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Modelling Analysis of Earthquake Impact on R.C Buildings in Baghdad using SAP200

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ABSTRACT

Most typical commercial reinforced concrete buildings in Iraq were designed using outdated building codes that did not consider horizontal seismic loads; they primarily focused on vertical loads. As a result, there is uncertainty regarding whether these conventional buildings can withstand recent earthquakes in Iraq. In this study, we created a three-dimensional finite element model using SAP2000 to represent scaled versions of typical multistory reinforced concrete commercial structures found in Iraqi cities. The primary objective was to investigate how these structures respond to seismic events, particularly the Ali Al-Gharbee earthquake that struck Maysan Province in southern Iraq in 2012, with a magnitude of Mw=4.9 and PGA=104.151 cm/sec^2 as the input ground motion. Our findings indicate that typical multistory reinforced concrete commercial buildings in Iraq can safely withstand earthquakes. However, when the magnitude increases to approximately Mw=5.2 (PGA=156 cm/sec^2), some members may experience cracking and exceed allowable drift limits. If the magnitude reaches about Mw=6 (PGA=208 cm/sec^2), these buildings may experience complete failure.

Keywords: Earthquakes; R.C Multistory; Finite Element; SAP2000.

1.0 INTRODUCTION

Earthquakes are unpredictable and highly destructive natural events. Despite significant efforts to enhance our understanding of these natural disasters and protect the built environment from their impact, earthquakes have continued to cause substantial human and economic losses throughout history. Seismologists often emphasize the importance of buildings in earthquake-related fatalities, as buildings are frequently at the forefront of earthquake mitigation efforts.The crucial stage preceding any structural design activity involves seismic loading calculations, a vital component of structural design techniques. In many cases, this also entails the determination of appropriate structural loads. Over the past six decades, extensive research has been conducted to comprehend the origins of earthquakes and assess the stress on buildings resulting from subterranean events. In Iraq, a significant portion of structures was inadequately prepared to withstand earthquakes. This is primarily because structures in such regions have traditionally been designed exclusively for gravity loads, often neglecting lateral loads and the seismic provisions outlined in building codes [1]. Despite a notable increase in seismic activity in the region in recent years, it has become imperative to analyse and incorporate seismic considerations into the design of future buildings, which is the focus of this article.

In a study conducted by Ahmed et al. [2], they examined the seismic response of a 15-story reinforced concrete frame coupled with shear walls. This structure was representative of a typical medium-rise office building in the western United States and had been designed in compliance with the provisions of the 1973 version of the Uniform Building Code. Their findings revealed that designs of reinforced concrete frames coupled with shear walls based on the Uniform Building Code provisions had significant deficiencies. Moreover, the analytical techniques commonly used to assess such designs, such as linear spectral analysis and inelastic time history analysis, also exhibited limitations.

Mohammed A. A. [3] conducted an analytical study to assess the effectiveness of seismic design code formulas, specifically the Iraqi Seismic Code [4], the Uniform Building Code [5], and the Euro Code [6]. The objective was to evaluate these codes' formulas for estimating base shear forces, as well as the distribution of these forces and displacements along the height of a 15-story reinforced concrete building used as a study model. The results obtained from these formulas were then compared with the outcomes of a dynamic response analysis carried out through finite element analysis on the same building under identical conditions, utilizing STAAD\PRO2000 software. The analytical findings demonstrated a strong agreement between the results obtained from the code formulas and those from the finite element analysis. Notably, the results generated using the Iraqi Seismic Code were found to be in close alignment with the results obtained from the other seismic codes.

Faiz and Kumar [7] investigated the seismic performance of multi-story buildings in seismic zones IV and V using two analytical methods, equivalent static analysis and response spectrum analysis. The analysis focused on

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key parameters such as max story displacement, max drift ratio, base shear, max axial force in columns, max bending moment in columns, and fundamental time period. The findings revealed that equivalent static analysis generally results in higher values for these parameters compared to response spectrum analysis. Notably, max story displacement is significantly influenced by the choice of analysis method, with equivalent static analysis showing a higher impact. However, the fundamental time period remained consistent between the two methods, regardless of building height. These findings have implications for seismic design and retrofitting strategies, highlighting the importance of selecting the appropriate analysis method to ensure the structural integrity and earthquake resilience of buildings in high seismic risk zones.

The analysis and results of the seismic vulnerability assessment study on existing reinforced concrete (RC) buildings in Duhok city provided critical insights into the structural performance of these structures under the potential impact of future earthquake events. Through rigorous modeling and analysis using ETABS software, the study conducted nonlinear static (pushover) analyses, yielding load-deformation (pushover) curves that shed light on the buildings' behaviour under lateral forces [8]. The application of the FEMA 440 method, specifically the improved capacity spectrum method tailored to the local seismic hazard, allows for a comprehensive evaluation of seismic performance. The study's findings revealed a common vulnerability pattern in these buildings, characterized by "weak column-strong beam" behaviour, with columns particularly at ground stories, being susceptible to seismic damage. The observed structural damages, primarily in the form of column cracking at lower stories, underline the need for retrofitting measures to enhance the buildings' seismic resilience. Notably, the study recommended prioritizing the strengthening of ground-story columns across all analysed buildings. This recommendation underscores the importance of proactive structural interventions to mitigate seismic risks and ensure the safety and durability of existing RC buildings in Duhok city [8].

Kumar and Rao (2017) [9] conducted a comparison between the equivalent static and response spectrum techniques to assess the structural performance of buildings under seismic loads, with the aim of mitigating earthquake-induced damage and ensuring the safety of occupants. The analysis examined both regular and irregular structures across various seismic zones, including ZONE-II, Zone-III, ZONE-IV, and ZONE-V, in accordance with IS-1893-2002 seismic load calculations. Key parameters such as base shear and lateral displacements at different levels were considered. By utilizing STAAD Pro software, the lateral forces were computed and compared between two seismic zones using both response spectrum and seismic coefficient techniques. The research is valuable for designing earthquake-resistant structures and optimizing lateral stiffness systems, ultimately contributing to the creation of more cost-effective and efficient seismic-resistant buildings.

Gottala *et al.* [10] focused on the analysis and design of reinforced concrete frame buildings in urban India, with a particular emphasis on the impact of earthquake forces. The research examined a multi-story (G+9) framed structure using both static (Seismic Coefficient Method) and dynamic (Response Spectrum Method) analysis approaches, as per IS-1893-2002-Part-1 guidelines. While static analysis has become routine due to modern computational tools, dynamic analysis, essential for earthquake resilience, presents additional complexities. The study compared and contrasted the outcomes of these two methods, encompassing parameters such as bending moments, nodal displacements, and mode shapes, offering valuable insights into the behaviour of RC frame buildings under dynamic loading conditions. The research contributed to the enhancement of earthquake-resistant design practices for urban structures in India.

2.0 METHODOLOGY

2.1 Case of modeling

Typical commercial buildings in Iraq are constructed with a reinforced concrete structure, comprising a ground floor and three standard floors above it. For the purpose of this study, a four-story office building was selected to illustrate the seismic behaviour criteria. This building is situated in Baghdad Alkarada and has a rectangular cuboid shape with dimensions of (20.0 x 25.0 x 13.5) meters, aligned with the (X, Y, Z) axes. It features five spans in the X-axis direction and six spans in the Y-axis direction, as depicted in Figure 1. The total structural height of the building is 13.5 meters, with each typical story having a height of 3.0 meters, except for the first story, which measures 4.5 meters in height, as illustrated in Figure 2. The building is supported by a total of 42 rectangular section reinforced concrete columns, each measuring (0.3 x 0.5) meters in dimensions on each floor (excluding the ground floor, which includes 40 rectangular columns and 2 additional circular columns with a diameter of 0.6 meters or a 0.3-meter radius). All the beams in the building have cross-sectional dimensions of 0.3 x 0.3 meters (0.3 x 0.3 m), and the slab thickness of 0.2 meters, as shown in Figure 3.

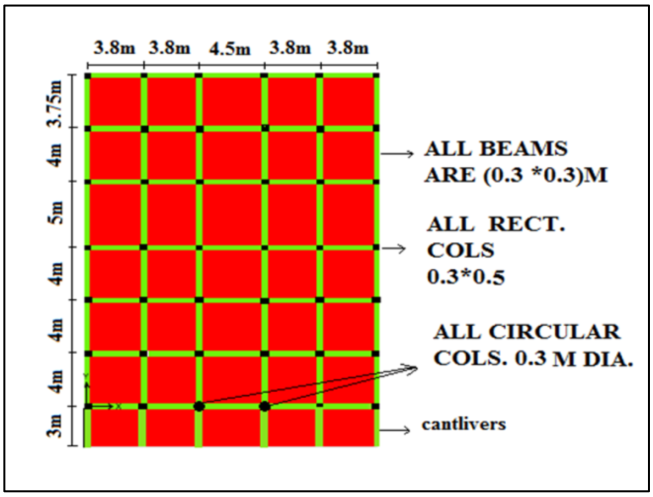


Figure 1. Typical Plan of Case Model Structure

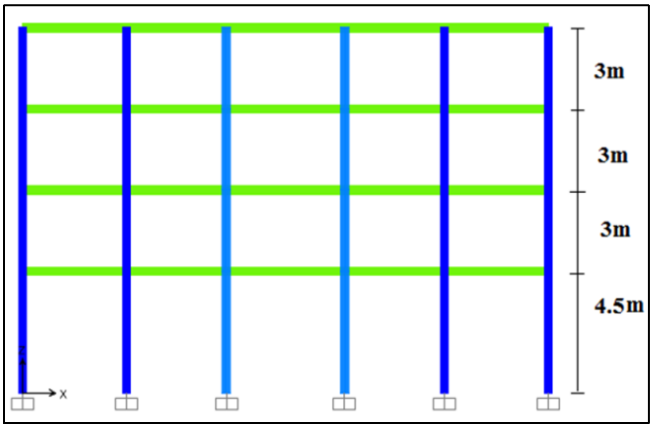


Figure 2. XZ Side View of Case Model Structure

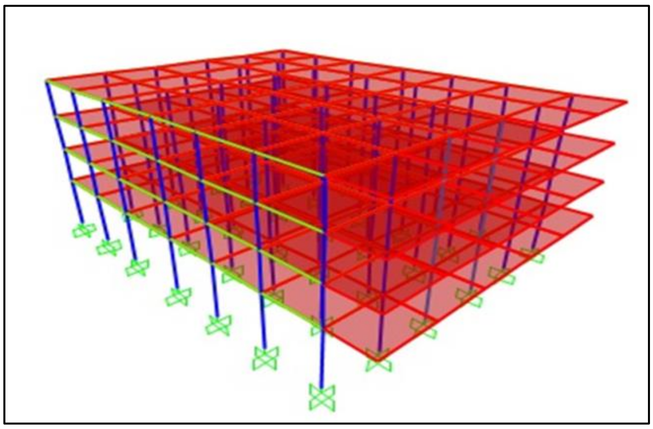


Figure 3. Typical Plan of Case Model Structure

The chosen building was subjected to an actual earthquake that occurred at the south of Iraq in Ali Al-Gharbee (Maysan province) on April 20, 2013. This earthquake had a magnitude of Mw=4.9 and a peak ground acceleration of 104.151 cm/sec^2. The input ground motion for this study is depicted in Figure 4.

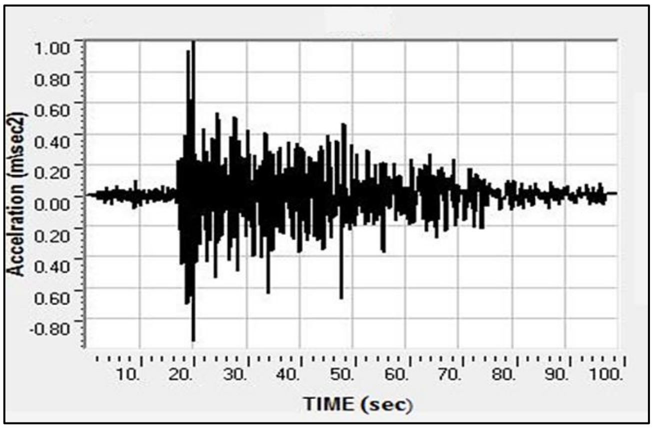


Figure 4. Ali Al-Gharbee Acceleration-Time Plot

3.0 ANALYSIS AND RESULTS

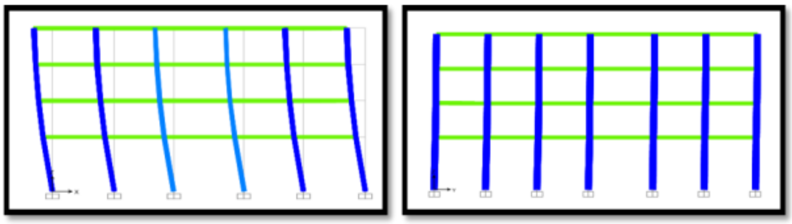
At the commencement of each dynamic analysis, it is essential to calculate mode shapes. Four mode shapes have been computed for the building structure, and their combined modal mass participation exceeded 90% of the actual mass in each of the orthogonal horizontal directions, in accordance with the ASCE 7-10 code [11]. The values of the natural period, natural frequencies, and modal mass participation in both the x and y directions are summarized in Tables 1 and 2. The deformed mode shapes in two orthogonal directions are depicted in Figure 5.

Table 1. Modal Mass Participation Ratio of Mode Shapes

Mode no.	Modal mass participation ratio in x direction (%)	Accumulative Modal mass participation ratio in x direction (%)	Modal mass participation ratio in y direction (%)	Accumulative Modal mass participation ratio in y direction (%)
1	85.816	85.816	0	0
2	9.191	95	0	0
3	0	95	91.307	91.307
4	3.835	98.13	0	91.307

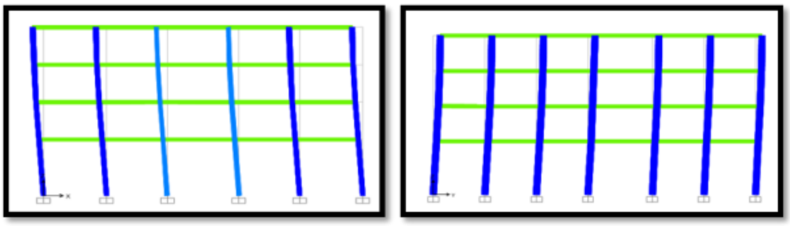
Table 2. Period and Frequencies of Mode Shapes

Mode no.	Period T (sec)	Frequencies f (cyc\sec)
1	1.114709	0.89709
2	0.917773	1.0896
3	0.842504	1.1869
4	0.333536	2.9982



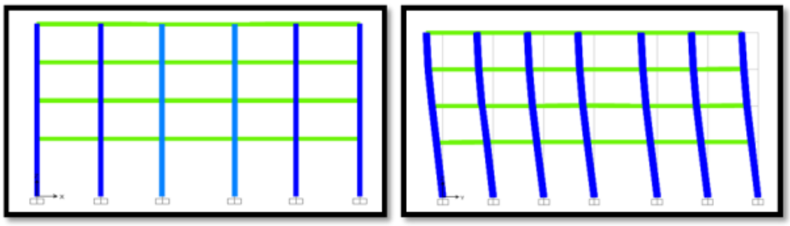
XZ YZ

(a) mode 1



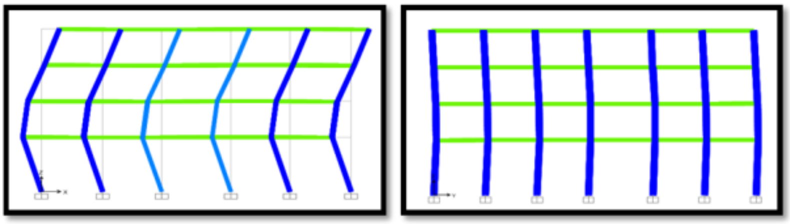
XZ YZ

(b) mode 2



XZ YZ

(c) mode 3



XZ YZ

(d) mode 4

Figure 5. Modes Deformed Shape of building with respect to X, Y, and Z plane

Subsequently, force vibration analysis was employed to ascertain the building structure's response, encompassing displacement, forces, stresses, and more, when subjected to seismic (earthquake) excitation. Three distinct methods of seismic response analysis were employed to derive the building's response:

1. Time history analysis:

The time history analysis conducted in this study was based on modal analysis, specifically mode superposition analysis. This approach is utilized to assess the dynamic response of the structure, employing a constant modal damping coefficient of 0.05, as per [11]. The Ali Al-Gharbee earthquake ground motion was applied to the structural models in two perpendicular directions at the building's foundation level. The first direction is the x-direction, which is parallel to the plane of the structure, while the other is the y-direction, perpendicular to the structure's plane. Given that the induced shearing forces, bending moments, and drifts in the typical multistory building resulting from the actual earthquake intensity were within permissible design limits, the ground motion from the Ali Al-Gharbee earthquake was incrementally increased until we reached a failure point. This allows us to identify the earthquake threshold at which our typical building may fail.

2. Response spectrum analysis:

Response Spectrum Analysis is a valuable method used to assess the dynamic effects of ground motions on structures. In this approach, the base shear was calculated by considering factors such as the time period and mass participation of the structure. As an engineer, it is essential to evaluate the base shear for both static seismic loads and dynamic seismic loads. The critical force obtained from this analysis was then utilised in the design process to ensure the structural integrity and safety of the building.

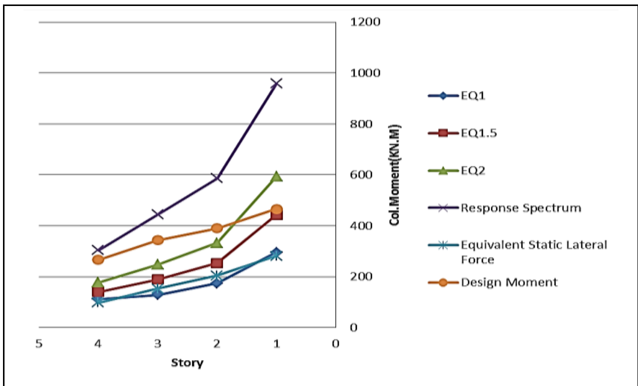
3. Static equivalent method:

Equivalent static method is one of the widely used methods of analysis used to estimate the amount of force on the structures. This analysis method can be used on regular and irregular structures and low-rise buildings. In this study, Response Spectrum Analysis and equivalent static lateral force solutions were determined in accordance with [4] and [12], utilizing the SAP2000 software program. The method factors for each approach are detailed in Table 3.

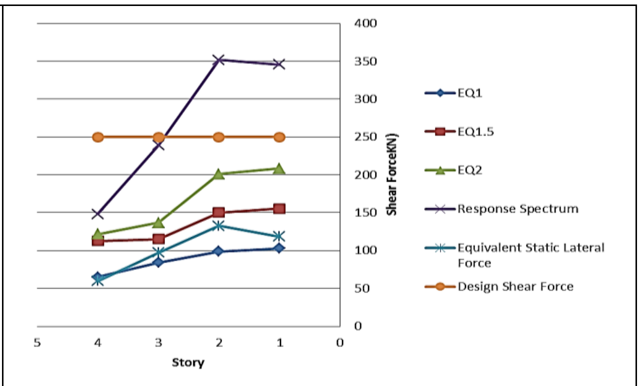
Table 3. Response Spectrum and Equivalent Static Method Factors

Factor	Spectral response acceleration parameter at short periods of 0.2s Ss	Spectral response acceleration parameter at period of 1s S_1	Importance factor I	Seismic design category SDC	Site Class
Value	1.24	0.56	1	D	D

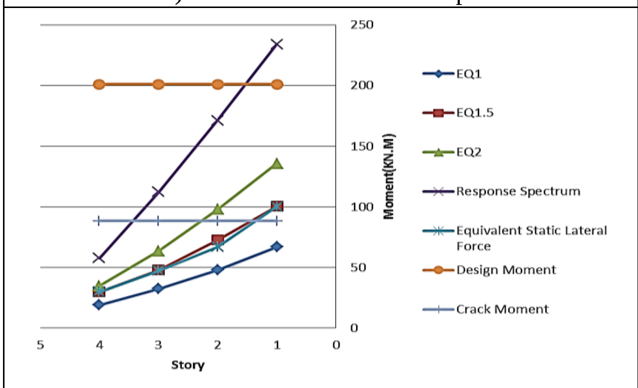
Figure 6 (A to H) presents the results of the time history analysis method using different ground motion intensities. EQ1 represents the original Ali Al-Gharbee earthquake ground motion. EQ2 corresponds to 150% of the Ali Al-Gharbee earthquake ground motion intensity, and EQ3 represents 200% of the Ali Al-Gharbee earthquake ground motion intensity. These figures also depict the results of the Response Spectrum and Equivalent Static Methods.



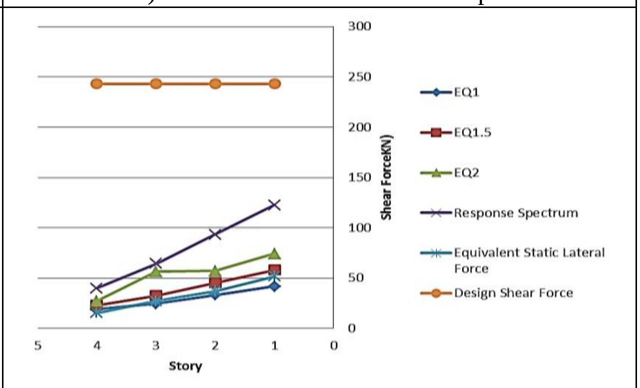
A) Columns Moment Comparison



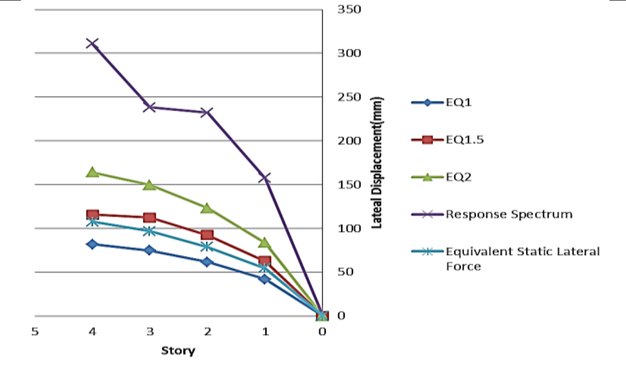
B) Columns Shear Forces Comparison



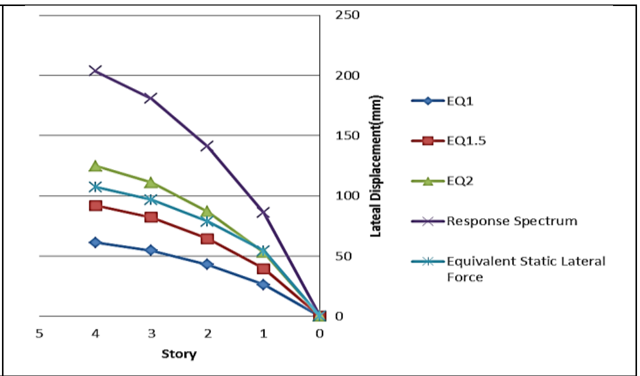
C) Beams Moment Comparison



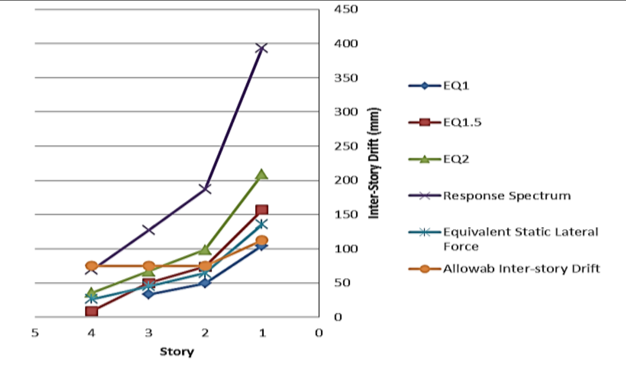
D) Beams Shear Forces Comparison



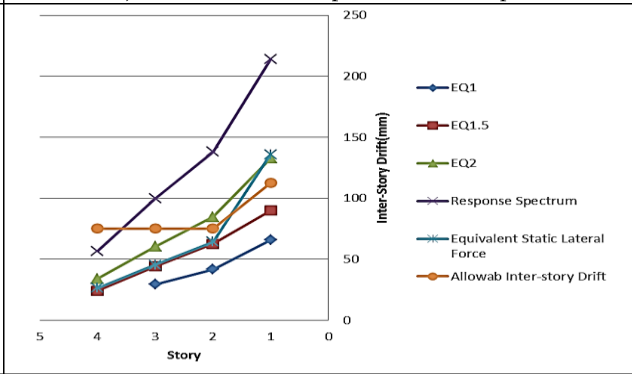
E) X-Direction Displacement Comparison



F) Y-Direction Displacement Comparison



G) X-Direction Inter-Story Drift Comparison



H) Y-Direction Inter-Story Drift Comparison

Figure 6. Building members (beam and column) characteristics with respect to the excitation magnitude

It is evident that if the original Ali Al-Gharbee earthquake was to occur within any Iraqi city, typical commercial reinforced concrete buildings would withstand such an earthquake magnitude without significant issues. The results from the time history analysis indicate that only approximately 63.3% of column failure moments and 41.2% of column failure shear forces were reached. About 33% of the beam failure moments, with 75.8% of beam cracking moments, and roughly 17% of beam failure shear forces were observed. Additionally, the inter-story drifts in the x-direction reached 92.8% of the code-permissible values, while in the y-direction, they reached 58.4%. Regarding the lateral force equivalent static force method, it is noteworthy that the maximum building column moments reached approximately 60.3% of column failure moments and 47.32% of column failure shear forces. Beam failure moments were at 49.8%, with beam cracking moments at 113%, and beam failure shear forces recorded at about 21%. However, the inter-story drift values in both directions exceeded 120% of the code-permissible values.

Regarding the response spectrum results, it was observed that the maximum building column moment reached approximately 205.6% of column failure moments, with 138% of column failure shear force. For beams, the results show 116.4% of beam failure moments, 265% of beam cracking moments, and about 50.4% of beam failure shear force. In terms of inter-story drifts, 350% of the code-permissible values were reached in the x-direction, and about 190% in the y-direction. It is important to note that the results obtained from the three analysis methods differ significantly, with the maximum values obtained from the Response Spectrum Analysis Method. These variations arise from the assumptions and procedures inherent to each method. As such, the results from each method cannot be directly compared, and designers must choose the method that best suits their needs. To assess when the building may fail in the time history analysis method, the earthquake intensity was increased to 150% and 200%. It was found that at 150% earthquake intensity (EQ2), the time history analysis results correspond to approximately 95% of column failure moments and 62.3% of column failure shear forces.

As the earthquake excitation increased to 150% of the original Ali Al-Gharbee intensity (EQ2), it was found that the column failure moments reached approximately 56%, with 113.7% of beam cracking moments, and about 23.8% of beam failure shear forces. However, it also resulted in 139% of the code-permissible inter-story drift in the x-direction and about 79.7% in the y-direction. When the earthquake excitation was further increased to 200% of the original Ali Al-Gharbee intensity (EQ3), the column failure moments reached 127%, with column failure shear forces at 83.3%. Beam failure moments were at 67.6%, with 153% of beam cracking moments and 30.5% of beam failure shear forces. Furthermore, this level of excitation led to approximately 185% of the code-permissible inter-story drift in the x-direction and about 118% in the y-direction. These findings clearly indicate that typical multistory structures used in commercial buildings cannot withstand twice the intensity of the Ali Al-Gharbee earthquake excitation.

4.0 CONCLUSION

I. The three-dimensional finite element model created using SAP2000 software in this study effectively and accurately simulated the response of a typical commercial reinforced concrete building in Iraq when subjected to actual earthquake loading.

II. Based on the results obtained, it can be concluded that if an earthquake with a magnitude of approximately Mw=4.9 (PGA=104 cm/sec^2) was to occur in any Iraqi city, typical commercial reinforced concrete buildings would withstand such a magnitude without encountering significant problems. However, when the earthquake excitation is increased to approximately 150% of the original earthquake intensity, cracks start to appear, and the drift at the first floor exceeds allowable limits. Furthermore, when the earthquake excitation is increased to 200%, the structure experiences failure. Therefore, it is evident that typical commercial reinforced concrete buildings in Iraq cannot withstand an earthquake with a magnitude of approximately Mw=6 (PGA=208 cm/sec^2).

III. The results of the response spectrum analysis lead to a clear conclusion that the use of this method is safe for analysing structures, even when subjected to an earthquake with a magnitude of approximately Mw=6 (PGA=208 cm/sec^2) excitation. In contrast, the results from the equivalent static method indicate that this approach is safe when analysing structures only under the original earthquake conditions with a magnitude of approximately Mw=4.9 (PGA=104 cm/sec^2) excitation.

IV. The analysis revealed that the initial and primary failure occurred at the upper part of the ground floor columns, where moments exceeded the design ultimate moments. Regarding drift, the results demonstrated that the drift increased with the height of the floors, and all drift values exceeded the limits set by the building codes.

V. The dimensions of the sections in typical buildings indicate that their behaviour under excitation is not ideal for earthquake resistance. The general behaviour observed is categorized as "strong beams and weak columns," whereas it should ideally be "strong columns and weak beams" to ensure that failure begins at the beams and prevents column failure. It is strongly recommended that Iraqi designers consider reducing beam sizes and increasing column sizes when designing buildings to withstand seismic hazards.

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