established in the norm E.030 or the NCh433. Since for Arequipa 2001, which has the maximum representative drift, it is 0.010 on the “x” axis and 0.024 on the “y” axis. For the common building, it is concluded that the drifts do comply with the provisions of E.030 and in some cases do not comply with NCh433. The representative result was that of Arequipa 2001, although the results of Maule 2010 were very close to those of the previous one mentioned. In "x" the representative drift was 0.0069, which does not comply with the Chilean standard. In "y" the drift was 0.002, which meets both South American standards.

In relation to the essential structure, it can be affirmed that for both S2 type floors the design spectrum of the E030 is above the site spectrum. However, the panorama is different for the common building since the site spectra of Arequipa 2001 represent 142% of S2 in Peruvian regulations. These results follow this trend for the NCH433 standard in the essential building but compared to the E030 the results are much higher in the common since they represent ES Arequipa 2001 for S2 145%. The parameter of the type of use used in both regulations allows to base this situation.

Finally, it is concluded that for the structures analyzed, the effect generated by the site spectra on the essential building is less than that provided in the dynamic modal spectral analysis of Technical Standard E.030 Earthquake-resistant Design and NCH433. However, in multifamily building the answers are much more significant for both standards considering a soil of type S2.

From the previous conclusions it can be affirmed that if it is possible to say that the site spectra are much more significant in an analysis of multifamily dwellings and that the standards of the South American norms would have no problem with an adequate seismic analysis. However, it is recommended for future research, perform the analyzes performed in this work for many more buildings.

5. References
[1] H. Tavera, "Evaluación del peligro asociado a los sismos y efectos secundarios en Perú", IGP, 2014.
[2] A. Eskandarinejad, H. Zafarani and M. Jahanandish, "Local site effect of a clay site in Shiraz based on seismic hazard of Shiraz Plain", Natural Hazards, vol. 90, no. 3, pp. 1115-1135, 2017.
[3] N. Lagaros, C. Mitropoulou and M. Papadrakakis, "Time History Seismic Analysis", Encyclopedia of Earthquake Engineering, pp. 1-19, 2013. Available: 10.1007/978-3-642-36197-5_134-1 [Accessed 20 October 2019].
[4] Papaspiliou and S. Kontoe, "Sensitivity of site response analysis on the number of ground motion records and implications for PSHA", Bulletin of Earthquake Engineering, vol. 11, no. 5, pp. 1287-1304, 2013. Available: 10.1007/s10518-013-9459-y [Accessed 28 January 2020].

[5] Y. Sonmezer, I. Kalkan, S. Bas and S. Akbas, "Effects of the use of the surface spectrum of a specific region on seismic performances of R/C structures", Natural Hazards, vol. 93, no. 3, pp. 1203-1229, 2018. Available: 10.1007/s11069-018-3347-3 [Accessed 29 January 2020].

[6] Alva, C, & Quispe, E. (2018). Propuesta de procedimiento estandarizado para la obtención de los parámetros de entrada del análisis de respuesta de sitio. Caso de estudio : Provincia constitucional del Callao. Universidad Peruana de Ciencias Aplicadas.

[7] A. Chopra., Dynamics of structures, 4th ed. Boston [etc.]: Pearson, 2014.