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ENGLISH VERSION..

Analysis of the magnitude of the seismic waves energy transferred to the foundation of a building

Análisis del grado de energía de las ondas sísmicas que se transfiere a la cimentación de una edificación

F. Del Carpio [1]* http://orcid.org/0000-0002-6334-7867
A. Soto Chacon** http://orcid.org/0000-0002-5503-7594

* Universidad Nacional De Moquegua, Moquegua - PERÚ
** Universidad José Carlos Mariátegui, Arequipa - PERÚ

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Abstract

The seismic waves transferred to the foundation of a building cause significant damage to the structure, producing its deterioration and instability. This paper presents the results of subjecting a structure to the effects of the earthquake and the physical mechanical properties of the soil, comparing a theoretical model of an embedded support with the structural dynamics model of D.D. Barkan - O.A. Savinov. Three hypotheses are evaluated: i) The negative effects on the proposed buildings are indirectly proportional to the increase of the seismic response characteristics detected in the soils; ii) The characteristics of the soil strata are directly proportional to the increase of the seismic response characteristics of the soils; and iii) The D.D. Barkan-O.A. Savinov model presents a lower range of embedded support than the theoretical model, which simulates a foundation. Some of the most relevant conclusions indicate that the structural dynamics model of D.D. Barkan - O.A. Savinov presents a more specific range in the reactions produced before the seismic forces, and the relationship in both cases is alleged to be indirectly proportional to the indicated characteristics.

Keywords: *Soil-structure interaction, structural dynamics, shallow seismic wave, laboratory tests, internal vibrations*

Resumen

Las ondas sísmicas que se transfiere a la cimentación de una edificación causan daños significativos a la estructura ocasionando su deterioro e inestabilidad. El presente artículo exhibe los resultados de someter una estructura a los efectos del sismo y a las propiedades físico – mecánicas del suelo, realizando la comparación de un modelo teórico de apoyo empotrado con el modelo de dinámica estructural de Barkan – Savinov. Se evaluaron tres hipótesis; i) Los efectos negativos causados en las edificaciones planteadas son indirectamente proporcionales, al incremento de las características de la respuesta sísmica que se detectan en los suelos; ii) Las características que presentan los estratos de los terrenos, es directamente proporcional al incremento de las características de la respuesta sísmica de los suelos y iii) El modelo de Barkan – Savinov presenta un rango inferior que el modelo teórico de apoyo empotrado, que simulan una cimentación aplicada en los suelos. Entre sus conclusiones más relevantes se deriva que el modelo de dinámica estructural de Barkan –Savino presenta un rango más específico en las reacciones producidas ante las fuerzas sísmicas y la relación en ambos casos se asevera que es indirectamente proporcional respecto a las características indicadas.

Palabras clave: Interacción Suelo-Estructura, dinámica estructural, sísmica somera, ensayos de laboratorio, vibraciones internas

1. Introduction

Earthquakes are natural disasters that have a great impact on the buildings, causing significant damage to the structures, sometimes irreparable, thereby leaving a critical scenario of human and economic losses in several countries around the world. Peru is not alien to these seismic movements (Tavera, 2001), whose force is a natural phenomenon that affects buildings, since the country is located on a strongly seismic area. This impact is bad for the structural behavior, because it entails serious consequences in the face of medium- and large-magnitude earthquakes (Añazco and Tavera, 2016). Over the years, the seismic events have encouraged actions among the population and the national government in order to minimize, as much as possible, the deterioration and collapse of the structures in case these natural disasters occur.

[1] ***Corresponding author:***
Universidad Nacional De Moquegua, Moquegua - PERÚ
E-mail: fabriziodelcarpiod@yahoo.com

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It should be highlighted that Peru is located in the Ring of Fire, which is an arch measuring 40,000 kilometers along the Pacific Ocean, where 85% of the earthquakes in the world take place, and the closest areas present a high risk of suffering earthquakes, because they are located on tectonic plates under permanent friction (Tavera, 2020). In addition to the structural and human damage, these earthquakes cause a series of social problems that notoriously affect the locality, immersing them in a poverty level that is hard to overcome. This entails further consequences such as the lack of quality of life, given the interruption of public utilities, which generates an unhealthy environment that causes health problems. Therefore, when watching a decaying economy and the exhaustion of basic supplies, the inhabitants of impacted environments tend to move to other cities, where they can perform some kind of economic activity that allows them to meet the basic needs such as food, housing, health and education. This reduces the population in the affected area and triggers a population growth in nearby cities.

Consequently, this paper reveals the results of a research analyzing the seismic waves' energy that is transferred to the foundation of a building, based on the study of physical and mechanical properties of the soil strata and the study of the seismic response of the ground. It was possible to establish different conclusions to increase the safety and improve the behavior in the face of this type of seismic events, thus offering the user a more favorable scenario, together with the possibility of feeling more confidence about the building. Additionally, the correlation between the variables was analyzed, with the aim of accepting or rejecting the referred hypothesis, which sought to verify whether the energy of the seismic waves is harmful to the foundation of a building in the city of Moquegua.

1.1 Physical and Mechanical Properties

Soil mechanics consists in the application of the laws of mechanics and hydraulics to engineering problems dealing with sediments and other unsolidified accumulations of solid particles, derived from the mechanical or chemical disintegration of rocks, with or without organic matter requirements. Soil mechanics includes theories on the behavior of soils subjected to loads, necessary supported simplifications given the condition of the foundation, theoretical grounds, research of the soils' physical properties, application of theoretical and empirical knowledge to practical problems. Lab research methods are included in the soil mechanics routine; in soils that do not only present problems in the steel and concrete (modulus of elasticity and rupture strength), and exaggerated by the higher complexity of the tissue, but also involving the variability that natural soil formation processes are out of the control of the expert.

It is important to note that soil classification systems were developed while executing the treatment of the samples: color, smell, texture, size distribution, plasticity, where soil classification and sampling were two essential requirements for the implementation of soil mechanics. Therefore, the modification of the seismic energy due to the effect of the soil's physical and mechanical properties in the interaction or occurrence of an earthquake is called seismic response by local site effect, which is increasingly or decreasingly altered in its intensity, according to the propagation means within its trajectory.

1.2 Barkan-Savinov Model

The model analyzes the interaction between the foundation and the foundation base through a clearly defined forced vibration process, designed in 1948, which is the basis for conducting statistical calculations scientifically grounded on the seismic calculation of buildings, thereby estimating the soil-structure interaction, which behaves as a non-stationary wavy process during an earthquake. It should be highlighted that, during an earthquake, all buildings work on an elastic soil and that the maximum stresses in the columns occur near the intersection with the beams, thus recommending the use of the dynamic Barkan-Savinov model, which is the least flexible. It should be pointed out that the behavior of the dynamic model of the Russian Standard SNIP 2.02.05-87 is very similar to the one already mentioned. The final way to calculate the compression and displacement coefficients of the base with the D.D. Barkan-O.A. Savinov model is the following (Equation 1) (Equation 2) and (Equation 3) (Villarreal, 2020); (Barkan, 1948):

$$\boldsymbol{C_z = C_0\left[1 + \frac{2(a+b)}{\Delta * A}\right] * \sqrt{\frac{\rho}{\rho_0}}} \tag{1}$$

$$\boldsymbol{C_x = D_0\left[1 + \frac{2(a+b)}{\Delta * A}\right] * \sqrt{\frac{\rho}{\rho_0}}} \tag{2}$$

$$\boldsymbol{C_\varphi = C_0\left[1 + \frac{2(a+3*b)}{\Delta * A}\right] * \sqrt{\frac{\rho}{\rho_0}}} \tag{3}$$

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Where:
C_0, D_0 = *Coefficients calculated through experiments carried out for* $\rho = \rho_0$;
a, b = *Dimensions of the foundations in the plan;*
Δ= *Empirical coefficient, assumed for practical calculations equal to* $= 1m^{-1}$.

For D_0 $coefficient$, *as shown in the experiments, the following empirical dependence can be used (Equation 4), (Equation 5) and (Equation 6):*

$$D_0 = \frac{1-\mu}{1-0.5*\mu} * C_0$$

For practical calculations, the following equations are recommended:

$$C_0 = 1.7 * \frac{E_0}{1-\mu^2} * 10^{-3} * \left(\frac{kg}{cm^3}\right)$$

$$D_0 = 1.7 * \frac{E_0}{(1+\mu)(1-0.5*\mu)} * 10^{-3} * \left(\frac{kg}{cm^3}\right)$$

Where:
E_0 = *Modulus of elasticity, experimentally calculated for static earth pressure of* $0.1 - 0.2\ kg/cm^2$.

2. Materials and methods

The analysis was based on an applied research method, with the aim of solving immediate practical problems and transforming the conditions of the didactic action, by generating knowledge about the execution of a direct solution to a specific problem affecting the society (Hernández and Mendoza, 2018). The design was almost experimental considering the statement of (Hernández et al., 2014), because the study subjects were not randomly assigned to the groups. Furthermore, the aim is to find the correlation between the magnitude of seismic waves energy and the foundation of a building in urban sprawl areas, with the objective of contributing to the urban planning and reconstruction of seismic geotechnical areas (SINIA, 2019).

Likewise, the population is defined by soils in the city of Moquegua that have been affected by a seismic fault. Moquegua was selected as a pilot center for making field measurements, since the city has been highly impacted by earthquakes for decades; the most recent one occurred on June 23, 2001 (Tavera, 2008). The sample is formed by the following human settlements located in the region, which have been most affected by the earthquake: Cruz del Siglo II, Barrios Altos and Centro de Red Sismológica (SINIA, 2021), from which samples were taken by means of test pits (Lozano, 2018). The following instruments were used for collecting the data:

- *The Refraction Microtremor (ReMi) survey, which allowed obtaining the soil's seismic characteristics for all the calculations of the research. It was executed three times in order to obtain average values therefrom; this method improved the accuracy of the data (Legowo and Rantanaka, 2021).*
- *Standard lab tests for soil surveys allowed obtaining the soil characteristics. They were executed three time in order to calculate average values therefrom, thus maximizing the accuracy of the data (Molina et al., 2018). The following tests were carried out: sand cone, moisture content, sieve analysis, unit weight of sand, unit weight of gravel, liquid limit, plastic limit, direct shear, consolidation.*
- *Sap 2000 is a software used for evaluating the proposed foundation models, thereby obtaining the respective data for the modeling process (Tapia et al., 2017).*

The SPSS 25 software was used following the survey data collection, in order to analyze the correlation between the variables through descriptive statistics, normality test and hypothesis testing.

3. Results and discussion

The research decided in favor of an urban sprawl study area. A georeferencing with Global Positioning System (GPS) was carried out, whose results are described below:

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3.1 *Finding a Point with GPS*

The activity was executed in approximately two hours, time enough to collect the data see (Table 1).

***Table 1.** Location*

Area	*Altitude*	*East*	*North*
Cruz del Siglo II	*1646.00 m.s.n.m.*	*294763.00 m*	*8096818.00 m*
Barrios Altos	*1487.00 m.s.n.m.*	*294991.00 m*	*8097000.00 m*
Centro de Red Sismológica	*1501.00 m.s.n.m.*	*294883.00 m*	*8097059.00 m*

3.2 *Refraction Microtremor Survey*

Next, the microtremor equipment, which measures the seismic waves, started operating. The following test was performed during three consecutive days in the same schedule. Readings were recorded in each specified location for half an hour (30 min), which is the time needed for the equipment to process the ground vibrations and establish the presence of different seismic waves detected at the time of the application (Kanao and Toyokuni, 2019) and (Stein and Wysession, 2003), see (Figure 1).

***Figure 1**. Microtremor*

(Table 2) below indicates the results of the average values:

***Table 2.** Geophysics – Average Value*

GEOPHYSICS – SOIL'S SEISMIC RESPONSE – AVERAGE VALUE							
	A (m)	*f (Hz)*	*T (s)*	*ω (s^{-1})*	*Vmax (m/s)*	*λ (m)*	*Vp (m/s)*
C - 01 / SR	*2.11*	*6.51*	*0.59*	*40.89*	*77.39*	*13.28*	*77.39*
C - 02 / SR	*2.27*	*6.24*	*0.55*	*39.23*	*101.85*	*14.27*	*101.85*
C - 03 / SR	*2.40*	*6.22*	*0.57*	*39.08*	*93.83*	*15.08*	*93.83*

3.3 Lab Tests for the Soil Survey

Once the test pits were excavated, the test for calculating the soil density in situ was carried out through the sand cone method (see (Figure 2), which lasted 10 to 30 min per test pit. The described activity was performed for approximately four and a half hours to six hours (4½ to 6 h), including the setbacks and unplanned events. The results are shown in (Table 3).

Figure 2. *Sand cone test*

Table 3. *Density Test IN SITU / EDIC per area*

Cruz del Siglo II		Seismological Center	Barrios Altos
Initial weight - sand	6,054.80 g	6,153.30 g	6,043.40 g
Final weight - sand	1,210.20 g	1,692.80 g	957.20 g
Cone weight correction	1,495.57 g	1,495.57 g	1,495.57 g
Weight – used sand	3,349.03 g	2,964.93 g	3,590.63 g
Unit weight–calibrated sand	1.31 g/cm3	1.31grs/cm3	1.31grs/cm3
Cavity volume	2,556.51cm3	2,263.31cm3	2,740.94 cm3
Soil weight - removed	5,085.90 g	4,736.20 g	5,557.90
Moisture content %	4.06 %	5.08 %	4.27 %
Wet density	1.99 g/cm3	2.09 g/cm3	2.03 g/cm3
Natural dry density	1.91 g/cm3	1.99 g/cm3	1.94 g/cm3

3.4 Sap 2000

The aforementioned steps allowed obtaining the necessary results to start the modeling with the Sap 2000 V.18 software, aimed at analyzing the two scenarios proposed in the research: embedded foundation base (Araca et al., 2020) and standard foundation design + dynamic model of D.D. Barkan–O.A. Savinov (Olfati and Shologin, 2020), which comply with the characteristics of the study. The respective structural comparison was carried out, thereby identifying the following main structural elements: columns, beams, and lightweight slab (Buendía and Reinoso, 2019). Next, the structural survey was performed on site and different measurements were obtained for making architectural drawings, load estimates and modeling. (Figure 3), (Figure 4), (Figure 5), (Figure 6) and (Figure 7) show the resulting drawings.

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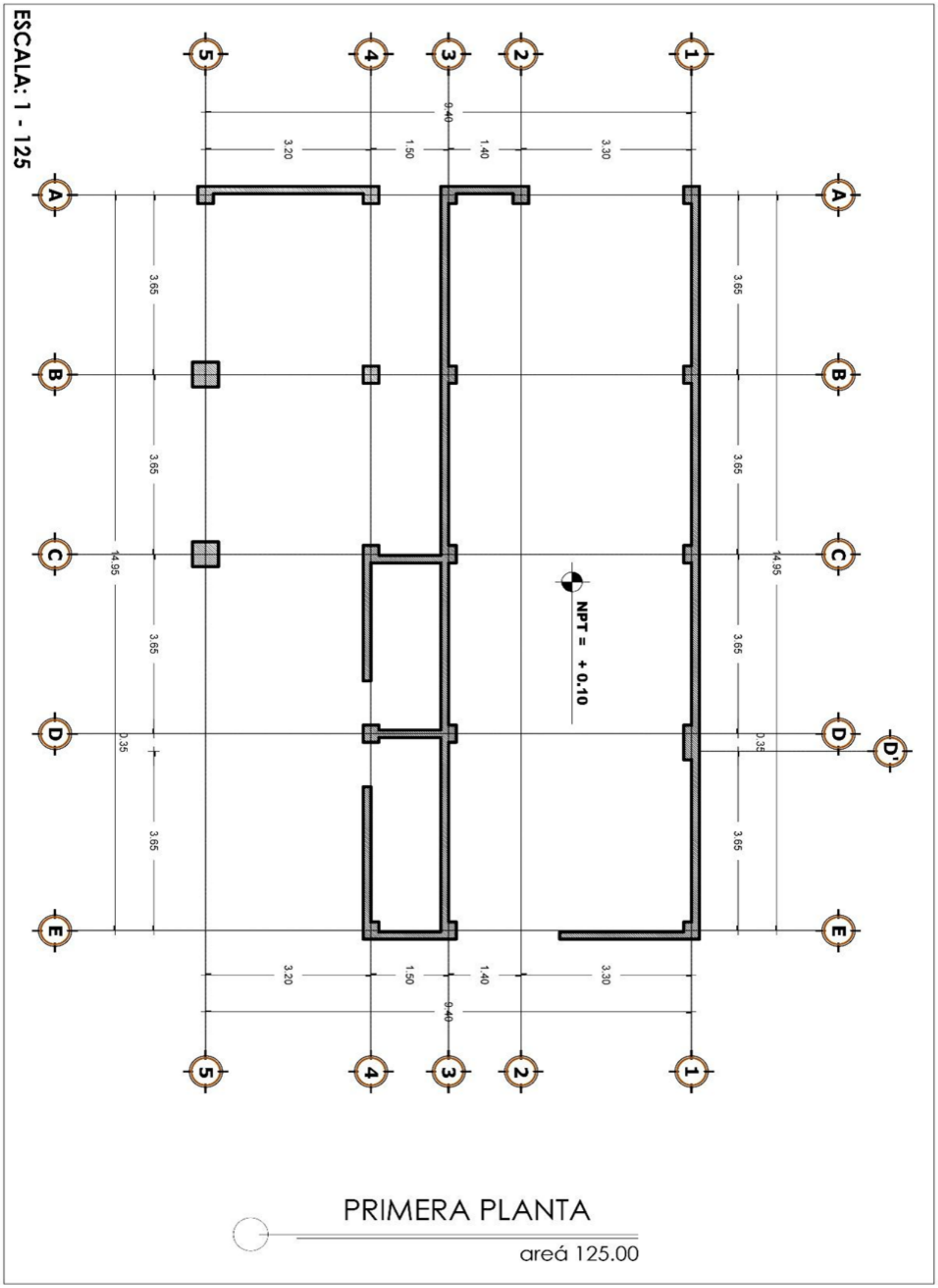

Figure 3. *First floor of the building*
Scale: 1:125

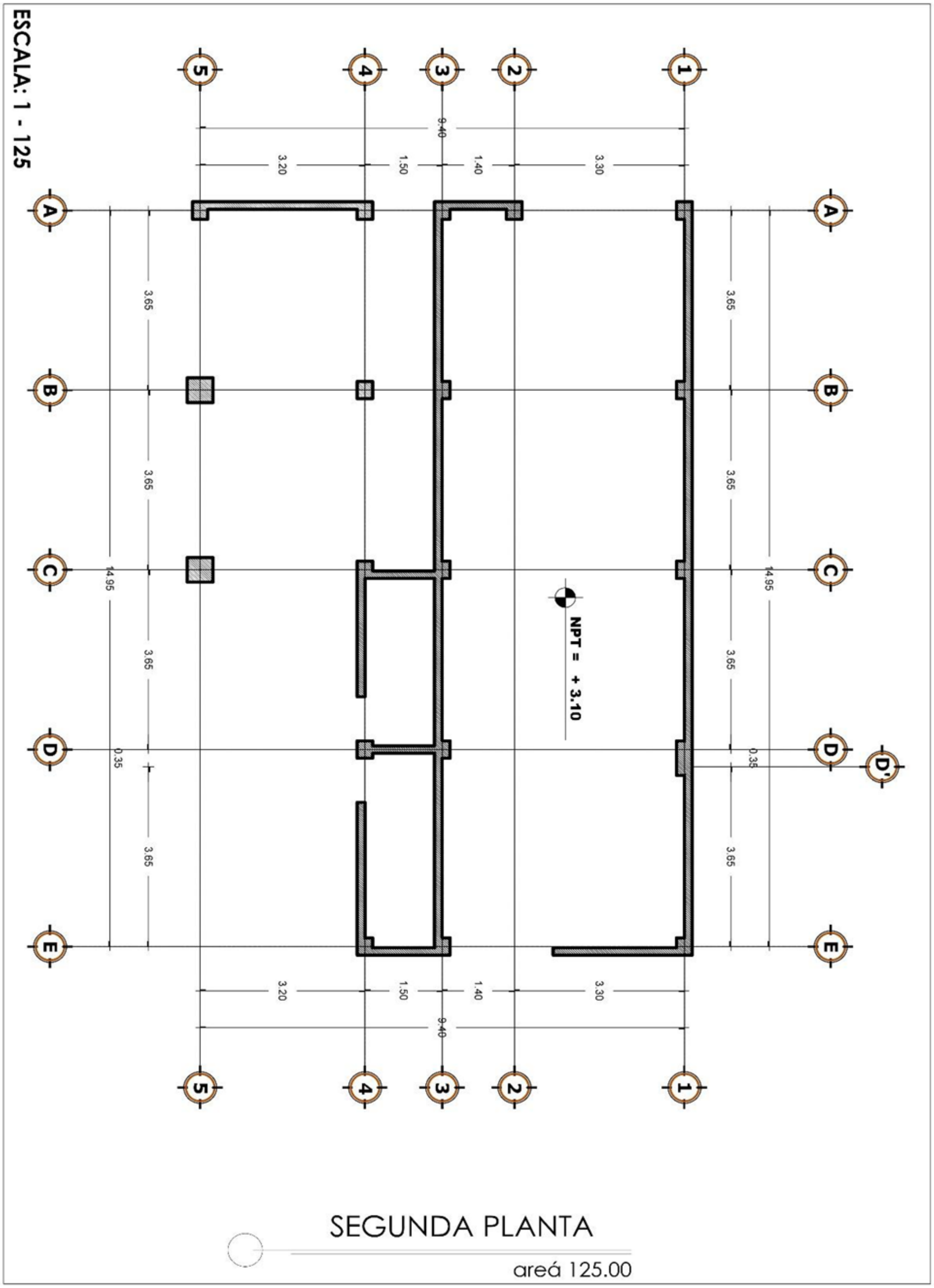

Figure 4. *Second floor of the building*

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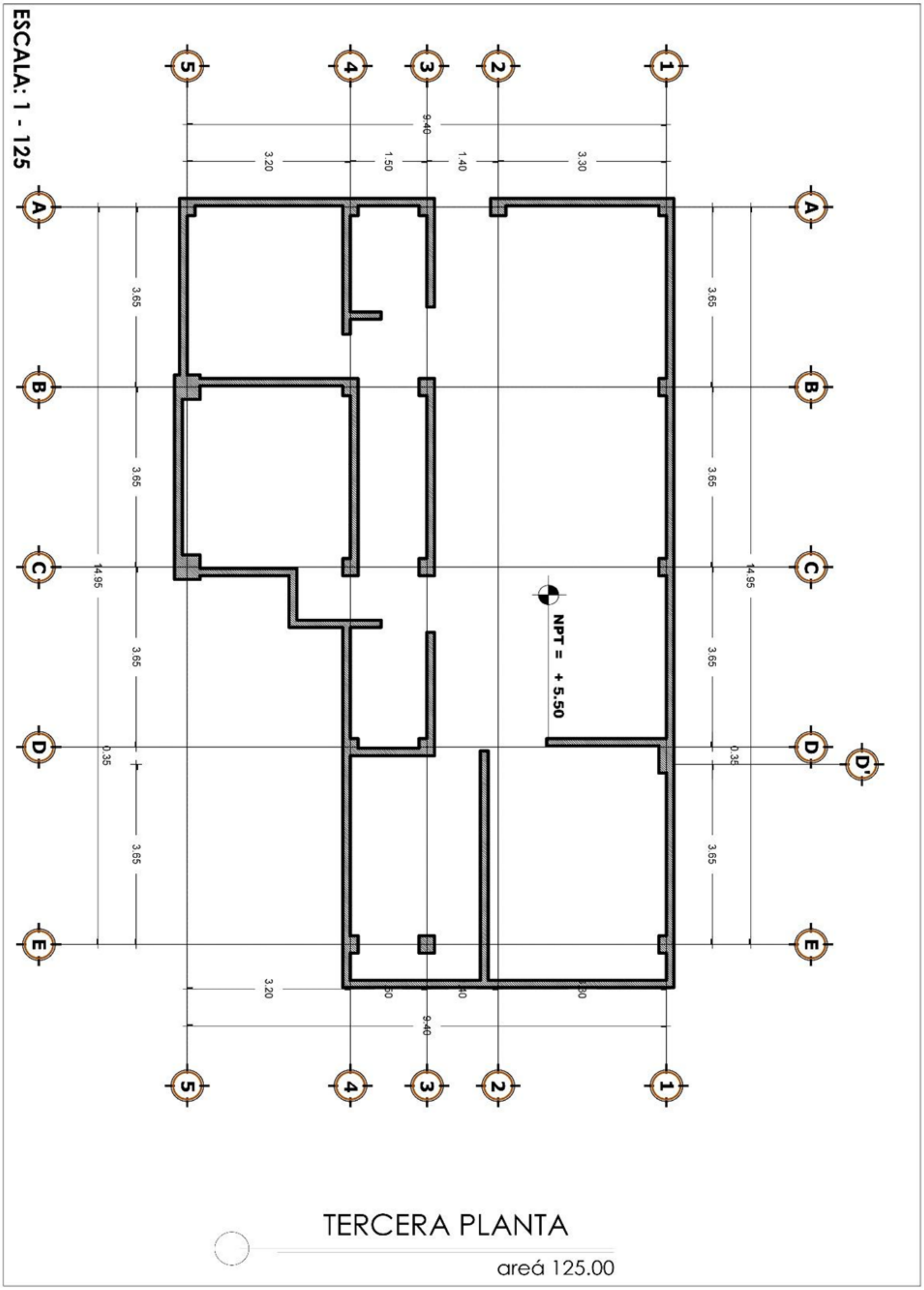

Figure 5. *Third floor of the building*

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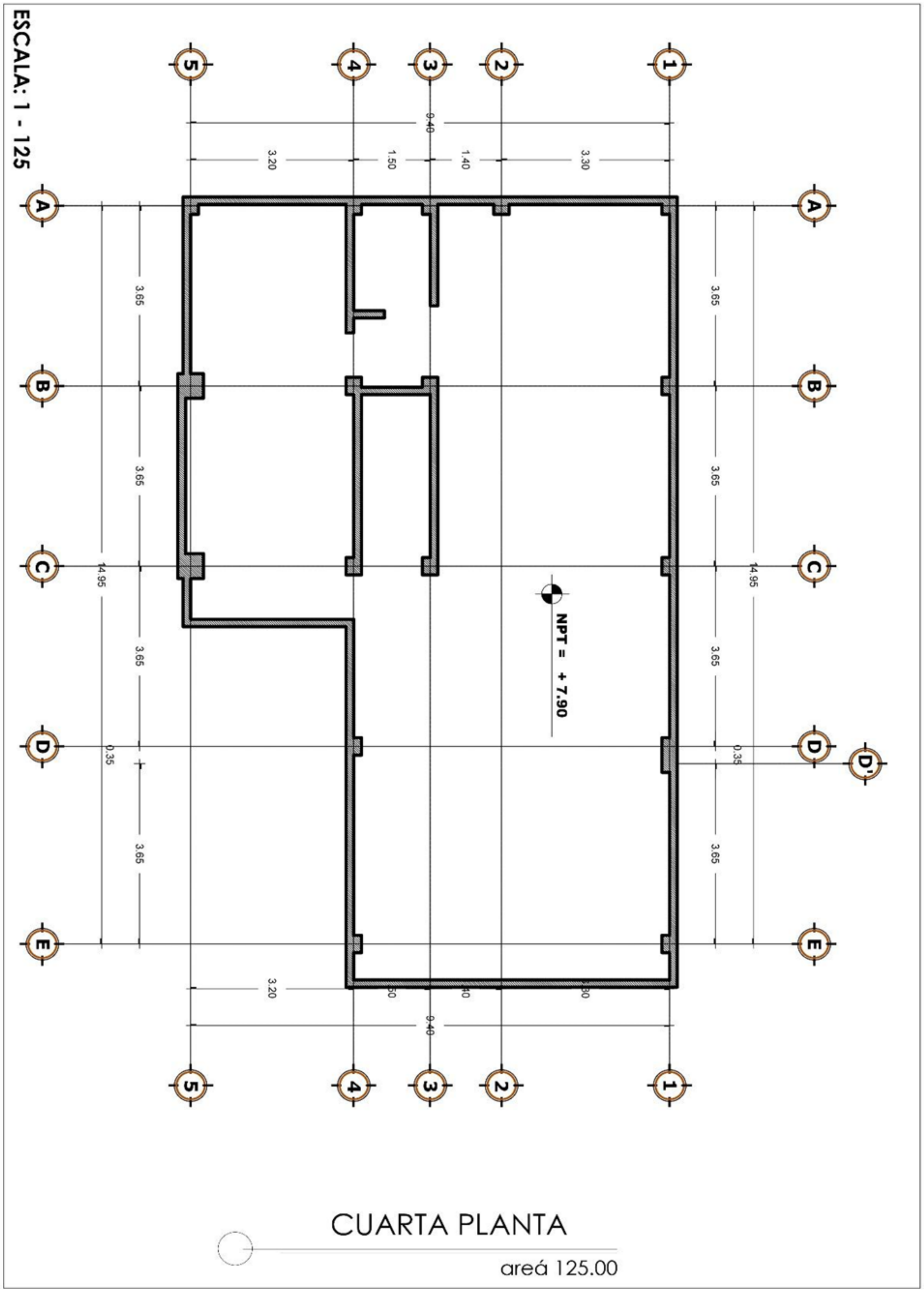

Figure 6*. Fourth floor of the building*

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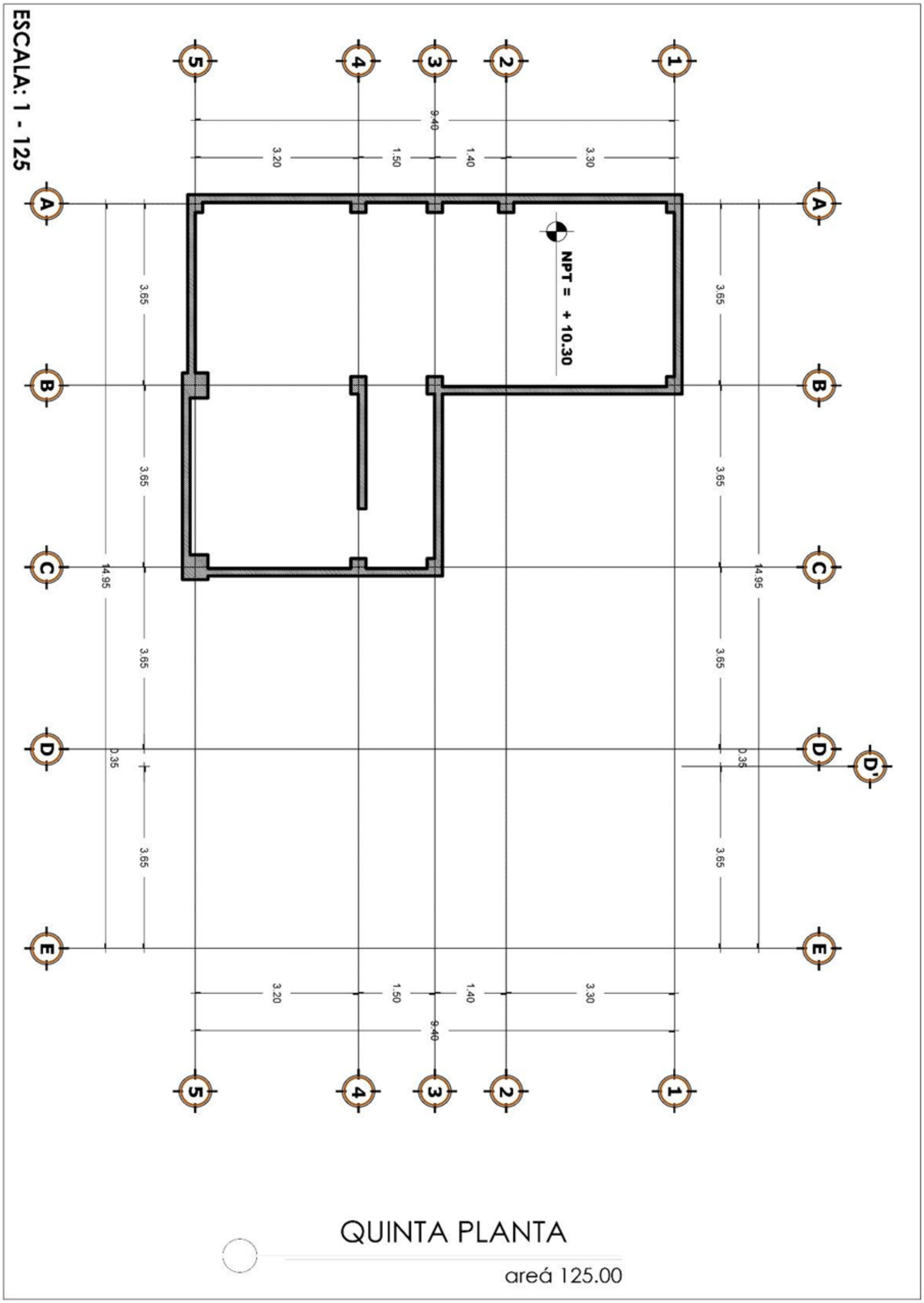

Figure 7. *Fifth floor of the building*

Subsequently, in order to know the weight of the building, load estimates by floors were carried out, with the aim of calculating the center of mass and the seismic force applied to the structure see (Table 4), and obtaining the results of the soil-structure interaction of the two proposals.

Table 4. *Total weight and center of mass of the building by floors*

TOTAL WEIGHT OF THE BUILDING						Center of Mass	
Floor	CM	CV	Type C	% CV	Total Weight	X (m)	Y (m)
	(Tn)	(Tn)	% CV	(Tn)	(Tn)		
1	101.57	23.21	25.00	5.80	107.38	6.69129301	5.24052757
2	98.13	23.21	25.00	5.80	103.93	6.69442997	5.25185491
3	98.13	23.21	25.00	5.80	103.93	6.69442997	5.25185491
4	48.89	5.15	25.00	1.29	50.17	3.09917297	3.86277022
TOTAL	346.72	74.78		18.69	365.41		

Following the data processing, it is possible to obtain the data of the physical mechanical properties consolidated in (Table 5).

Table 5*. Physical mechanical properties – Study area*

Test Pit	Df (m)	LL (%)	LP (%)	IP (%)	G (%)	A (%)	F (%)	SUCS	γ (g/cm³)
C - 01	3.00	29.38	5.99	23.39	33.59	81.71	0.86	CL-OL	1.910
C - 02	3.00	28.48	18.44	10.04	44.02	77.56	1.02	CL-OL	1.990
C - 03	3.00	27.83	17.30	10.53	37.39	81.05	1.73	CL-OL	1.940

Additionally, an isolated footing design was made for calculating the dimensions, which took into account the parameters stipulated by the National Building Regulations (RNE, in Spanish). These regulations indicate a series of verifications to be undertaken in order to gain absolute certainty that the calculated dimensions will bear the weight of the building accordingly and tolerate a proper behavior in the face of external forces see (Table 6).

Table 6. *Footing dimensions*

FOOTING DIMENSIONS						
Study Area	Footing	Weight	Length	Base	Height	Depth
		P (Tn)	L (m)	B (m)	hz (m)	d (m)
Cruz del Siglo II	A - 1	25.19	1.77	1.71	0.35	0.23
	B - 3	19.67	1.57	1.51	0.35	0.23
	B - 5	36.63	2.10	2.10	0.35	0.23
	C - 1	22.74	1.68	1.63	0.35	0.23
Centro Sismológico	A - 1	25.19	1.64	1.58	0.35	0.23
	B - 3	19.67	1.45	1.39	0.35	0.23
	B - 5	36.63	1.94	1.94	0.35	0.23
	C - 1	22.74	1.56	1.50	0.35	0.23
Barrios Altos	A - 1	25.19	1.66	1.61	0.35	0.23
	B - 3	19.67	1.47	1.41	0.35	0.23
	B - 5	36.63	1.97	1.97	0.35	0.23
	C - 1	22.74	1.59	1.53	0.35	0.23

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As a result, (Figure 8) shows the modeling of the structure.

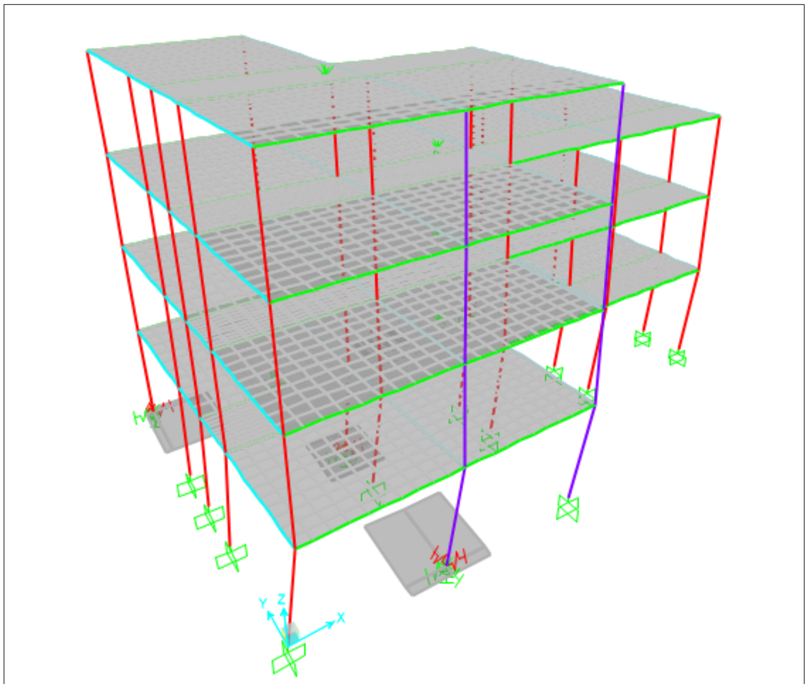

Figure 8. *Modal analysis of the structure*

3.5 Correlation Results

Data matrices for each study area were generated and processed in SPSS 25, in order to produce the output. Given the extension of each matrix, a summary of the resulting values is presented in (Table 7), where Cronbach's Alpha was used to measure the correlations between the variables, and the Kolmogorov-Smirnov test was used to measure the consistency level among the distribution of the data, also known as normality test. The third column indicates the statistical test (parametric or non-parametric) according to each normality result.

Table 7. *Consolidation of correlational results*

Hypothesis H1	***Cronbach's Alpha***	***Kolmogorov-Smirnov Normality***	***Statistical Test***
The negative effects on the proposed buildings are indirectly proportional to the increase of the seismic response characteristics detected in the soils of urban sprawl areas in the city of Moquegua.	*0.987*	*0.00 (zone 1)* *0.00 (zone 2)* *0.00 (zone 3)*	*Kruskal – Wallis H test (Non-parametric) = 0.001 H1 is accepted, because p-value > α = 0.15*
The characteristics of the soil strata are directly proportional to the increase of the seismic response characteristics of the soil in urban sprawl areas in the city of Moquegua.	*0.996*	*0.00 (zone 1)* *0.02 (zone 2)* *0.18 (zone 3)*	*Single factor Anova (parametric) = 0.998 H1 is rejected, because p-value > α = 0.01*
The D.D. Barkan – O.A. Savinov model presents a lower range than the theoretical model of embedded support, which simulates a foundation on the soils of urban sprawl areas in the city of Moquegua.	*0.863*	*0.00 (zone 1)* *0.04 (zone 2)* *0.02 (zone 3)*	*Mann – Whitney U test (non-parametric) = 0.13 H1 is accepted, because p-value < α = 0.16*

The median values from each analyzed effect were obtained after the respective statistical analyses were completed for each variable. A cross table for comparing the relationship concerning the selected urban sprawl areas see (Table 8) and a table for evaluating the relationship see (Table 9), were prepared.

Table 8. *Comparison of the median – Statistical analysis of the median / CEM-ZERO*

Comparison of the Median of the Study Area						
Items	***Seismic Response***			***Classification of the Median***		
	C - 01	C - 02	C - 03	C - 01	C - 02	C - 03
A (m)	2.59	2.35	3.31	Medium	Low	High
f (Hz)	8.50	6.12	9.10	Medium	Low	High
T (s)	0.18	0.55	0.14	Medium	High	Low
ω (s^{-1})	53.38	38.43	57.15	Medium	Low	High
Vmax (m/s)	170.22	142.39	227.33	Medium	Low	High
λ (m)	16.26	14.77	20.82	Medium	Low	High
Vp (m/s)	170.22	142.39	227.33	Medium	Low	High
Average				Medium	Low	High
Items	***Physical Mechanical Properties***					
Geotechnics	22.34	23.01	22.58	Low	High	Medium
Items	***Reactions***					
Structure	12.46	11.86	11.98	High	Low	Medium

Table 9. *Evaluation of the relationship - Statistical analysis of the median / CEM-ZERO*

Evaluating the Relationship – Seismic Response vs Reactions						
Cross Table		Reactions in the Structure			Relationship %	
		C - 01	C - 02	C - 03	Direct	Indirect
Seismic Response	C - 01	Indirect	Indirect	Direct	33.33	66.67
	C - 02	Indirect	Direct	Indirect	33.33	66.67
	C - 03	Direct	Indirect	Indirect	33.33	66.67
				Diagonal	33.33	
						66.67
Evaluating the Relationship – Physical Mechanical Properties vs Seismic Response						
Cross Table		Seismic Response			Relationship %	
Physical Mechanical Properties	C - 01	Indirect	Direct	Indirect	33.33	66.67
	C - 02	Indirect	Indirect	Direct	33.33	66.67
	C - 03	Direct	Indirect	Indirect	33.33	66.67
				Diagonal	0.00	
						100.00

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3.6 Discussion of the Seismic Response Results

In respect to the soil analysis using seismic measurement equipment, peculiarities were found in the characteristics of the waves, mainly in their length, with substantial differences in the groups of values from the study areas of Cruz del Siglo II and Seismological Center, which kept a similar data tendency, unlike the area of Barrios Altos which showed dispersion of the data.

With regard to the velocity values, there is inequality in the median values, obtained from the average velocity and maximum velocity in the study areas. In relation to the dispersion and accumulation of the data of the different characteristics, it is possible to observe that angular velocity and frequency have the greatest dispersion in their data.

As for the scale defined for the seismic response, the median of the study areas was analyzed, thereby establishing that the test pit c – 01 presents a "medium" rating, the test pit c – 02, a "low" rating, and the test pit c- 03, a "high" rating. When evaluating the relationship with regard to the reactions produced in the structure, an indirectly proportional tendency is assumed.

In relation to the significance level that arises from the comparison of the values of the three studied areas, a variance was established, because the contrast statistics produced a p-value = 0.00, which is lower than the Alpha with a α value = 0.15, thereby demonstrating a relevant difference.

The above is consistent with the conclusions of (Medina and Galarza, 2020), confirming the displacement results obtained with NSP applied to structures having characteristics similar to those of the present study.

3.7 Discussion of the Physical Mechanical Properties

Regarding the analysis of soil properties with laboratory tests, the results of the three study areas do not evidence a conclusive difference. This means that these areas were modified by a seismic fault and the distance between adjacent test pits does not exceed the 300 ml, so there is a chance that their strata were subjected to the same external agents during their constitution and formation processes.

When analyzing the median resulting from each study area, it is possible to appreciate that the difference does not exceed 0.99, a value that is lower than one. From the statistical point of view, it would be a rather imperceptible inequality; however, for the engineering, this value defines the peculiarity of each area.

Regarding the tests for establishing the soil characteristics, a significant difference is evidenced in the consistency derived from the Liquid Limit, Plastic Limit and Plasticity Index analyses. This allows visualizing the effects from subjecting the soils to different moisture proportions, which presents a notorious change of consistency in relation to the rest. As for the dispersion and accumulation of the data of the different characteristics, the study areas of the Seismological Center and Barrios Altos evidence a similar tendency, but the area of Cruz del Siglo II shows a tendency with a less noticeable difference. It should be noted that the three (3) areas have a similar tendency.

As for the scale defined in the physical mechanical properties, the median of the study areas was analyzed, thereby establishing that the test pit c – 01 presents a "low" rating, the test pit c – 02, a "high" rating, and the test pit c- 03, a "medium" rating. When evaluating the relationship with regard to the soil's seismic response, an indirectly proportional tendency is assumed.

In relation to the significance level that arises from the comparison of the values of the study areas of Cruz del Siglo II, Seismological Center and Barrios Altos, it was established that there is no variance, because the contrast statistics produce a p-value = 0.998, which is higher than the Alpha with α = 0.004, thereby demonstrating an irrelevant difference. However, as mentioned earlier, these soil characteristics are actually relevant for the engineering.

The resulting statistical data coincide with the specifications for soil index properties and soil composition indicated by (Capa, 2021) in his research on soils affected by earthquakes and volcanic eruptions in the city of Quito, Ecuador.

3.8 Discussion of the Comparison between the D.D. Barkan – O.A. Savinov Model and the Theoretical Model of Embedded Support

The analysis of the proposed models using the SAP 2000 software evidenced that the results for the areas of Cruz del Siglo II, Seismological Center and Barrios Altos do not show a conclusive difference. Nevertheless, the relationship between the theoretical model of embedded support and the D.D. Barkan – O.A. Savinov model shows a very sharp inequality; therefore, it is a statistically relevant value.

The analysis of the median resulting from each study area allows evidencing that the difference does not exceed 0.69, which is less than one. From the statistical point of view, this inequality is almost imperceptible, but for the engineering, this value should be considered in the structural design, as well as in the necessary calculations for buildings with the proper safety to resist external forces and the passing of time. Whereas the analysis of the median derived from the comparison between the theoretical model of embedded support and the applied D.D. Barkan –

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O.A. Savinov model, shows a range difference of $8.3865 < \Delta < 8.9842$*, which is a relevant difference among the observed models.*

Regarding the dispersion and accumulation of data from the Seismological Center and Barrios Altos, they show a similar tendency; but the area of Cruz del Siglo II presents a tendency with a rather imperceptible difference. It should be noted that the three (3) areas present a similar tendency.

As for the evaluation of the ranges concerning the reactions obtained from the D.D. Barkan – O.A. Savinov model in the study areas, it was found that it is more specific when evaluating the structure's compensation effects to external forces, compared with the embedded support model. This lower range characteristic will allow engineers to make calculations that are more accurate vis-a-vis the reality, thereby specifying all possible actions and variables.

Considering the significance observed in the comparison of the values between the theoretical model of embedded support and the D.D. Barkan – O.A. Savinov model, a variance was established, based on the fact that the contrast statistics showed a range of $0.112 < p - value < 0.155$*, below the Alpha with* $\alpha = 0.16$*, which indicates an average p-value* $= 0.126 \approx 0.13$*, thereby demonstrating a relevant difference.*

When comparing these values with those of (Villarreal, 2020) and (Aguiar, 2016), there is consistency in the fact that, during an earthquake, all buildings are located on an elastic surface and the maximum stresses in the columns are located near their joint with the beams, thus encouraging the use of the dynamic model of D.D. Barkan – O.A. Savinov, because it offers less flexibility and does not present the level of destruction evidenced in the dynamic model of V.A. Ilichev.

4. Conclusions

Further studies are required regarding the seismic response and physical mechanical properties of the soil, which allow using structural designs that are much similar to reality, in order to reduce the effects of external forces on the buildings and lower the range in the accuracy of the results. Likewise, this study evidences that the negative effects on the buildings are indirectly proportional to the increase of the seismic response characteristics. These events are corroborated by seismic response data as well as by the evaluation of the median based on the effects. Furthermore, after the procedure applied in the statistical analysis (Kruskal – Wallis H test), an average p-value = 0.00102114 was defined.

The above allows confirming that the characteristics of the soil strata are not directly proportional to the increase of the seismic response characteristics of the soils. This corroborates the event regarding both the data of the physical mechanical properties and the evaluation of the median, which define a p-value = 0.998293, following the procedure applied in the statistical analysis (single factor Anova).

Consequently, this study certifies that the D.D. Barkan – O.A. Savinov model has a lower range than the theoretical model of embedded support, thus confirming the event by both the data of the physical mechanical properties and the evaluation of the median. Next, following the procedure applied in the statistical analysis (Mann – Whitney U test), the p-values were obtained with a level of confidence of 84%; for the area of Cruz del Siglo II, the p-value = 0.15474, for the area of Centro de Red Sismológica, the p-value = 0.112322, and for Barrios Altos the p-value = 0.112322.

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