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Seismic Assessment of Three RC Buildings Using Pushover Analysis Method

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Abstract: The study highlights the effectiveness of pushover analysis in assessing structural performance and ensuring safety under seismic conditions. To achieve this, the study employs numerical modeling to analyze the structural behavior of reinforced concrete (RC) buildings under seismic hazards, utilizing nonlinear static analysis methods. Based on the validation of previous empirical and theoretical studies, this study created three-dimensional finite element models using the CSI-ETABS V.19.1.1 software. The study also addresses the limitations of the Egyptian Code for Loads (ECP-201), which lacks provisions for nonlinear static analysis. To overcome this, the pushover analysis technique, a nonlinear static method known for its accuracy in predicting structural performance and identifying plastic hinge locations, is applied. The analysis evaluates RC frame buildings of 15, 20, and 25 stories designed according to ECP-201 and compares the results with standards from ATC-40, FEMA-356, and FEMA-440. The findings indicate that these buildings can sustain seismic base shear ranging from 65% to 85% of their ultimate capacity, as determined by pushover analysis in both X- and Y-Directions.

Keywords: Seismic assessment, Pushover analysis · Nonlinear static analysis, Performance-based evaluation.

1. Introduction

Pushover analysis is static nonlinear research performed to determine the building's pushover or capacity curve. Nonlinear static analysis must be performed to track the structures' gradual yielding. The structure is being loaded laterally. The building's motion can be controlled by amplifying the weight. This target displacement is the maximum allowable response to a ground excitation of the given magnitude [14].

Recently, different countries around the world have been hit by horrific earthquakes with effects ranging from slight damage to irreparable damage. As a result, Egypt has paid close attention to understanding how concrete buildings behave during earthquakes.

This study aims to address several key objectives. First, it aims to evaluate the performance of traditionally constructed buildings by incorporating new developments and current structural specifications. Second, apply design techniques relevant to Egyptian buildings, as outlined by FEMA 440, FEMA 356, and ATC 40. Third, it focuses on enhancing the structure’s capability, strength, and stiffness to mitigate earthquake-induced damage. Fourth, it aims to minimize both human and economic losses that arise from seismic events. Finally, it will discuss engineering judgments, suggestions, and recommendations for future improvements. This research presents through numerical simulation nonlinear static analysis to evaluate the expected performance of a commercial building of reinforced concrete (RC) frames variable in the number of floors consisting of 15, 20, and 25 floors and two basements, located in the New Administrative Capital. The structural system for all the studied structures was moment resisting RC frames. The numerical study was accomplished by modeling the structure in Etabs program and then analyzing it with pushover analysis (non-linear static analysis).

At first, the analysis was performed under the influence of equivalent static loads, and then the non-linear static analysis was performed according to what was recommended by international codes and references specialized in seismic assessment, such as ATC40, FEMA365, and FEMA440, under the influence of two different levels of earthquakes in two perpendicular directions The study's findings indicate that well-designed buildings in Cairo can withstand the seismic loads of the city, and it is evident that the current structure behaves similarly to the mechanism of the weak beam—the strong column.

Recently prepared and made available for immediate application, the Egyptian code (ECP-201, 2020) [1] includes seismic design regulation. The design of buildings and other structures must adhere to the minimum load requirements established in this code. Both the maximum permitted load and the maximum load that may be safely applied are specified.

The ECP design process typically uses a linear force analysis method as opposed to a displacement analysis method. Most structural engineers use the linear analysis method since it is simple to compute. The method considers the nonlinear response of structures by means of the response reduction parameter for the entire structure [2, 3].

Various methodologies exist for determining the seismic performance of a building, which vary depending on the specified requirements. FEMA 356 [4] proposes the use of the displacement coefficient method (DCM), while ATC40 [5] provides information on the capacity spectrum technique (CSM). FEMA 440 [6] introduced enhancements to both the DCM (Displacement Control Method) and CSD (Capacity Spectrum Method). The Eurocode 8 [7] implemented the N2 technique, which demonstrates a modified version of the CSM.

For seismic assessment and design, most building codes (e.g., ATC, FEMA) use performance-based design criteria to predict the building's nonlinear response. Building a model of the structure and running simulations of how it would respond to an anticipated seismic excitation are the first steps in performance-based design. So that a structural engineer can control the risk of damage in terms of recovery cost, each simulation offers the level of damage. The force-displacement curve in Figure 1 depicts the behavior of the global structure under lateral load and displays the performance level of the building presented. Nonlinear static analysis, often known as pushover analysis, is used to extract the curve.

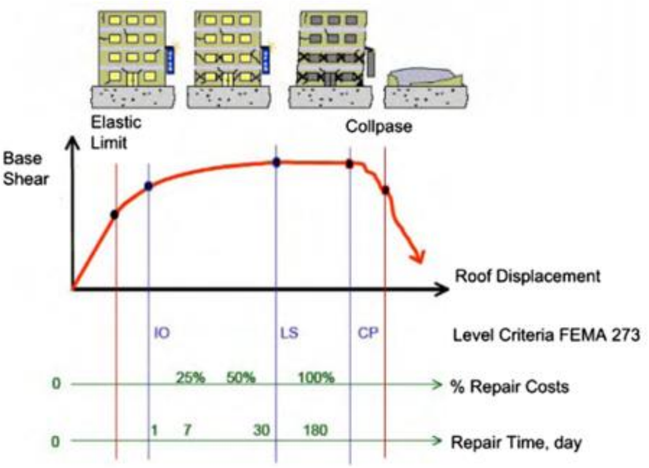

Figure 1. Performance-based design concept [4]

In performance-based design, the engineer designs a structure in response to a specified performance level for the building. Table 1 displays performance levels in accordance with ATC-40 [5].

Table 1. Performance level of buildings [5]

Level	Description
Operational	Very little damage, temporary drift, structure retains original strength and stiffness, all systems are normal
Immediate occupancy	Little damage, temporary drift, structure retains original strength and stiffness, elevator can be restarted, fire protection still works
Life safety	Fair damage, some permanent drift, some residual strength and stiffness left, damage to partition, building may be beyond economical repair
Collapse prevention	Severe damage, large displacement, little residual stiffness and strength but loading bearing column and wall function, building is close to collapse

Multiple studies have elucidated how reinforced concrete structures respond to seismic activity. Kadid and Boumrkik [8] performed a performance-based optimization analysis (pushover analysis) on three buildings with different framing systems, each having 5, 8, and 12 stories. The researchers determined that the quality of materials employed and the prevalence of weak column and strong beam construction in Algeria contributed to the failure of reinforced concrete structures during the earthquake in Boumerdes city. Vivinkumar and Karthiga [9] conducted a comparative analysis of force-based design and direct displacement-based design (DDBD). Using the following codes: IS 1893 [10], FEMA 356 [4], and the two design techniques, four, eight, and twelve story two-dimensional bare frames were designed and analyzed.

Using non-linear time history analysis for 16 different ground motions of PGA = 0.32 g, both design approaches are validated.

The authors came to the conclusion that the proportionally DDBD structure works well across all structural parameters and that the produced design behaved better and was safer than forced based design buildings.

Mouzzoun et al. [11] evaluated the seismic behavior of a five-story reinforced concrete building in line with the seismic regulations of Morocco. It was discovered that the structure is susceptible to major earthquakes, yet it functions satisfactorily under moderate levels of danger.

Chaudhari and Dhoot [12] conducted an analysis and design of a four-story reinforced concrete (RC) structure in accordance with the Indian Standard code IS 456 [13]. The assessment of the building's performance level in terms of life safety was also carried out. The analysis was conducted in compliance with ATC 40 [5] and FEMA 273 [14]. It was discovered that the building's performance level meets the expected assumption. Li et al. [15] assessed the suitability and precision of pushover analysis in comparison to time history analysis for RC ductile frames subjected to multiple loads shaking table tests.

The structure's seismic load-carrying capacity improves with Performance-Based Seismic Design (PBSD). Erdem and Karal examined three-, five-, and eight-story reinforced RC buildings [30]. RC buildings with steel bracings and RC jackets on the inside columns were reinforced. After reinforcing the buildings to Turkish and American standards, story drifts decreased. Chaudhary and Chaudhary [31] covered everything in their extensive literature review on design building codes, displacement, performance-based design, and unified PBD.

2. Pushover Analysis Methodology

The pushover analysis depends on the structure's response being usable with an equivalent SDOF system. A consistent mode shape in the time history response indicates that a single mode regulates the reaction. Although neither assumption is correct, studies [14, 15] have demonstrated that the assumptions can accurately predict the maximum seismic response when a single mode dominates the response of a structure with multiple degrees of freedom (MDOF). Nonlinear dynamic analysis [17–22] is considered a more accurate method for seismic analyses, but it is difficult to implement because it requires a time history of ground motion data and detailed structural member hysteretic behavior, which are unpredictable. This analysis is better suited for research and critical structural design.

2.1 Target Displacement

Target displacement is essential to determining building performance criteria. In recent years, the number of methods for quantifying target displacement has increased. The approaches that can be identified are as follows:

1. The capacity spectrum method (ATC-40) [4].
2. The displacement method (FEMA-356) [5].
3. The displacement modification method (FEMA-440) [6].

2.2.1 Capacity Spectrum Method

Represent the capacity curve and demand response as a capacity spectrum (S_a & S_d), an acceleration displacement response spectrum (ADRS) representation of capacity curve [3]. The following equations determine the modal participation factor (MPF1) and modal mass coefficient [4], which are needed to convert the capacity curve into the capacity spectrum.

$$MPF_1 = \frac{\sum m_i \ \phi_{i1}}{\sum m_i \ \phi_{i1}^2} \quad (1)$$

$$\alpha = \frac{[\sum m_i \ \phi_i]^2}{[\sum_{i=1}^{N} mi][\sum_{i=1}^{N} m_i \ \phi_{i1}^2]} \quad (2)$$

Where mi is the floor-specific mass, ϕ_{i1} is the amplitude of mode No.1 on floor i, N is the total floor number. The capacity curve is then solved for at each location to obtain S_a and S_d:

$$\frac{S_a}{g} = \frac{V_b}{w}\frac{1}{\alpha} \quad (3)$$

$$S_d = \frac{\Delta_{roof}}{MPF_1 \Phi_{roof1}} \quad (4)$$

Where V_b is the base shear, w is the total building weight, and Δ_{roof} is the roof displacement.

Using the following equation, can get the value of S_d at each point along the curve, which is necessary for transforming a demand spectrum from S_a and T format to ADRS format.

$$S_d = \frac{T^2 \ S_a}{4\pi^2} \quad (5)$$

Figure 2 demonstrates the capacity spectrum technique. To assess effective damping and spectral demand reduction, a bilinear capacity spectrum representation was needed. The trial performance point must be defined (a_{pi}, d_{pi}). At the estimated point, intersect the lowered response spectrum and capacity spectrum to find the performance point.

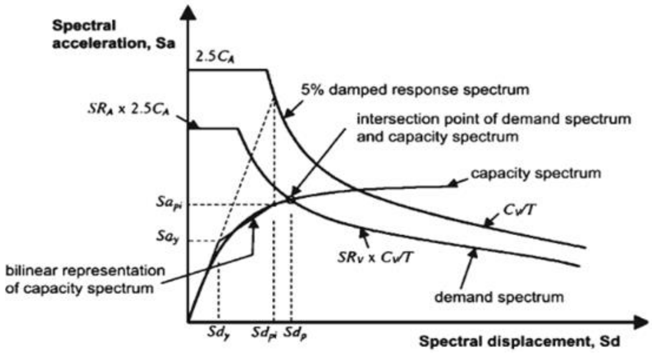

Figure 2. Performance point according to capacity spectrum method [4]

2.2.2 Displacement Coefficient Method (FEMA 273/356)

FEMA 356 presents static nonlinear procedure. This approach is accomplished by adjusting the elastic response from SDOF equivalent with coefficient factors C_0, C_1, C_2, and C_3 [4] as follows:

$$\delta_T = C_0 \ C_1 \ C_2 \ C_3 \ S_a \left(\frac{T_e}{2\pi}\right)^2 \ g \quad (6)$$

Figure 3 displays the target displacement (δ_T) calculation using the displacement coefficient approach. Beginning with an inelastic situation, an effective fundamental period is determined. The maximum spectral acceleration (Sd) is represented by the effective fundamental period, which is the linear stiffness of the comparable SDOF system. After that, you can use Eq. 6 to define the desired angular displacement. All of the structures that were tested had their performance points estimated using the ATC-40 and FEMA 356 methods, respectively, of the capacity spectrum and the coefficient. Consideration and presentation of results are made with respect to overall demands, failure modes, capacity curves, interstory drifts, and ductility requirements [23], [24].

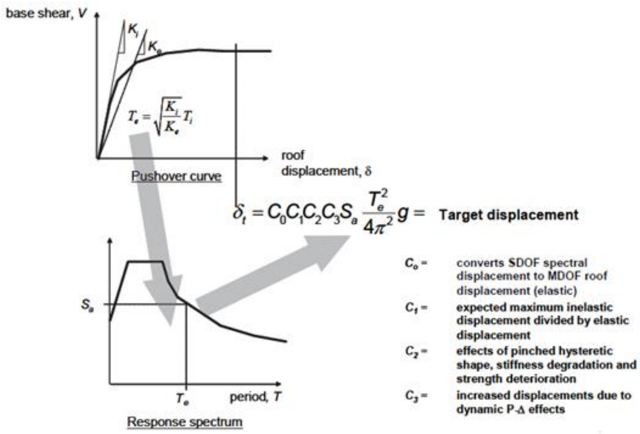

Figure 3. Performance point according to the displacement coefficient method [5]

2.2.3 Displacement Modification (FEMA 440)

This methodology incorporates an equation that has resemblance to the displacement coefficient approach in order to ascertain the target displacement (δ_T) [6]. Nevertheless, there exist some alterations that can be employed to ascertain the values of C_1 and C_2, which are outlined as follows:

$$C_1 = 1 + \frac{R-1}{aT_e^2} \quad (7)$$

$$C_2 = 1 + \frac{1}{800}\left(\frac{R-1}{T_e}\right)^2 \quad (8)$$

2.2 Nonlinear Plastic Hinge

The analysis of pushover requires the establishment of the force deformation curve for the critical section of beams and columns, as outlined in reference [6]. The curve depicted in Figure 4 is presented.

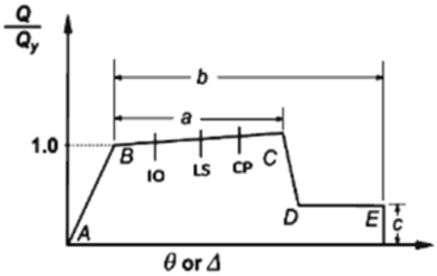

Figure 4. Force-deformation curve [6]

2.3 Performance Limits

In general, there are two types of performance restrictions: global structural limits and local element limits [2, 5, 25, 26]. If the capacity of a certain member to support gravity load is reduced, the structure must be able to shift that load to other elements. Lateral deformations need to be compared to the allowed ranges of displacement, as stated in Table 2.

Table 2. Deformation limits for each performance levels (ATC-40)

Immediate occupancy	Damage control	Life safety	Structural stability
0.01	0.01–0.02	0.02	0.33 Vi/Pi

3. Nonlinear materials

Using the CSI-ETABS V.19.1.0 software [25], pushover analysis shows the material's "hysteretic behavior," which is a non-linear static process that loses energy by deforming. Various hysteretic models can be used to depict the properties of various materials. With each hysteresis model, you can do things like:

- The behavior of materials under stress and strain.
- Hinge types with just one level of freedom, like M3 or P hinges, for frames. Collaborative hinges, like P-M3 or P-M2-M3.

3.1 Structure-plastic hinge assignment

When different structural elements are allocated concentrated plastic hinges that contribute to the resistance to lateral loads, it is believed that the structure would exhibit nonlinear behavior. In ASCE 41-17 [27], the distribution of concentrated plastic hinges and their length "lp" for shear walls are presented, as seen in Figure 5. Additionally, Fig. 6 illustrates the distribution of curvature, both real and idealized, in a section of wall that demonstrates the occurrence of elastic and plastic rotation.

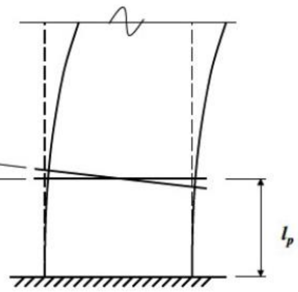

Figure 5. Rotation of plastic hinges in shear walls [5]

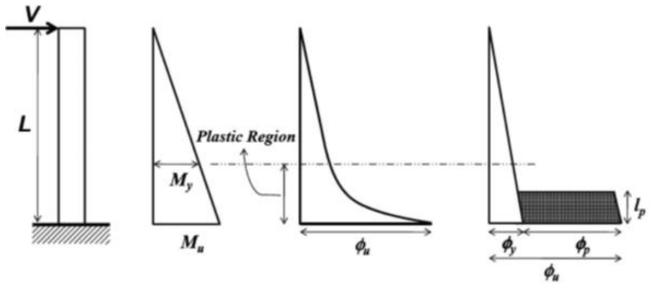

Figure 6. Actual and idealized curvature distribution in a shear wall [5]

The value of "lp" in analytical models of shear walls and wall segments should be set to half of the element's flexural depth, and it should not exceed one story for shear walls and half of the element's length for wall segments. Figure 7 displays the distribution of concentrated plastic hinges, as well as their length "lp" for the frame element.

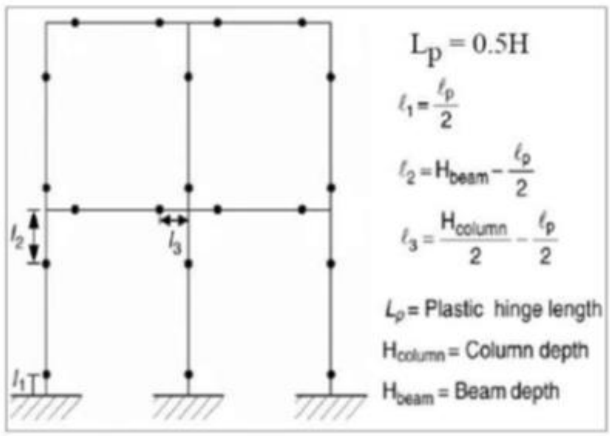

Figure 7. Distributing beam and column plastic hinges [5]

4. Verification Models

4.1 Model (1)

According to Hakim et al. [28], there are areas in the Kingdom of Saudi Arabia with low to moderate seismic activity based on their research and observations. Many structures lacked the necessary details to manage lateral loads, and their primary purpose was to sustain gravity loads. This investigation focuses on buildings' performance in resisting anticipated seismic loadings. Using ATC-40-recommended pushover analysis, one frame in three dimensions was examined. The Saudi Building Code (SBC-301) dictated the construction of one frame, whereas a different practice took into account solely the gravity load in the other. The results showed that the building's design, solely focusing on the gravity load, was considered insufficient. On the other hand, the SBC-301-designed structure meets the ATC-40-required Immediate Occupancy (IO) acceptance standards.

Figure 8 displays the reinforced concrete frames designed by the Etabs program. We compared the load-displacement curves of the presented frame with those from Etabs and Sap. As shown in Figure 9, the analytical load-displacement curves are in agreement with one another. People frequently prefer quadratic meshing over linear meshing because it produces more precise analytical results. The quadratic curve can also describe the analytical answers derived using this approach. The quadratic meshing technique reduces the accuracy. The comparison of the analytical values of ultimate flexural strength between Etabs and Sap is shown in Table 3.

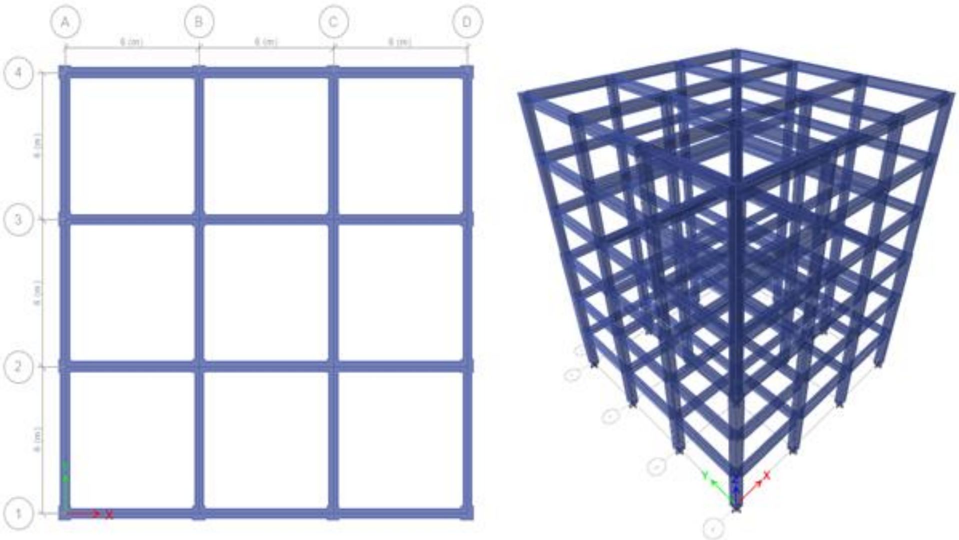

Figure 8. Structure layout and 3D model (Etabs)

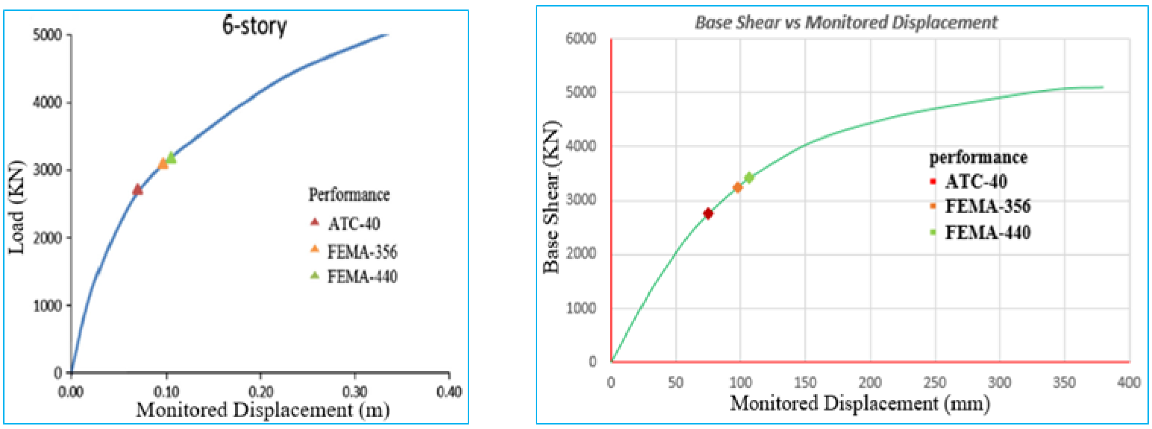

Figure 9. Results of modeling for Performance points

Table 3. Numerical results comparison for case study No. (1)

Code	Item	Hakim et al. [28]	This work	Difference %
FEMA 356	Base shear (kN)	3167.20	3250	2.60 %
	Displacement (mm)	101.21	97.79	3.38 %
FEMA 440	Base shear (kN)	3198.31	3420.50	6.95 %
	Displacement (mm)	110.32	106.41	3.54 %
ATC 40	Base shear (kN)	2753.7	2800.3	1.70 %
	Displacement (mm)	79.40	77.90	1.89 %

4.2 Model (2)

Using reversed cyclic loading, Korkmaz et al. [29] examined a one-bay, two-story bare RC specimen that lacked an infill wall as shown in Figure (10). This test was intended to be an experimental investigation of the Turkish EQ Code and its proposed strengthening approach. Seismic action at ground level was replicated by subjecting the specimens to a lateral load. A forward cycle and a retrograde cycle were both given names. There was also an axial load applied to the column tops. The test specimens' dimensions and features are displayed.

Figure (11) illustrates the experimental investigation using the ETABS analysis model, which illustrates the formation and crushing of plastic hinges in concrete.

In Figures (12), we can see a contrast between the mathematical and experimental load-displacement curves for all of the reinforced concrete frames. The graphic clearly demonstrates that the experimental and analytical load-displacement curves are in agreement. Due to the fact that quadratic meshing improves the accuracy of analytical results, it is often preferred over linear meshing. Consequently, the analytical results obtained with quadratic meshing are also referred to as the quadratic curve. Ultimate flexural strength values were compared between experimental and analytical methods, as shown in Table (4).

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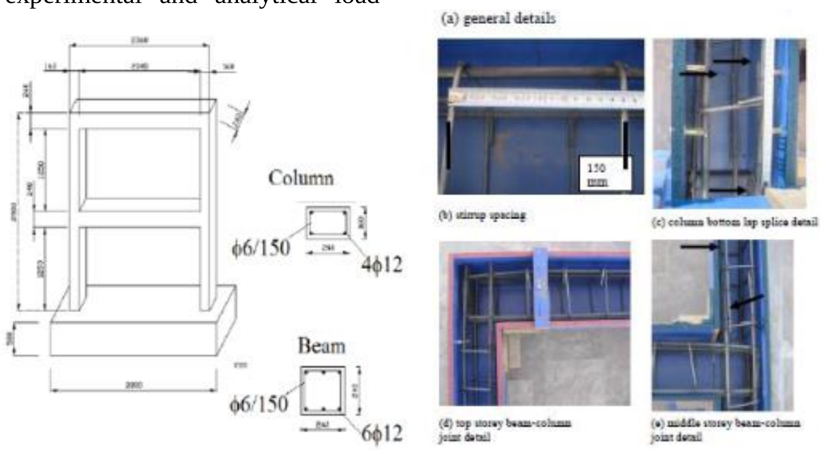

Figure 10. Details and dimensions of specimens [29]

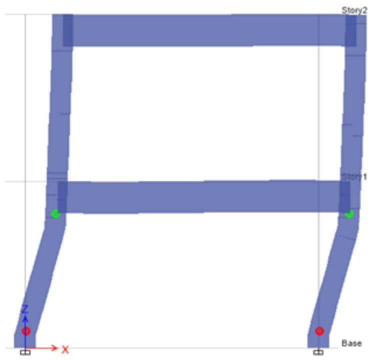

Figure 11. Plastic hinges in model

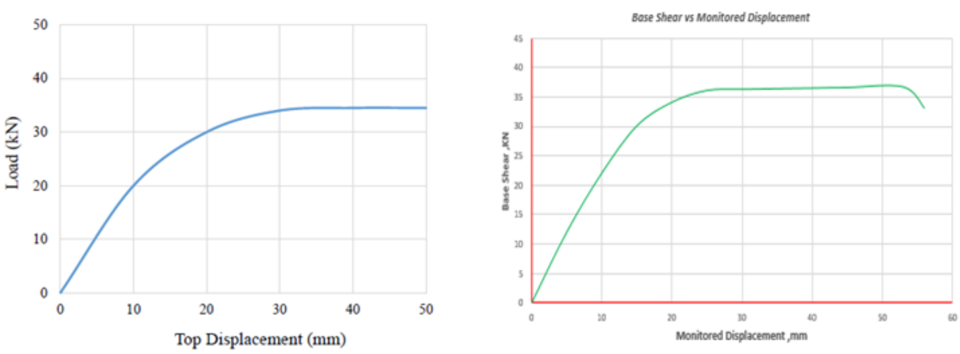

Figure 12. The Results of the Modeling Process for RC Frame Samples

Table 4. Numerical results compared to experimental results for case study No. (2)

Item	Korkmaz, et al. [29]	This work	Difference %
Base shear (kN)	34.51	34.77	0.75 %
Displacement (mm)	40	34.75	13.13 %

5. Numerical Study

5.1 Description of Buildings

This study investigates the seismic behavior of a multi-story reinforced concrete frame buildings consisting of 15, 20 and 25 floors with 2 basements for commercial use. The building shown in figure 13.

The typical floor height is 3.6 m, except the basement floor height, which is considered to be of 3.3 m, which represents a typical building constructed in the new administrative capital, Egypt.

5.2 Material properties

High-grade steel with a yield strength of f_y = 360 N/mm2 is utilized for analysis and design, along with concrete with a characteristic strength Fcu of 25 N/mm2 after 28 days for beams, and the characteristic strength of concrete for columns and cores is 30 N/mm2. Using the formula $E_c = 4400\sqrt{fcu}$ (ECP-201, 2020), we may calculate the modulus of elasticity given the specific weight of reinforced concrete, γc = 25 kN/m3. Consider a value of 210 KN/mm2 for steel's elastic modulus. We assume that the Poisson's ratios for concrete and steel are 0.2 and 0.3, respectively.

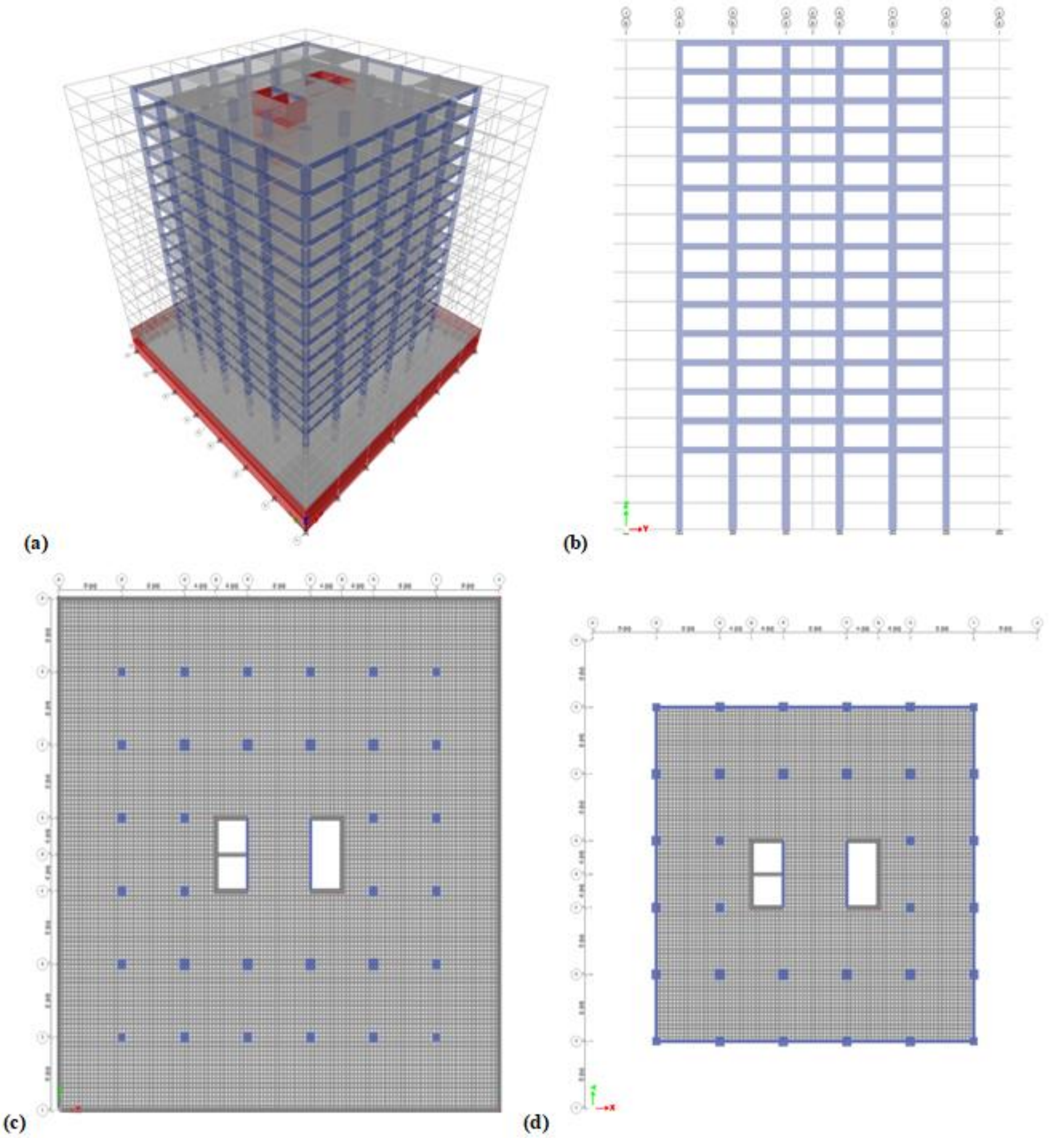

Figure 13. Schematic representation of **(a)** building 3D view **(b)** building elevation **(c)** floors plan of the 2 basement **(d)** and typical floors plan of the 15-storey framed building.

5.3 Section properties and reinforcement details

Cross sections for the interior, exterior, and edge columns are assumed to be square. It is assumed that all columns to be fixed at the foundation level. The selected reinforcement ratios for the beams fall within the allowable range, with 1.25 % and 0.3 % being the upper and lower limits, respectively (ECP-201, 2020).

Steel reinforcement ratios have been chosen to satisfy the Egyptian code requirements in which the range allowed for maximum and minimum percentage of steel reinforcement are 4.0% and 0.8% for the proportion of steel reinforcement. The floor slabs in an RC building are 0.26 m thick, making them stiff floor diaphragms.

5.4 Gravity loads

The loads exerted on the RC building can be classified into two main categories: gravity loads and lateral loads. Gravity loads encompass both dead loads and live loads, while lateral loads include seismic loads. The designated values for the dead loads are 2 kN/m² for the weight of the flooring cover and 2 kN/m² for the weight of the partitioning parts. The structural software package automatically calculates the self-weight of the structural components as part of the dead loads. According to the Egyptian code, the designated live load value for residential reinforced concrete (RC) buildings is 3 kN/m², with the imposed load set at 1.2 kN/h/m for all levels. Additionally, the designated value for the dead load, specifically the weight of the flooring cover, is 3.5 kN/m². The live load value for the roof floor of a residential reinforced concrete (RC) building is determined to be 2 kN/m².

5.5 Lateral static loads equivalent to seismic loads

In the seismic design of buildings, the loads taken into consideration consist of the complete dead loads in addition to 50% of the live loads, as specified by the ECP-201 (2020). The seismic parameters required for calculating the base shear force of the building are provided in Table 5, which is based on the seismic characteristics specific to Cairo city. The pushover analysis method was utilized to conduct the structural assessment of the structure. There were two types of loads considered: the GRAVITY load and the other type of load, which is the application of fixed vertical forces like dead and live loads. The lateral loads applied in the x-direction and y-direction are denoted as PUSH X and PUSH Y, respectively.

5.6 Numerical Analysis Procedure

The ETABS software program has been utilized for the purpose of conducting the analysis. The nonlinear analysis was conducted using a three-dimensional model for each building [25]. The beams and columns are represented as nonlinear frame elements, incorporating lump plasticity at both the beginning and end of each element. The software ETABS version 19.1.1 has predefined hinge types for structural elements, specifically PMM hinges for columns and M3 hinges for beams, which are in accordance with the specifications outlined in FEMA-356.

The displacement-controlled pushover analysis of the models is conducted after assigning all properties. The application of incremental loads follows the application of gravitational loads. The models are thereafter subjected to triangle and uniform load patterns, respectively, until the desired displacements are achieved. In order to achieve this objective, it is necessary to establish a series of steps that specify the displacement and target displacement at the roof.

In this study, the seismic responses of structures are evaluated using the design-level earthquake in Cairo as specified in the ECP-201 code.

Table 5. The Seismic Design Data

S.N.	Parameters for design	Values
1	Response Curve	1
2	Importance factor γ_c	1
3	Building location (zone)	Zone (3)
4	Response reduction factor (R)	5
5	Type of soil	Soil C
6	Damping ratio	5%
7	Type of frame	Moment resisting frame
8	Number of floors	15-20-25
9	Number of basements	2
10	Basement floor height	3.30
11	Typical floor height	3.60

6. Result and Discussion

The depicted curves illustrate the overall characteristics of the frame in terms of its stiffness and ductility. The rate of decline in the slope of pushover curves is shown to progressively decrease as the lateral displacement of the building increases. The progressive development of plastic hinges in the beam and column components of the structure is responsible for this phenomenon.

As previously stated in Section 2.3, pushover analysis takes into account two performance restrictions. The initial item pertains to the limit of structural stability. The limit state is established both at the overall structure level, specifically in relation to lateral load resistance, and at the individual story level, specifically in relation to the maximum inter-story drift ratio.

The second limitation is determined by the plastic hinge rotation capacities acquired for each member, which are contingent upon their respective cross-sectional geometries.

The three methodologies, namely ATC-40, FEMA-356, and FEMA-440, employed for assessing performance points exhibit variations in their outcomes. The Capacity Spectrum Method, as outlined in the ATC-40 guidelines, identifies the performance point with the lowest level of structural capacity. Nevertheless, all three approaches consistently demonstrate that the margin of safety against collapse is substantial, and there exists ample strength and displacement reserves.

After each iteration of deformation, pushover analysis color-codes the plastic rotation hinges in the elements to show which ones have reached the IO, LS, and CP FEMA limit states. The creation of plastic hinges has been observed at a range of displacement values and performance trajectories, Fig. 1 4Pushover curve in X direction at 0.15g and Fig. 1 5Pushover curve in Y direction at 0.15g.

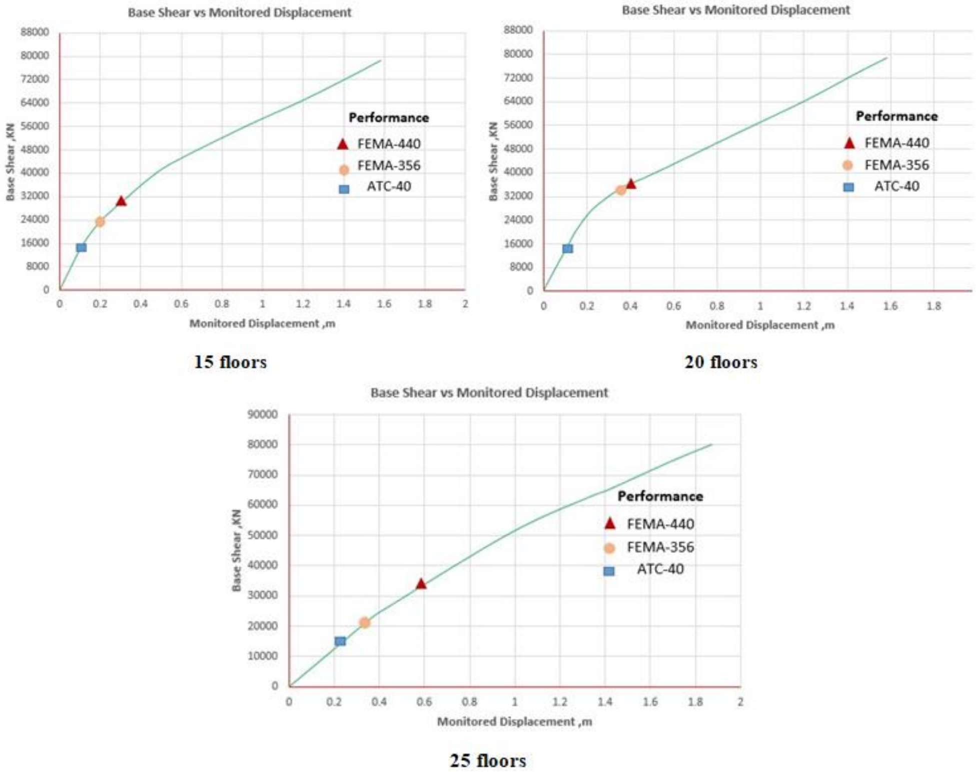

Figure 14. Pushover curve in X direction at 0.15g

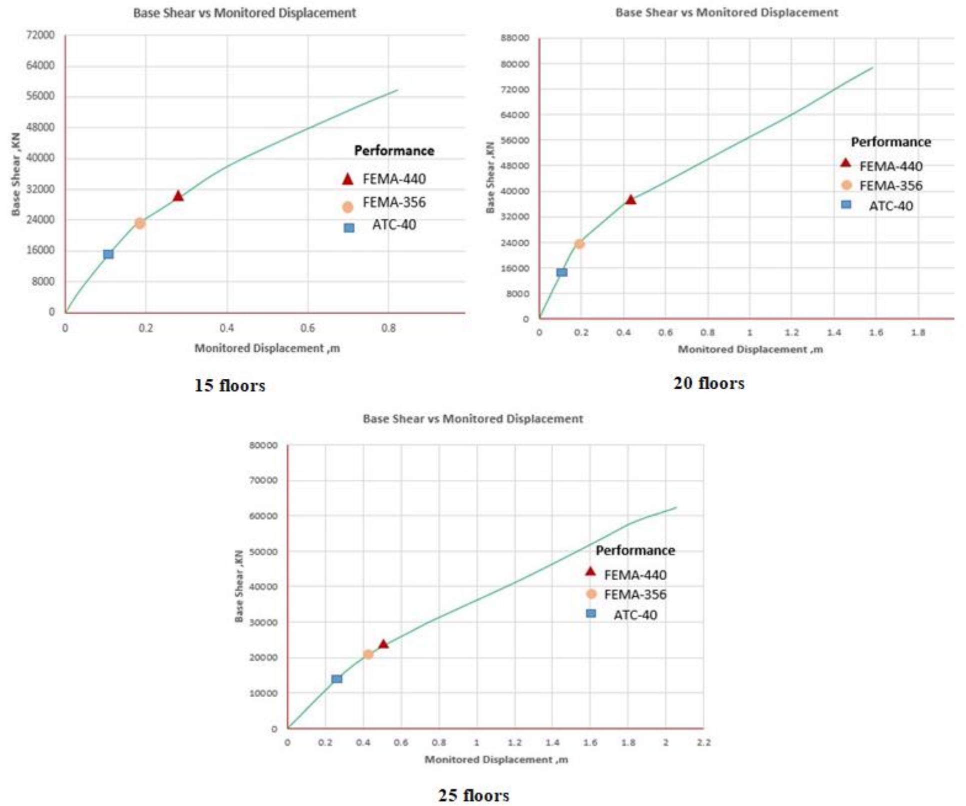

Figure 15. Pushover curve in Y direction at 0.15g

7. Conclusion

A research project investigates the efficacy of pushover analysis in assessing structural performance and ensuring safety during seismic events. This work utilizes numerical modeling to examine the structural response of reinforced concrete (RC) buildings to seismic hazards, employing nonlinear static analysis techniques. For this research three buildings were studied, all of which adhere to the standards established by ECP-201. Pushover analysis has been conducted utilizing the capacity spectrum method (ATC-40), the displacement coefficient method (FEMA-356), and the displacement modification methods (FEMA-440).

The primary findings of the study provided above are as follows:

1. The use of pushover analysis offers a straightforward approach to observe the nonlinear response of a structure.
2. Distinct outcomes are obtained when employing the three methodologies (ATC-40, FEMA-356, and FEMA-440) for the determination of target displacement (δt). The Capacity Spectrum Method, as outlined in the ATC-40 guidelines, provides the minimum goal displacement, denoted as δt.
   Nevertheless, all three approaches consistently demonstrate that the margin of safety against collapse is significant, and there exist ample reserves of strength and displacement.
3. The maximum story drifts range from 0.01H to 0.02H, falling within the damage control (DC) category.
4. Since the worst-yielding elements have IO to LS levels, the structural damage to all buildings is still manageable.
5. In general, RC frame structures built in 2020 in accordance with ECP-201 are compliant with all three methods (ATC-40, FEMA-356, and FEMA-440).

The conclusions of the current study are constrained due to the consideration of only a single symmetry scheme inside a certain seismic zone. Furthermore, the pushover analysis is an approximation method that may not effectively capture dynamic phenomena with a high level of precision. The analysis has taken into account numerous aspects that are typically considered deterministic. However, it is important to acknowledge that these parameters exhibit considerable statistical variations. Therefore, a reliability-based framework is necessary to properly address these variations in the study. The buildings can withstand seismic base shear ranging from 65% to 85% of their ultimate capacity from pushover analysis in x- and y-directions.

REFERENCES

[1] The Egyptian Code for Calculation of Loads and Forces in Structural and Building Work 2020. ECP-201, Housing and Building National Research Centre. Ministry of Housing, Utilities and Urban Planning, Cairo, Egypt.

[2] Mondal, A.; Ghosh, S.; Reddy, G.: Performance-based evaluation of the response reduction factor for ductile RC frame. J. Struct. Eng. 56, 1808–1819 (2013).

[3] Whittaker, A.; Hart, G.; Rojahn, C.: Seismic response modification factors. J. Struct. Eng. 125(4), 438–444 (1999).

[4] FEMA 356, "Prestandard and Commentary for the Seismic Rehabilitation of Buildings," Federal Emergency Management Agency, Washington, D.C., 2000.

[5] ATC-40.: Seismic Evaluation and Retrofit of Reinforced Concrete Buildings: Applied Technology Council (1996).

[6] FEMA 440, "Improvement of Nonlinear Static Seismic Analysis Procedures," Federal Emergency Management Agency, Washington, D.C., 2005.

[7] Eurocode 8, "Design of Structures for Earthquake Resistance," European Committee for Standardization, Brussels, 2004.

[8] A. Kadid and A. Boumrkik, "Pushover Analysis of Reinforced Concrete Frame Structures," Asian Journal of civil Engineering (Building and Housing), vol. 9, no. 1, pp. 75-83, 2008.

[9] R. V. Vivinkumar and S. Karthiga, "A Comparative Study on Force Based Design and Direct Displacement Based Design of Reinforced Concrete Frames," International Journal of Research in Engineering and Technology (IJRET), vol. 4, no. 4, pp. 46-53, 2015.

[10] IS 1893 (Part 1), "Indian Standard Code of Practice for Criteria for Earthquake Resistant Design of Structures," Bureau of Indian Standards, New Delhi, 2002.

[11] M. Mouzzoun, O. Moustachi, A. Taleb and S. Jalal, "Seismic Performance Assessment of Reinforced Concrete Buildings using Pushover Analysis," Journal of Mechanical and Civil Engineering (IOSR-JMCE), vol. 5, no. 1, pp. 44-49, 2013.

[12] D. J. Chaudhari and G. O. Dhoot, "Performance Based Seismic Design of Reinforced Concrete Building," Open Journal of Civil Engineering, vol. 6, no. 2, pp. 188-194, 2016.

[13] IS 456, "Indian Standard Code of Practice for Plain and Reinforced Concrete," Bureau of Indian Standards, New Delhi, 2000.

[14] FEMA 273, "NEHRP Guidelines for the Seismic Rehabilitation of Buildings," Federal Emergency Management Agency, California, 1997.

[15] S. Li, Z. Zuo, C. Zhai and L. Xie, "Comparison of Static Pushover and Dynamic Analyses using RC Building Shaking Table Experiment," Engineering Structures, vol. 136, no. 1, pp. 430-440, 2017.

[16] S. K. Kunnath, "Modeling of Reinforced Concrete Structures for Nonlinear Seismic Simulation," Journal of Structural Integrity and Maintenance, vol. 3, no. 3, pp. 137-149, 2018.

[17] Giannopoulos, P.I.: Seismic assessment of RC building according to FEMA 356 and Eurocode 8. In: 16th Conference on Concrete, TEE, ETEK, 21-23/10/2009.

[18] Fajfar, P.: Structural analysis in earthquake engineering a break-through of simplified non-linear method. In: 12th European Conference on Earthquake Engineering, Paper Ref: 843 (2002).

[19] Martino, R.; Spacone, E.; Kingsley, G.: Nonlinear pushover analysis of RC structures. Adv. Technol. Struct. Eng., 1–8 (2000). Doi: 10. 1061/40492(2000)38.

[20] Vijayakumar, A.; Babu, D.L.V.: Pushover analysis of existing reinforced concrete framed structures. Eur. J. Sci. Res. 71(2), 195– 202 (2012)

[21] Poluraju, P.; Rao, N.: Pushover analysis of reinforced concrete frame structure using SAP 2000. In: International Journal of Earth Science and Engineering ISSN 0974-5904, Volume 04, No 06 SPL, pp. 684-690 (2011).

[22] Elnashai, A.S.: Advanced inelastic static (pushover) analysis for earthquake applications. Struct. Eng. Mech. 12(1), 51–69 (2001).

[23] Favvata, M.J.; Naoum, M.C.; Karayannis, C.G.: Seismic evaluation of infilled RC structures with nonlinear static analysis procedures. In: Proceedings of the 15th World on "Earthquake Engineering" Lisbon, Portugal, 24–28 September (2012).

[24] Favvata, M.J.; Naoum, M.C.; Karayannis, C.G.: Limit states of RC structures with first floor irregularities. J. Struct. Eng. Mech. 47(6), 791–818 (2013)

[25] ETABS User's Manual. 2013. Integrated Building Design Software. Computer and Structure Inc. Berkeley, USA.

[26] EL-MAHDY, Osama Omar; HAMDY, Gehan Abdelrahman; YASSIN, AHMED SAAD. Performance Based Seismic Design of Two RC High-Rise Buildings. Engineering Research Journal (Shoubra), 2023, 52.2: 101-113.

[27] ASCE/SEI 41-17, "Seismic Evaluation and Retrofit of Existing Buildings," American Society of Civil Engineers, Reston, Virginia, 2017.

[28] R. A. Hakim, M. S. Alama and S. A. Ashour, "Seismic Assessment of an RC Building Using Pushover Analysis," Engineering, Technology & Applied Science Research, vol. 4, no. 3, pp. 631-635, 2014.

[29] Korkmaz, S. Z., Kamanli, M., Korkmaz, H. H., Donduren, M. S., & Cogurcu, M. T., "Experimental study on the behaviour of nonductile infilled RC frames strengthened with external mesh reinforcement and plaster composite," Natural Hazards and Earth System Sciences, vol. 10, no. 11, pp. 2305-2316, 2010.

[30] R. T. Erdem and K. Karal, "Performance Evaluation and Strengthening of Reinforced Concrete Buildings," Journal of Construction, vol. 21, no. 1, pp. 53-68, 2022.

[31] S. Chaudhary and S. Chaudhary, "Performance-Based Seismic Design: A Review," in International Conference on Advances in Structural Mechanics and Applications, 2022.