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Original Article

Influence of Change of Use on the Seismic Performance of Reinforced Concrete Buildings through Nonlinear Analysis

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Abstract *- An increasing problem in cities in Latin America is the reuse of reinforced concrete structures, where residential structures are often converted into office, School, or commercial use with little serious structural assessment. These changes modify the distribution of mass and stiffness, thereby raising seismic requirements and possibly endangering safety. This paper is an evaluation of the seismic performance of a seven-story reinforced concrete building when subjected to nonlinear static analysis (pushover) and based on four representative conditions, namely, housing, office, School, and commercial. The nonlinearity of the modeling process consisted of concrete walls, beams, columns, and slabs, which were a plastic hinge and fiber section as per the ASCE 41. The outcomes show that, according to SEAOC performance standards, the building is able to sustain the level of Life Safety in all scenarios. However, there were differences in capacity and displacement; as an example, the housing base had a peak base shear of 502.7 tonf and final displacement of 0.382 m. Conversely, the school scenario had strength gains of up to 0.3%, albeit a 1.3% decrease in displacement capacity. The business case implied the greatest base shear (505.6 tonf) and a minor reduction in ductility. These results indicate that, despite the performance category staying the same, structural risk gradually increases with functional changes, and in certain instances, the building might be moved to the boundary of Near Collapse, which is why technical assessment beforehand is crucial.*

Keywords *- Change of use, Seismic performance, Compressive Strength, Reinforced concrete, Pushover analysis.*

1. Introduction

The functional restructuring of the existing reinforced concrete buildings has become a crucial structural problem in the context of large Latin American cities, including Lima, Santiago, and Mexico City. It is a usual custom to convert residential buildings to offices, learning institutions, or commercial areas (Figure 1) without careful technical analysis to confirm the capacity under new seismic conditions [1, 2].

These changes cause a major change in the initial design conditions, raising the gravitational loads and changing the mass and stiffness distributions, which directly influence the dynamic behavior of a structure [3, 4]. Past studies reveal that these unregulated interventions may severely decrease the available ductility and can cause brittle failure modes, especially in constructions developed according to old codes [5, 6].


Fig. 1 Use of schools as housing in Peru

The primary methodology employed in this study is Nonlinear Static Analysis (pushover), a technique that evaluates the seismic performance of existing structures by characterizing lateral capacity, global ductility, and damage progression through the application of incremental lateral loads [7, 8]. This approach has proven particularly effective in assessing typologies undergoing functional changes. For instance, prior studies on healthcare facilities have quantified the reduction in seismic capacity under increased live loads [9–11]. Similarly, research on educational infrastructure has established correlations between occupancy changes and specific failure mechanisms. In the context of heritage structures, this method has successfully identified vulnerabilities to guide rehabilitation strategies [12, 13], demonstrating its utility in defining retrofitting needs for critical buildings [14].

Most recent developments in computational modeling can now perform a more accurate analysis of structural behaviour during extreme seismic requirements [15]. The developments are redefining the assessment criterion of existing buildings, whereby functional flexibility is a major parameter in rehabilitation. By combining the concepts of the circular economy and sustainability [16, 17] with innovative structural analysis, it is possible to address the whole gamut of evaluations that do not focus only on the present load-bearing capacity but also on the adaptability and the service life of the structure.

Nevertheless, the literature still has a large gap: there is a dearth of systematic comparative studies that would quantify the particular effect of multiple occupancy scenarios on a single structural typology. This study fills this gap by assessing the effect of the functional modifications on the seismic performance of a seven-story reinforced concrete structure. Based on the analysis of four typical scenarios: housing, office, School, and commercial, the study employs Nonlinear Pushover Analysis in ETABS [18] to offer technical requirements in structural decision-making in terms of drift limits, displacement capacity, and plastic hinge formation.

2. Materials and Methods

This part of the materials and sections outlines the characteristics of the building that was used as a reference, change of use scenarios that were taken into account, characteristics of the materials, and the structural modeling carried out on ETABS [18] and the configuration that was adopted in this study to carry out the seismic performance of the reference building.

2.1. Building Description

The object studied in this paper corresponds to a seven-story reinforced concrete building that has a structural configuration based on common typologies in the Peruvian context [19]. The structural system is composed of shear walls in both main directions, combined with frame elements of beams and columns. Most of the lateral stiffness is focused on continuous walls in the Y direction, with the walls being strategically placed in locations that are not obstructive to the architectural design of the building in the X direction [20]. Besides, there is the presence of elevator shafts and stairwells that serve as rigid cores and play an important part in the shear of the building. This design enables greater seismic performance with a combination of frame resistance and wall stiffness.

Figure 2 shows the floor plan of the typical levels, where the location of the structural walls, service cores, and beam grids can be seen, together with the general dimensions and the location of the main elements, which allows the geometric and structural distribution of the building to be characterized.

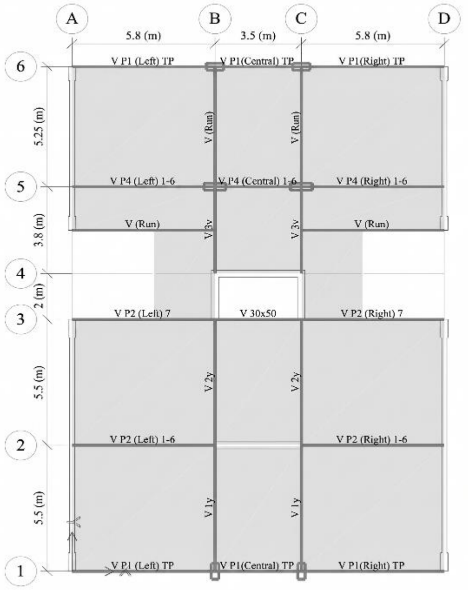


Fig. 2 Structural configuration of the building under study

The building has a total height of 22.0 m, with a first-story height of 4.0 m and typical story heights of 3.0 m, with a floor plan configuration of 15.2 m x 22.20 m. Finally, the dimensions of the structural elements and the general configuration of the system are detailed in Table 1, while the design criteria were defined according to the Peruvian Technical Standard E.030 [20] and Standard E.060 [21].

Table 1. Structural configuration

Parameter	Value / Description
Column Section	C1 0.30 x 0.70 m C2 0.30 x 0.90 m
Beam Section	VP 0.30 x 0.50 m
Concrete wall thickness	T1 0.20 m T2 0.30 m
Story height	4.0 m (1st story) - 3.0 m (typ.)
Solid slab	0.18m
Concrete strength	280 kgf/cm^2
Modulus of elasticity	250998.00 kgf/ cm^2
Poisson's ratio	0.15
Steel strength	4200 kg/cm2

2.2. Change of use Scenarios

Four representative functional scenarios were considered to evaluate the influence of a change of use on the seismic performance of the analyzed building. These scenarios were defined based on the most frequent transformations observed in the Latin American urban context, where reinforced concrete buildings are often adapted to new demands without prior technical studies. The methodological strategy consisted of keeping structural geometry constant and modifying only the gravitational loads and the mass distribution, in accordance with Standard E.020 [20] and Standard E.030 [21].

The first scenario evaluated in this research corresponds to a building with a residential usage that is characterized by live loads and regular partitioning. The second scenario considered is the office-use building that presents an increase in live loads due to the higher occupancy density and the redistribution of interior partitions. The school scenario is the third one analyzed, and it incorporates significantly higher live loads that are associated with the concentration of people in classrooms and common spaces. With regards to the commercial scenario, this one introduces a rise in both dead and live loads due to the presence of heavy furniture and equipment, and this situation reflects a more demanding functional operating condition [22].

Table 2 presents a summary of all overload values assigned to each scenario and the building category. In this classification, the seismic mass is determined, and it is also considered in the analysis: for category C buildings, 100% of the dead load plus 25% of the live load is used, while for categories A and B, 100% of the dead load plus 50% of the live load is taken. This distinction clearly shows how varied types of occupancy directly influence the seismic demands of a building as well as the structural safety requirements.

Table 2. Use the category and associated overload according to standards for each change of use scenario

Use scenario	Category	Overload
Residential use	C	2.00 kN/m2
Office use	C	2.50 kN/m2
Commercial use	B	5.00 kN/m2
School use	A	4.00 kN/m2

2.3. Nonlinear model for Reinforced Concrete

The representation of nonlinear behavior in reinforced concrete structures requires the incorporation of constitutive laws that adequately reproduce the inelastic response of the materials. A common strategy consists of using simplified stress–strain curves for concrete and reinforcing steel, which allow capturing stiffness degradation, ultimate strength, and ductility. These curves are constructed from experimental results widely documented in literature, ensuring correspondence between the numerical model and the actual material response [23].

In this study, the model for confined and unconfined concrete was adopted, which defines the stress–strain relationship as a function of compressive strength, modulus of elasticity, and ultimate strain. For reinforcing steel, a model including the strain-hardening stage was used. Both models are widely employed in structural analysis tools, as they allow a practical representation of nonlinear behavior in nonlinear static analyses [24, 25]. Figure 3 shows the proposed model for monotonic loads in confined and unconfined concrete, while Figure 4 presents the stress–strain curve for steel.

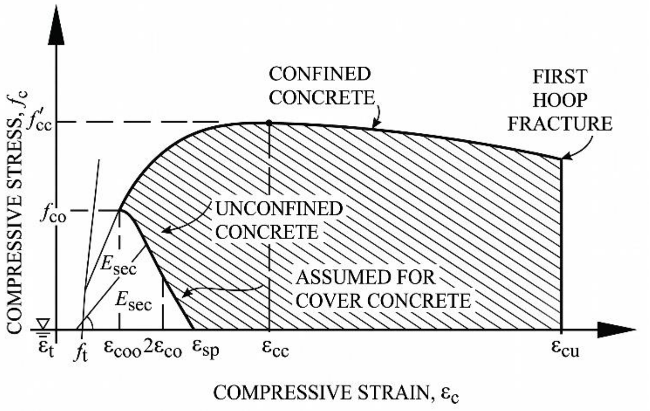


Fig. 3 Proposed model for monotonic loads in confined and unconfined concrete [22]

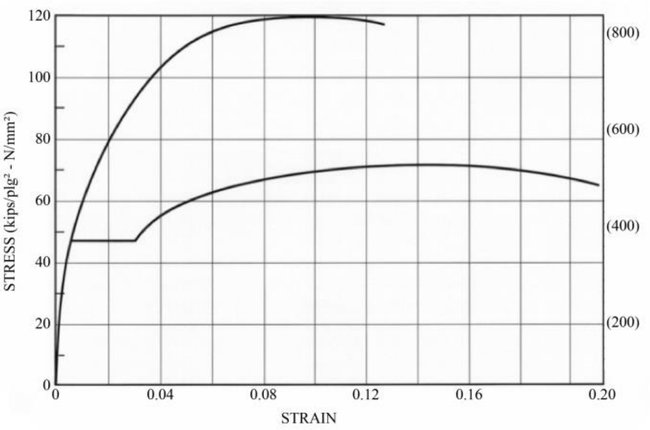


Fig. 4 Stress–strain curve of reinforcing steel [23]

2.4. Structural Modeling

The numerical model was developed in ETABS using a three-dimensional representation of the building. Beams and columns were defined as frame elements with rectangular sections, while walls and slabs were represented with shell elements, allowing a more accurate capture of their stiffness and behavior under lateral loads [26].

The foundation was modeled as fixed supports at the base, and the cores formed by elevator shafts and stairwells were modeled as rigid regions, recognizing their contribution to global stability [23]. Figure 5 shows the isometric view of the building modeled in ETABS, where the adopted structural representation can be observed.

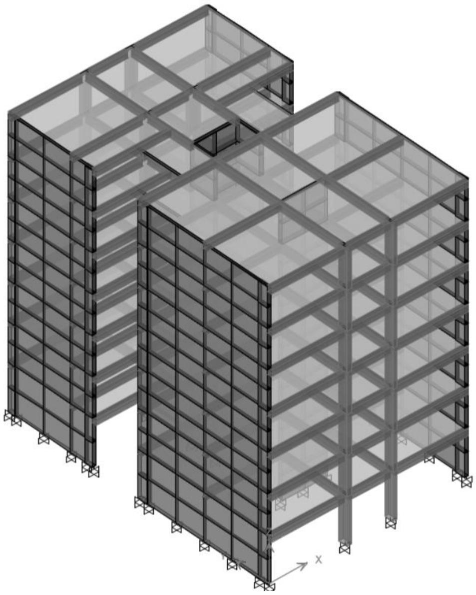


Fig. 5 Isometric view of the structural model

2.5. Nonlinear Analysis Configuration

The nonlinear static analysis was carried out through the pushover procedure, which consists of the incremental application of lateral loads until the global collapse of the structure is reached. The inelastic behavior was represented by assigning plastic hinges in beams and walls, as well as by using fiber sections in the columns, following the guidelines of ASCE 41, which allowed capturing the sequence of failure mechanism formation from the progressive degradation of stiffness and strength [27].

In the beams, plastic hinges were concentrated at the ends, representing in a simplified way the possible flexural failure mechanisms. In the case of columns, fiber sections were used to model the interaction between concrete and steel under bending and axial load. Similarly, for structural walls, the fiber model was also applied, which allowed representing failure modes due to shear and flexure, as well as the progressive degradation of stiffness [28]. This global representation of the elements is summarized in Figure 6.

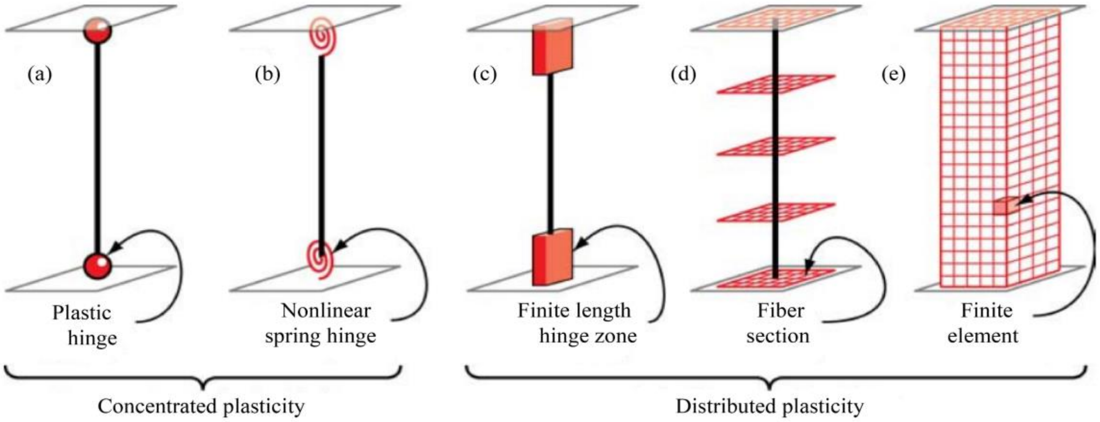


Fig. 6 Idealized models of beam-column elements

2.6. SEAOC Seismic Performance

The structural performance evaluation was carried out following the methodology proposed by the Structural Engineers Association of California in Vision 2000 [29], which establishes four seismic performance states: Immediate Occupancy, where the building maintains its stiffness and functionality with minimal damage; Life Safety, which allows moderate inelastic deformations and ensures the safe evacuation of occupants; Near Collapse, characterized by severe damage and significant loss of stiffness, although with some residual capacity; and Collapse, where the structure globally loses its load-bearing capacity.

The classification into these states was determined based on parameters such as maximum drifts, displacement capacity, and the sequence of plastic hinge formation obtained from the pushover analysis. Figure 7 graphically shows the procedure followed to identify the performance level reached by the building according to the relationship between structural demand and capacity.

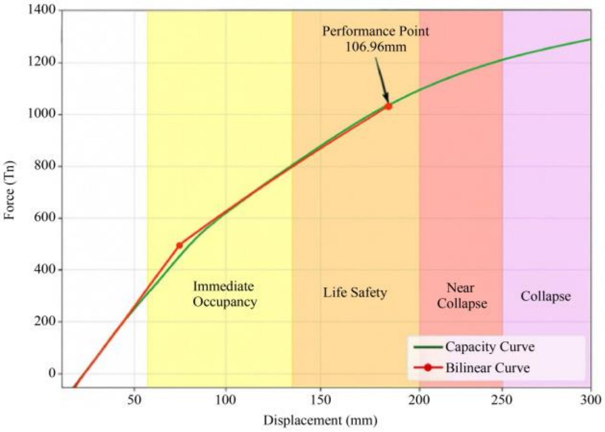


Fig. 7 Determination of seismic performance according to the states defined by the SEAOC Vision 2000 methodology [29]

3. Results

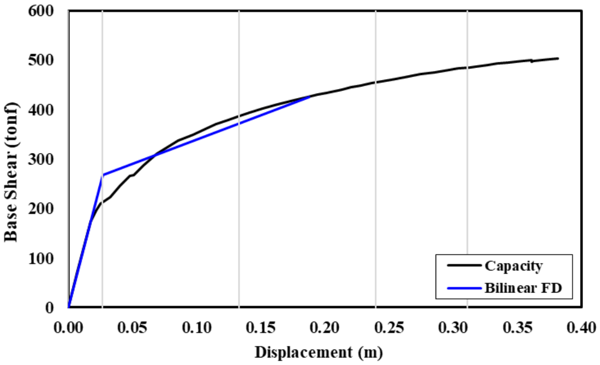
The results obtained from the nonlinear static analysis allow the seismic capacity of the building to be characterized under the different change of use scenarios defined in the study. For each case, the relationship between base shear and roof displacement was evaluated, represented in the bilinear and experimental capacity curves. These graphs make it possible to identify the initial elastic behavior, the incursion into the inelastic range, and the performance point according to SEAOC criteria.

In the following sections, the results for the four analyzed scenarios, which are the residential, office, commercial, and School, are presented separately. Each includes the description of structural behavior, the maximum values of base shear and displacement, as well as the performance classification achieved. The organization of the data in this way permits a direct comparison of the influence exerted by the change of use of these constructions on their structural safety and seismic performance level.

3.1. Residential Scenario

Figure 8 exhibits the capacity curve obtained after the simulations for the residential scenario. The evaluated building, which has a residential purpose, exhibits a predominantly elastic initial behavior up to a displacement of 0.026 m, after which it enters the inelastic range. The maximum base shear reached in the negative direction (X−) was 502.72 tonf. This behavior is associated with an ultimate displacement of 0.382 m, while in the positive direction (X+), the maximum value recorded was 498.61 tonf; this corresponds to an ultimate displacement of 0.381 m. These outcomes indicate that there is a consistent structural response in both directions, putting in evidence a stable and symmetrical seismic performance of the building when put under incremental lateral loads.

According to the SEAOC performance classification, this building in this scenario is classified within the Life Safety range, meaning that it maintains adequate capacity to resist the design earthquake without imminent risk of collapse, although with moderate structural damage.



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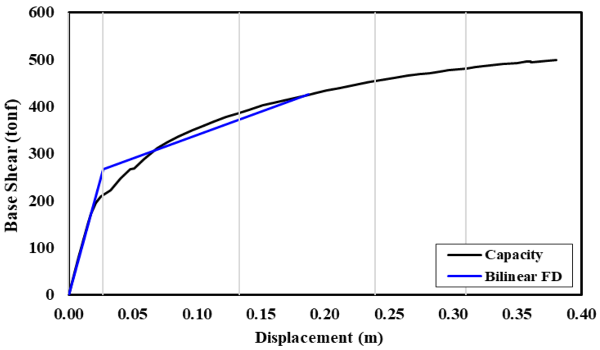
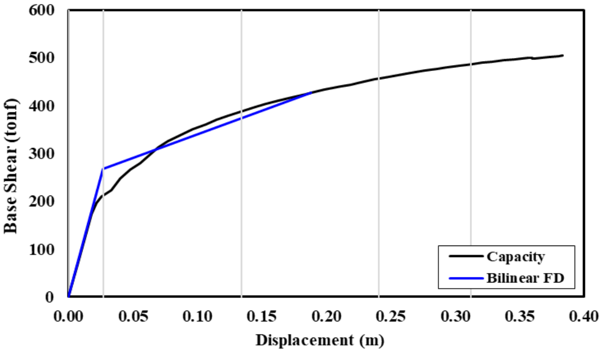


X+

Fig. 8 Capacity curve for the residential scenario

3.2. Office Scenario

The capacity curve obtained for the office scenario is shown in Figure 9. The analyzed structure exhibits an initial elastic behavior up to a displacement of approximately 0.027 m. After this displacement, the inelastic response begins to develop. The maximum base shear reached was 504.18 tonf, and this corresponds to an ultimate displacement of 0.383 m. It was noticed that this result remained consistent in both load directions, positive (X+) and negative (X−), putting in evidence a symmetrical performance of the building when it is put under lateral loads. Additionally, according to the SEAOC performance classification, the building in this scenario is situated within the Life Safety range, meaning that the structure maintains sufficient capacity to protect the safety of its occupants during a severe seismic event, but still experiences some moderate structural damage.



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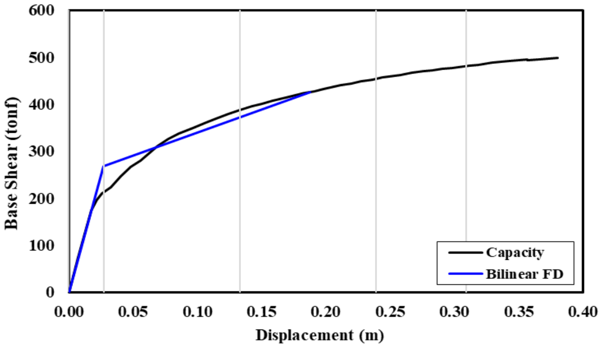


X+

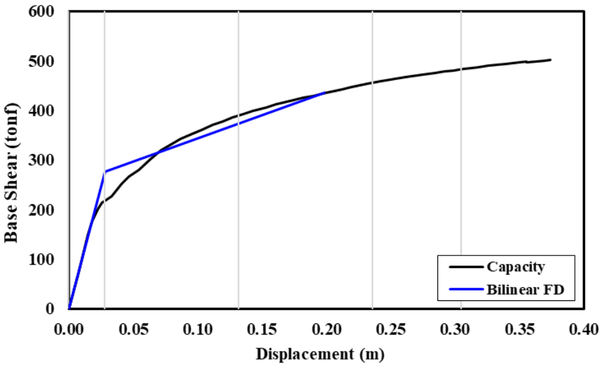
Fig. 9 Capacity curve for the office scenario

3.3. Commercial Scenario

The capacity curve obtained for the commercial scenario is exhibited in Figure 10. The analyzed structure unveiled an elastic behavior up to a displacement of approximately 0.028 m, entering the inelastic range after it. The maximum base shear reached was 505.62 tonf, which is associated with an ultimate displacement of 0.376 m.

All the obtained results remained similar in both analysis directions (X+ and X−), which confirms a practically symmetrical structural performance under opposite lateral loads. The outcomes in this scenario reflect an increase in gravitational demands when compared to the residential and office ones, resulting in a greater participation of the walls in the drift control and energy dissipation.

According to the SEAOC performance classification, the scenario of this building under commercial use conditions is classified to be within the Life Safety range, indicating that although significant structural damage occurs, the building retains its capacity to prevent collapse and ensure occupant protection during a severe seismic event.



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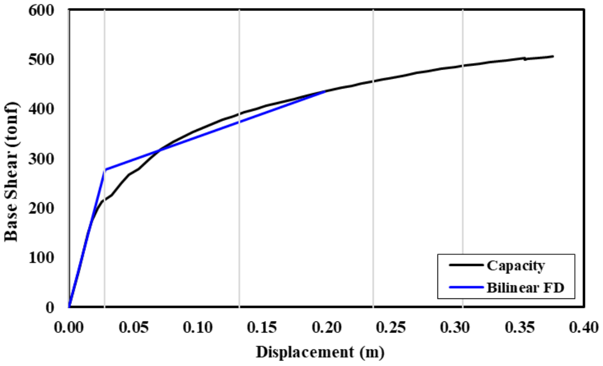


X+

Fig. 10 Capacity curve for the commercial scenario

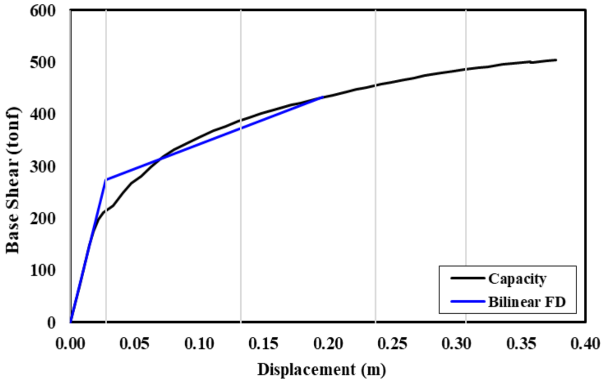
3.4. School Scenario

In Figure 11, the capacity curve corresponding to the school scenario is shown. The building in this scenario exhibited an initial elastic behavior up to a displacement of 0.027 m, entering the inelastic range right after it. The maximum base shear recorded reached 504.28 tonf; this is associated with an ultimate displacement of 0.376 m. This performance remained consistent for the nonlinear analysis when lateral loads were applied in both the positive (X+) and negative (X−) directions. This situation reflects the symmetry and stability of the structural response under seismic demands in both directions.

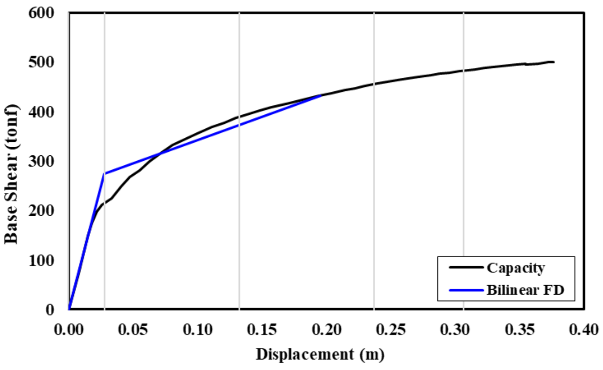
As mentioned in the SEAOC performance classification, the structure in this scenario is classified to be within the Life Safety range, meaning that although it enters the inelastic range and develops moderate damage in elements, it maintains global stability and adequate capacity to protect the occupants' lives.

In general, the findings in this study indicate that the four scenarios analyzed preserve the Life Safety performance level according to SEAOC, yet the lateral demands and displacements increase significantly when changes are used. In the base residential setting, the maximum base shear reached 502.7 tonf with an ultimate displacement of 0.382 m. For the contexts of offices and commercial use, these values increased by approximately 0.5% and 1.5%, respectively, while in the school scenario, the increase was about 3.0% when compared to the residential case.

Even though the performance classification indicates that it remains at Life Safety levels, the variations observed in these scenarios reflect a higher cumulative risk because the increase in gravitational loads modifies the seismic demand. Considering the context of the School, it can be argued that the noticed behavior shows an approach towards the Near Collapse threshold, manifesting that even small percentage increments in response parameters can compromise the structural safety of the buildings. These findings attained in this study highlight the need for performing rigorous evaluations when buildings with a determined type of purpose go through a change of use, and this is necessary even in constructions with robust structural systems.



X-



X+

Fig. 11 Capacity curve for the school scenario

4. Discussion

The results demonstrate that while the structure maintains the Life Safety performance level across all four scenarios, changing the occupancy type progressively increases seismic demands. It is most evident in the school and commercial situations, where the base shear and displacements increased up to 3 per cent. over the original residential base. These results are consistent with the vulnerabilities found in educational structures by Işik et al. [4] and validate the risk of functional adaptability found in the literature [16], where retrofitting is not done, so that the use changes and safety margins are reduced. This research quantifies the relative impact of various occupancies as opposed to previous studies, which only consider one use, like a hospital [7, 8] or industrial facilities [13].

It is desired to mention that only one geometric model was used in this study. No geometric variants were created due to the specific aim of the project: it was necessary to assess the sensitivity to occupancy loads strictly. This was done by fixing the geometry so that any change in structural response was caused only by mass increments and not by changes in geometric stiffness.

4.1. Sensitivity Analysis and Study Limitations

The sensitivity analysis was conducted to determine the effect of changes in live loads on structural response to varying occupancy levels. The findings suggest that the system is very sensitive to the mass increase related to both Category A (educational centres) and Category B (commercial premises). In particular, an increase in live load by 50% causes a non-linear decrease in the displacement capacity of the structure. Although the building is still within the "Life Safety" range, the data demonstrates that safety margins are being eroded gradually, bringing the building to a very dangerous area of the "Collapse Prevention" range.

On the modeling assumptions, the analysis was based on fixed-base boundary conditions and a damping ratio of 5 percent, where plastic hinges were defined according to the ASCE 41 guidelines. Nonetheless, this research has limitations that need to be captured in future research.

The current assessment relies on a deterministic approach, assuming a constant concrete compressive strength (f'_c = 280kgf/cm²). In practice, existing buildings often exhibit material heterogeneity or construction defects not captured by this model. Probabilistic analysis should thus be included in future research in order to better account for these uncertainties in both materials and technical modeling.

5. Conclusion

The analysis proves the positive correlation between the functional changes in reinforced concrete buildings and the seismic demands. Although the four considered scenarios had the same level of performance in terms of safety concerning SEAOC requirements (Life Safety), there was a gradual decrease in the level of safety margin as the occupancy loads rose. The residential baseline was providing a stable base shear of 502.7 tonf, but a change in usage to commercial and School use changed this balance.

In particular, the commercial scenario had the greatest lateral requirement, resulting in a base shear of 505.6 tonf. More importantly, the worst behavior was observed in the scenario of the School, the deformation of which is characterized by a 1.3% decrease in the displacement capacity in comparison to the initial design. The differences may seem insignificantly small numerically, but are a non-linear loss of ductility in the structure.

Conclusively, therefore, it is established that although the building does not collapse immediately due to the new loads, the functional adaptation without retrofitting brings the structure to the very edge of the Near Collapse threshold. This confirms that the major risk associated with changing the use of a building is not only the increase in the static weight, but the change in the dynamic response and energy dissipation capacity, and that rigorous technical verification is required before any occupancy change is made.

Nomenclature

- V_{base}: Base shear
- Δu: Ultimate displacement
- f'_c: Concrete compressive strength
- f_y: Steel yield strength

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