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Comparing Analysis of Earthquake-Resistant Housing Construction Methods in Ecuador: Frames vs. Walls

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Abstract - This research work aims to determine the most earthquake-resistant and cost-effective structural model for housing construction in Ecuador. Currently, the prevalent construction method in the country involves reinforced concrete frames, which may not provide sufficient protection against seismic activity. To address this issue, the conventional method of reinforced concrete frames is compared within the reinforced concrete walls. This research work will focus on four houses of varying dimensions, up to two levels in height, adhering to the guidelines outlined in the Ecuadorian Construction Standard (NEC). To assess the structural integrity, SAP 2000 is used which will enable a comparison of drifts and displacements as the basal shear progressively increases to the ultimate capacity limit for each house. Additionally, an economic analysis is conducted by preparing a budget for the superstructure of each house using both construction methods. The objective is to identify the most accessible and affordable option for the community while eliminating the least viable choice.

By conducting this comparative analysis, the aim is to provide a technical and economic conclusion regarding the optimal structural model for earthquake-resistant housing in Ecuador. This information will be valuable for future housing developments and contribute to the safety and well-being of the community.

***Keywords*:** Earthquake, housing construction, frames, walls

1. Introduction

In Ecuador, the use of reinforced concrete frames is the most common construction method in the country, according to data from INEC (National Institute of Statistics and Census). In 2021, the building statistics (ESED) measured the behavior of the construction field and estimated at least 42,787 homes were projected to be built. The results revealed that the number of buildings to be constructed at a national level was 30,895, which represents a 24,8% increase compared to the previous year. In relation to this, 16,648 of these buildings were in the coastal region [1]. Figure 1 illustrates the cantons with the largest number of buildings to be built, as we can see the number of homes built in the city of Guayaquil goes from 3,132 in 2020 to 3,368 in 2021.

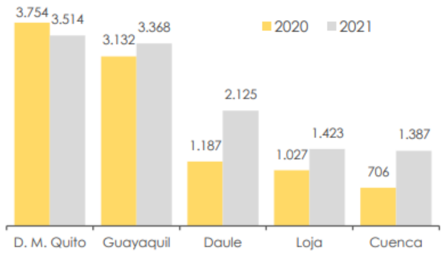


Fig. 1: Statistics of buildings 2021 [1]

The construction area of the analyzed homes is 55.7% less than 200 m2. In Guayaquil this figure is significantly lower, with an average area of 96 m2 per-home [1].

Figure 2 displays the most used materials according to different stages of construction.

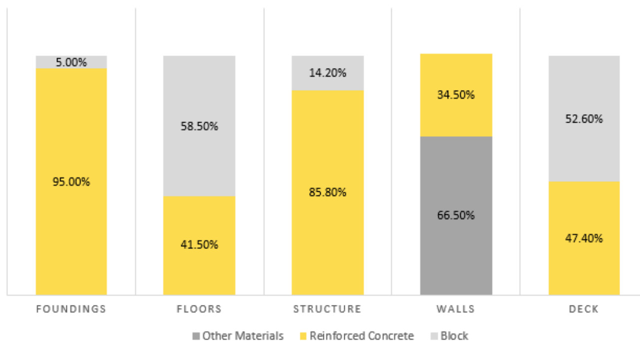


Fig. 2: Statistics of buildings 2021 [2]

Reinforced concrete plays a crucial role in nearly all stages of home construction, demonstrating its widespread use. However, it is important to highlight that walls or partitions are still constructed using masonry blocks. While masonry blocks do not contribute significantly to the overall strength of a home, they are considered as a quantifiable load during the design of other structural elements in the project.

Ecuador is located within the 'Pacific Ring of Fire', a region prone to high seismic activity. There are historic earthquakes like the 1906 earthquake, which registered a magnitude of 8.8, making it one of the largest recorded earthquakes in history. Another significant vent was the 1997 Bahía de Caráquez earthquake, measuring 7.1 on the Richter scale, which highligted certain issues related to seismic-resistant design in Ecuador [3].

To construct a seismic-resistant system of reinforced concrete frames, double transverse reinforcement is required in pedestals and columns. This reinforcement ensures the adequate confinement of the concrete core and stability of the bars, providing resistance against shear forces. On the other hand, the confined masonry system has a shorter period, indicating better dynamic behavior. Displacements at the top of the structure are lower compared to the reinforced concrete frame system, making the latter is more flexible [4] - [6].

In 2005, only 3% of homes in the city of Chile were built with reinforced concrete walls. However, over time, the construction of walls using reinforced concrete has gained popularity, representing 11 % of the total homes built by 2014. This methodology employs a more mechanized construction and reduces considerable the labor requirements. The typical thicknesses of these reinforced concrete walls ranges between 100 and 140 mm, which is comparable to or less than the traditionally used thickness of 140 mm in masonry walls [7]. It has also been shown that the application of reinforced concrete walls provides in most cases a better seismic performance of the structure for multi-story buildings as in study in [8].

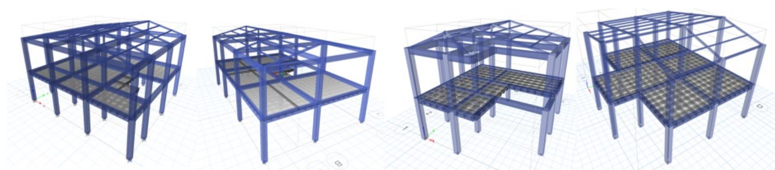
The objective of this research work is to determine which is the best construction method to implement within our environment by employing a comparative analysis with the progressive increase of the basal shear of 4 buildings, to provide greater security in the community.

2. Methodology

The methodology employed in this research work includes both quantitative and qualitative approaches to comprehensively understand the deformations and seismic-resistant responses of housing structures [9]. The main focus is on two construction methods: reinforced concrete frame and load-bearing wall. The analyzed housing units are two-stories buildings with regular geometry featuring spans of less than 4 meters between columns. This facilitates the individual and group analysis of their components, including beams, walls, columns, and slabs.

The following data will be compared: (1) base shear, (2) seismic response spectrum, (3) deformations, (4) economic viability, and (5) final evaluation. To determine the best cost-performance option for a specific construction area in Ecuador, the collected data will be evaluated using a cost vs. resistance graph. The specimens will meet the minimum requirements proposed by the current standards in Ecuador.

For the technical analysis, a finite element software will be employed to develop the structural models of the houses. A total of 4 houses will be analyzed, incorporating variations between reinforced concrete frames and load-bearing walls. A computer code will be created to facilitate the structural modelling in the finite element program. In this program, the load parameters will be defined, and deformation graphs, as well as basal shear, indicating the maximum strength value of the structure will be obtained. After completing the technical evaluation of the structural performance of the houses, a comparison of construction costs will be conducted for each case. Both methods to be studied will be carried out for each model represented, within the Etabs Ultimate 21 application the concrete frames in each model will be replaced by the confined masonry (CM) walls to realize the comparative analysis, using the same loads.



Model 1/ Frames Model 2/ Frames Model 3/ Frames Model 4/ Frames

Fig. 3: Modeling of houses with concrete frames to analyze.

The design criteria applied to the superstructure elements must comply to the minimum requirements and standardized geometry specified in the Ecuadorian construction standard (NEC). This compliance is guided by three codes: Seismic hazard and earthquake resistant design requirements NEC-SE-DS [10], the Reinforced concrete structures NEC-SE-HM [11] and the structural masonry structures NEC-SE-MP [12].

3. Analysis

For each model of building, the same requirements according to the Ecuadorian construction standard NEC were stablished: using columns of 0.30x0.30m, beams of 0.25x0.30m, a height between floors of 3.0 m and the light must not exceed 4 m. Each model has a different structure to verify the most efficient method. The first model has a square structure, the second a rectangular structure, the third presents an L shape and the fourth presents a T shape.

Before an analysis its crucial to verify that the drift does not exceed 2% indicated by the NEC [10], the four models meet the requirement. First, we analyze the reinforced concrete frames buildings method of construction. The basal shear increases progressively from 0.1 to 0.5. Besides the range established for the basal shear we analyze the maximum displacement that each structure can handle, by means of a graph we will see how it increases proportionally to the shear. The maximum displacement we can have been: 53.3 mm. For this analysis the value of the displacement of the house was recorded by increasing the basal shear progressive (0.1, 0.2, 0.3, 0.4, 0.5), and the maximum shear value was recorded in which the maximum displacement of the house is obtained in the Etabs program.

Figure [4]-[5]. shows the maximum base shear coefficient of the 4-housing using the frame and walls system, showing the difference in rigidity that the housing develops when we opt to use a walls system for a construction, in both directions 'x' and 'y'.

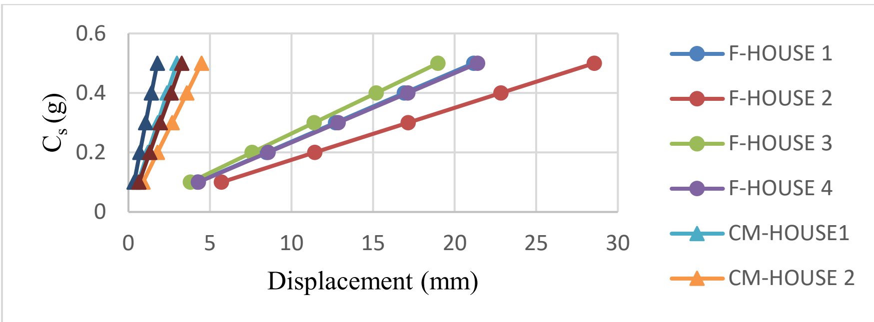


Fig. 4: Frame system vs walls system: base shear coefficient (Cs) vs displacement, (direction 'x')

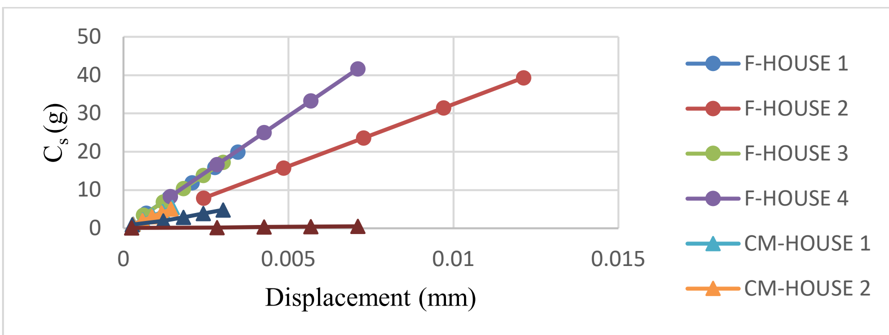
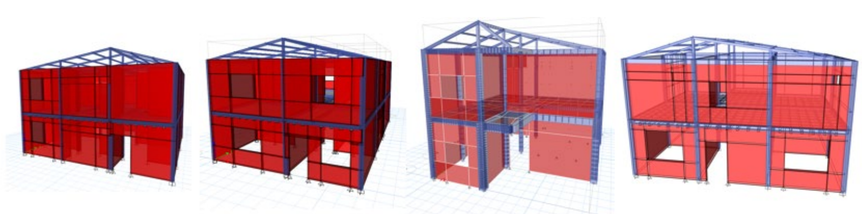


Fig. 5: Frame system vs walls system: base shear coefficient (Cs) vs displacement, (direction 'y')



Model 1/ CM Model 2/ CM Model 3/ CM Model 4/ CM

Fig. 6: Modeling of houses with confined masonry walls to analyze.

Table 1 Model 1: Elastic Drift in both methods (Frames and Walls)

FRAMES SYSTEM				**WALLS SYSTEM**		
SEISM Y				SEISM Y		
Cs (g)	U (mm)	Δ	Δ (%)	U (mm)	Δ	Δ (%)
0,1	3,974364	0,000693	0,16%	1,086996	0,000296	0,07%
0,2	7,948728	0,001386	0,31%	2,173992	0,000592	0,13%
0,3	11,92309	0,002079	0,47%	3,260988	0,000888	0,20%
0,4	15,89746	0,002772	0,62%	4,347984	0,001184	0,27%
0,5	19,87182	0,003465	0,78%	5,43498	0,00148	0,33%

Table 2 Model 2: Elastic Drift in both methos (Frames and Walls)

FRAMES SYSTEM				WALLS SYSTEM		
SEISM Y				SEISM Y		
Cs (g)	U (mm)	Δ	Δ (%)	U (mm)	Δ	Δ (%)
0,1	7,864292	0,002425	0,55%	1,00033	0,000289	0,07%
0,2	15,72858	0,00485	1,09%	2,00066	0,000578	0,13%
0,3	23,59288	0,007275	1,64%	3,00099	0,000867	0,20%
0,4	31,45717	0,0097	2,18%	4,00132	0,001156	0,26%
0,5	39,32146	0,012125	2,73%	5,00165	0,001445	0,33%

Table 3 Model 3: Elastic Drift in both methos (Frames and Walls)

FRAMES SYSTEM				**WALLS SYSTEM**		
SEISM Y				SEISM Y		
Cs (g)	U (mm)	Δ	Δ (%)	U (mm)	Δ	Δ (%)
0,1	3,447186	0,000605	0,14%	0,9634	0,000272	0,06%
0,2	6,894372	0,00121	0,27%	1,9268	0,000544	0,12%
0,3	10,341558	0,001815	0,41%	2,8902	0,000816	0,18%
0,4	13,788744	0,00242	0,54%	3,8536	0,001088	0,24%
0,5	17,23593	0,003025	0,68%	4,817	0,00136	0,31%

Table 4 Model 4: Elastic Drift in both methos (Frames and Walls)

FRAMES SYSTEM				**WALLS SYSTEM**		
SEISM Y				SEISM Y		
Cs (g)	U (mm)	Δ	Δ (%)	U (mm)	Δ	Δ (%)
0,1	8,325072	0,00142	0,32%	0,103985	0,00025	0,06%

0,2	16,650144	0,00284	0,64%	0,20797	0,0005	0,11%
0,3	24,975216	0,00426	0,96%	1,96257	0,00075	0,17%
0,4	33,300288	0,00568	1,28%	2,61676	0,001	0,23%
0,5	41,62536	0,0071	1,60%	3,27095	0,00125	0,28%

4. Discussion

The models studied through comparisons obtained as a result that the houses with walls tend to cause less displacements and with it fewer elastic drifts, the differences obtained for each house in terms of maximum displacements are:

House 1 presents a displacement reduction of 57,1% when the walls system is used. House 2 presents a displacement reduction of 43,9% when the walls system is used. House 3 presents a displacement reduction of 59,7% when the walls system is used. House 4 presents a displacement reduction of 62,7% when the walls system is used.

According to the NEC, if an approximation of the period of the structure is made in the frame system using the indicated coefficient a period of 0,32 s is obtained. As a result, we can determine that the use of retaining walls is a beneficial practice within the construction, which should be more used to increase the level of safety in the community. In addition to the reduction in displacement represented by using a wall system, more economical housing is also obtained compared to the frame system. Carrying out an approximate analysis of the gray work in a construction between both methods, the use of a wall system reduces the use of concrete, steel, masonry, and formwork, all due to the reduction of sections in the structural elements.

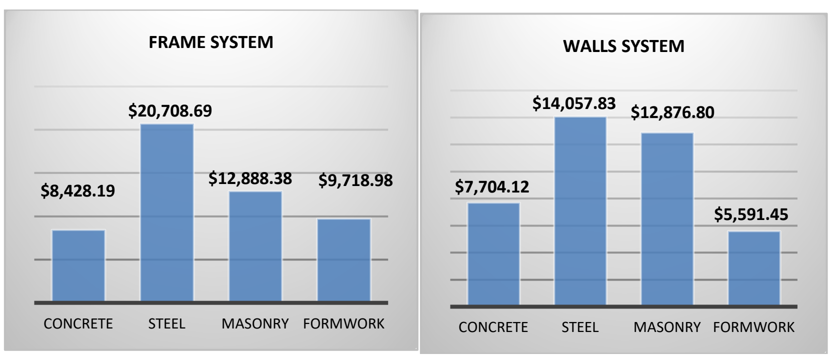


Fig. 7: Price comparison in USD dollars between the study methods

5. Summary and conclusions

- The use of a system of walls provides greater rigidity in a house during a seismic event, while a frame system has a greater flexibility in its structure, therefore is more deformable.
- During a severe seismic event, in the wall system, these are the ones that support the whole load, presenting little localized damage, while in the frame system the damage to non-structural elements is very evident.
- Using a system of walls implies following certain conditions just as if the structure is regular or not, which should be for using this method and also there must be continuity between these walls.
- The best option in both economic and structural analysis is the use of a walls system, which provides greater security within the home for users and there is a price reduction due to the smaller dimensions used.

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