Evaluation of seismic damage to Iraqi educational reinforced concrete building using FEMA P-58 methodology

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Abstract. The building seismic performance assessment can be defined as a posterior phase of investigation in which a detailed analysis is executed in order to evaluate seismic damages and quantify the sequences of the earthquake for a building, this approach could be probabilistic evaluation or deterministic one. The aim of this paper is to perform seismic damage evaluation for educational multi-storey reinforced Concrete Building in Al-Mustaqbal University College (MUC) in Al-Hilla City, Babylon governorate in the middle of Iraq by using FEMA P-58 methodology. A 3D mathematical modelling, pushover analysis by using SeismoStruct software. In addition, incremental dynamic analysis (IDA) and fragility curve according to FEMA P-58 are developed in order to obtain damage limits in term of performance levels of the case study building. Fragility curves are useful tools for showing the probability of structural damage due to earthquakes as a function of ground motion indices. IDA is performed for those simulated building using twelve ground motions with scaling peak ground acceleration increased every 0.1g until it achieved 1.5g to determine the drift capacity of the building in four performance levels, operational (OP), immediate occupancy (IO), life safety (LS) and near collapse (NC) as defined in FEMA P-58. Based on those capacities, fragility curves were developed in terms of peak ground acceleration (PGA) and elastic spectral displacement for drift levels with lognormal distribution assumption.

1. INTRODUCTION

Iraq with an area 438 320 km², it is bordered by six countries from all directions in addition to Arab Gulf as a natural border in the southeast. Iraq lies in the northern portion of the Arabian plate bounded in the north and east by the Bitlis–Zagros fold-and thrust belt, where the convergent tectonic boundary between the Eurasian and Arabian plates generates intense earthquake activity. The rest of the country is largely located on the Arabian platform, away from major plate boundaries. The Dead Sea fault system, a major left-lateral transform fault, forms the western boundary of the Arabian platform, about 250 km away from the westernmost part of Iraq. Selected active faults in Iraq are illustrated in figure 1 and they are: 1) lower Zab fault, 2) Diyala River fault, 3) Badra-Amarah fault, 4) Euphrates fault, 5) Hummar fault, 6) Al-Refaee fault, and 7) Kut fault. [1].

![Figure 1. Active faults in Iraq](image_url)
In the eighties, Iraqi code was based on the American and British codes, it was covering only the design and implementation of reinforce concrete constructions. In 1987, the code suggested used optionally for two years. Iraqi designers and engineers did not use the code, and were depending on ACI and British codes in their works for the last forty years and the well-known codes in Iraqi building are (ASCE/SEI 7-10; (2006 – 2009) IBC; ACI 318 –05 /08) (Code Committee, 1987). The new Iraqi seismic code published in 2017 by MOCHPB of Iraq / the committee of Codes and specifications of Iraqi construction. The code is primarily concerned with setting basic engineering conditions to avoid human losses and ensure the functionality of the building and the protection of buildings and structures from collapse that cause serious damages and led to significant economic and human losses. The code includes details for the system of the structures should use for each seismic design category and other related information [2 & 3]. Al-Sinawi et al. [4], utilized the data of earthquakes that returning to the 1900-1988 period in order to draw the PGA contour maps for Iraq zone by applying of twenty-five, fifty, hundred and two-hundred years as return periods. Eivne lines sources and four seismic area sources were utilized in their study. And they utilized an attenuation relationship given by Esteva 1974 in conjunction with Poisson distribution in the Probabilistic seismic hazard analysis (PSHA) to draw these maps. They were found that the PGA increases towards the east-northeast and the east. The de-clustering process was not applied on the earthquakes data in the previous two studies, which means, their data includes dependent events whereas Poisson distribution is used for independent events.

Also, Ameer et al. [5] & Onur et al. [1] investigated earthquakes in the region of Iraq utilizing earthquake data prepared and collected for the period 1900-2009. The completion analysis demonstrated that seismic data had been completed for Ms≥4.8. They also found that parameters of activity (b & a) for the full data for Iraq were 0.89 and 6.49, respectively. A model of seismic resources was proposed for the Iraq area, which included 13 sources from the region. The criteria for activity of these sources were assessed, but their studies did not continue to be included in each PSHA process. Also, contour maps for PGA and spectral acceleration were plotted at 1.0 and 0.2 seconds for a 2475-year return period.

Mohammed and Sa’ur [6], they try to produce a data base for the dynamic characteristics of various soils in earthquake active areas in Iraq utilizing the cross hole results and tests of down hole. From the collected data base it was observed that the average vertical compressional wave velocities ranges differ depending on Iraq parts: in the North = (1125-2500) m/s, in the Middle = (306-1544) m/s, in the south-western (805-1812) m/s, in the south-eastern (377-1326) m/s and in the South (334-1404) m/s Iraq. And the average vertical shear wave velocities were ranged from (225-476) m/s in the North, (111-408) m/s in the Middle, (268-659) m/s in the western south, (131-380) m/s in the eastern south and (102-365) m/s in the South of Iraq.

Farman and Said [7] applying a comprehensive methodology to investigate the behaviour of a moment frame system with respect to its height after subjected to the design ground motion at Baghdad according to the recently developed seismic hazard maps and, after developing and designing the required configurations of archetype models, specifying life safety as an aimed performance level, modelling nonlinearity and applying the nonlinear static analysis (NSP) according to ASCE/SEI 41-13, FEMA356 and FEMA P-695. This methodology is started by sizing member cross-sectional dimensions and applying reinforcement detailing requirements according to ACI318-14. Results show that, for a given building height and number of bays, inelastic drifts increase with decreasing the bay width because the overall building stiffness is decreased and it will be slenderer, and consequently, the P- delta effects increased. Also, as the building height increased, both, target and minimum shear capacities decrease and the target displacement increases under the effect of the same earthquake ground motion. Consequently, a necessary limitation on the height of these buildings were deduced to ensure their ability to withstand the future ground shaking and, in the same time, maintaining the life safety performance level of damage. Where, it is found that the maximum allowed heights of framed buildings in Baghdad are 17, 25 and 32 stories for 6, 7.5 and 9 m bay widths, respectively.

2. METHODOLOGY

2.1. Earthquake Damage and Loss Estimation

Earthquake loss estimation (ELE) studies establish a central component in the causal chain from the basic research disciplines involved to prevention and mitigation actions against the causes of the natural hazard earthquakes as shown in Figure 2. The main intention of the studies for seismic loss assessment is to produce certain estimates of expected damages as well as the economic and social losses that are related to the damages either in a direct or indirect way.
It could be classified the ELE approaches and methodologies in many types. Majdi and Văcăreanu have classified the methods of ELE into main two groups, the first one focus on a shocked building stock in a specific city or settlement, the second one on specific building or structure [10].

2.2. Performance-based and Resilience-Based Design.
Performance-Based Seismic Design (PBSD) is a concept that enable the plan and erection of the structures with a realistic and reliable knowledge of the risk of life, occupancy, and economic losses that may happen as a result of future earthquakes. PBSD is based on an assessment of a building’s design to determine the probability of experiencing different types of losses, considering the range of potential earthquakes that may affect the structure. This allows a building owner or regulator to select their desired performance goal for their building.

Current building codes are prescriptive in nature and are principally intended to provide a life-safety level of protection when a design-level event, such as an earthquake, occurs. While codes are intended to produce buildings that meet a life-safety performance level for a specified level of ground shaking, they do not provide designers with a means to determine if other performance levels would be achieved. During a design level earthquake, a code-designed building could achieve the goal of preventing loss of life or life-threatening injury to building occupants, but could still sustain extensive structural and nonstructural damage and be through service for an elongated period of time. In some cases, the damage may be too costly to repair, leaving demolition as the only option [8].

PBSD has many advantages over the conventional seismic design method [12]. It sets more adaptive objects, results in less life cycle cost, and is friendly to new structural system and construction materials. And it depends on Code design (ASCE7, etc.) and (AB 083, ASCE 41, etc.) for safety goal purposes. And enhanced modelling and design scrutiny. A new design methodology is developed called "Resilience-Based Design" (RBD) which can be considered as an extension of Performance-Based. The goal of RBD is to make individual structures and communities as "Resilient" as possible, developing technologies and actions that allows each structure and/or community to regain its function as promptly as possible. The method describes a holistic framework for measuring disaster resilience at the community scale. Seven dimensions characterizing community functionality have been represented by the acronym PEOPLE.

Also Resilience-Based Design (or “PBD Generation 2”) has many advantages due to produce it for Safety goal, Repair time goal, Repair cost goal also enhanced modelling and design scrutiny.

Figure 3 illustrate the process of resilience-based design or performance based design 2.
2.3. FEMA P-58 Methodology
In the new American Applied Technology Council (ATC) approach with titled of FEMA P-58, a performance level is normally defined as the maximum acceptable damage which a building suffers when it’s subjected to a given level of an earthquake. The damages suffered by the structural and the nonstructural elements, the contents, and the availability of the utilities of the site which are necessary to the building function are normally considered when defining the performance levels [9].

Based on the classification of FEMA 273, there are four performance levels which are defined by FEMA P-58:
- Operational (Or Fully Operational) (OP)
  In this level, the backup utility services maintain functions. There is very little damage.
- Immediate Occupancy (IO)
  In this level, the building is safe to be occupied and receives a ‘green tag.’ Only minor repairs are required.
- Life Safety (LS)
  In this level, the Safety Level Structure is stable and there’s a significant reserve capacity. The hazardous nonstructural damages are properly controlled.
- Collapse Prevention (Or near Collapse NC)
  In this level, the structure remains standing, but any other damage or loss is acceptable.

The discussed performance levels are normally applied to both the nonstructural and the structural components and are mainly assessed at specified seismic hazard levels. Although these levels provided a way by which the engineers can quantify and communicate the seismic performance to the clients and the other stakeholders, the implementation of the present-generation procedures in practice revealed certain limitations and identified the enhancements which were needed.

FEMA P-58 is a novel probabilistic performance prediction technique which is developed by Federal Emergency Management Agency (FEMA) and released in 2012. And it uses (PBSD) concept by using of various performances measures that can easily be understood and interpreted by decision makers. The performance objective of this methodology is based on the level of damage by a building and the likely results of the damage including possible loss of occupancy, casualties, and reconstruction as well as repair costs. The methodology is published in seven volumes and volume one includes methodology, volume two describe the implementation guide, while the third volume consist of supporting products, these are electronic materials and background documentation, volume four describes methodology for assessing environmental impacts, volume five is for estimating the expected Seismic performance of code conforming buildings, volume six provides guidelines for performance-based seismic design of buildings and volume seven provides a Guide to State-of-the-Art tools for seismic design and assessment. The main tool that used to implement this method is PACT (Performance Assessment Calculation Tool). It helps applicants to

![Flowchart of the performance-based design process](image)
accumulate building performance models and carry out recurring calculations linked with the Monte Carlo analysis. It provides models for ten different types of buildings depending on its usage. These include commercial offices, healthcare, hospitality, residential buildings.

In order to identify and categorized fragility curve according to the component types, PACT uses NISTIR 6389 classification systems. This system is based on the UNIFORMAT II classification system and has six main classes and four sub levels.

FEMA P-58 used a clear procedure as shown in figure 4 in order to predict the damages in the entire building, each storey or in the structural and nonstructural components as groups or as single parts.

![Figure 4. Procedure of FEMA P-58 Methodology](image)

In order to apply FEMA P-58 methodology for a specific building, many data should be collected to achieve accurate results. These data include details about the building and their likelihood of damage when exposed to seismic activities. It’s requires information regarding to site location, structural system, occupancy, number of floors, structural and non-structural components and their location and vulnerability, etc. The other important input data is defining the earthquake hazard. FEMA P-58 provide three types of assessment that can be categorized into intensity, scenario, and time-based assessments. This method is applicable for estimating the performance for both new and existing building.

After defining of the performance level and entering the input data of the building and ground motion, the analysis will be performing to obtain the building responses and develop the collapse fragility function. The user then will be evaluating a performance assessment, which is intended to determine if the selected performance level is met, or exceeded, at the chosen hazard level.

In any assessment, the consequences of building collapse include the causalities, the cost repair the building and downtime. These consequences are calculated by utilizing many large numbers to get the bests and predictable outcomes in such conditions of uncertainty.

As summary of the procedure of FEMA P-58, the Volume1 provides a detailed description of the methodology, the main steps for this methodology are:
- Assemble Building Performance Model
- Define Earthquake Hazards
- Analyse Building Response
- Develop Collapse Fragility
- Calculate Performance: Intensity Based and Scenario Based Assessments or Time-Based Assessments

The limitations by using performance assessment methodology are it take into account the losses within the building without consider the possibility of losses in power, water and sewage services, and without consider the damages and casualties outside the building when damage leads to debris that falls in the surrounding area. Also it’s not take into account the probable significant impacts such as initiation of fire and release of dangerous materials.
3. BUILDING PERFORMANCE MODEL

3.1. Site description
Al-Mustaqbal University College (MUC) is located in front of the University of Babylon in the province of Babylon - Iraq on the public street (highways) link between the province of Babylon and the province of Najaf. MUC is one of the private universities located in Babylon province/Iraq. Al-Mustaqbal University College MUC consists of fifteen departments and more than 7000 students, starting from the Engineering departments, humanities and medical departments.

3.2. Building information
The selected building is located at the entrance of the MUC at the Northeast as shown in figure 5, and it is a multi-story building consists of four-story in order to satisfy the students and staff requirement. The building was constructed in 2018 as an in-situ concrete frame that filled bricks masonry by using ordinary Portland cement and different seize steel bars with local sand and gravel and water, the bricks were a local one. It is a registration building, so it will contain the new students and graduate student in addition to the staff to help them, therefore it should have a waiting area and offices room. Therefore, the staff number in the building is 54 persons and the highest students’ number during the registration period is about (500-1000) per day. Table 1 shows a summary of the general information about the area and occupancy of each floor in the building.

![Figure 5. Case study building and its location in MUC campus](image_url)

Table 1. Area and occupancy of each floor in the building

| No | Floor     | Area (m²) | Height (m) | Remarks (occupancy)            |
|----|-----------|-----------|------------|--------------------------------|
| 1  | Ground floor | 300      | 2.5        | Documentation and archive      |
| 2  | 1st floor  | 330       | 3          | Student registration and waiting area |
| 3  | 2nd floor  | 375       | 3          | Place of studies and research unit Staff |
| 4  | 3rd floor  | 375       | 3          | Accounting and Human resources |
|    | Total     | 1380      | 11.5       |                                |
3.3. Modelling of the Building

The 3D modelling of the case study building is performed by SeismoStruct 2018 to simulate the response of it and obtain its results of non-linear analysis as shown in figure 6.

![3D Model of the building, deformed and un-deformed.](image)

4. NONLINEAR STATIC ANALYSIS

4.1. Pushover Analysis

Nonlinear pushover analysis is a static analysis that has become quite important due to its easy application, compared to the dynamic approaches. According to EC8-1/2004 it is defined as ‘a non-linear static analysis carried out under conditions of constant gravity loads and monotonically increasing horizontal loads’. In other words, in a nonlinear static procedure, the model is both under permanent vertical loads and gradually increasing static lateral loads. However, due to the inelastic behaviour, a structure can develop larger displacements in the inelastic range even though lateral force would remain constant. In order to capture the post-peak behaviour of structures displacement control is usually preferred. In this case global displacement of one node is incremented (instead of a force value) and then the corresponding loading factor is calculated. At first a “target displacement” of a chosen node (control point) must be defined. Then the analysis is conducted until the displacement at the control point reaches the target displacement.  

For the case study building, pushover curve and its performance curve are shown in figures 7, 8, 9 and 10 respectively.

![Pushover curve](image)

Figure 7. Pushover curve
Figure 8. Performance curve for pushover analysis

Figure 9: Performance curve for pushover analysis, 2D in main direction

Figure 10: Performance curve for pushover analysis, 2D in minor direction
5. DEFINE EARTHQUAKE HAZARD

FEMA P-58 used Probabilistic seismic hazard analysis (PSHA) approach for the estimation of seismic design loads for engineering structures. The use of probabilistic concept has allowed uncertainties in the size, location, and rate of recurrence of earthquakes and in the variation of ground motion characteristics with earthquake size and location to be explicitly considered for the evaluation of seismic hazard. In addition, PSHA provides a framework in which these uncertainties can be identified, quantified and combined in a rational manner to provide a more complete picture of the seismic hazard [13]. The main parameter that used to quantify ground motion in PSHA is PGA. It’s useful for defining lateral forces and shear stresses in the procedures of equivalent-static-force for some codes of building, and in liquefaction analyses. Nowadays, the preferred parameter is Response Spectral Acceleration (SA), which gives the maximum acceleration experienced by a damped (Typically 5% damping ratio), single-degree-of-freedom oscillator (a simple representation of building response). In FEMA P-58 methodology there are some considerations that should be take into account by selection of ground motions, in this report the motions were selected to match the Conditional Mean Spectrum CMS over the period range of interest (0.2T1 to 2.0 T1), as required in the ATC-58 Methodology, these limits could be computed as following:

\[
T_a = C \cdot h_x \quad \text{(Equation 12.8.7 in ASCE/SEI 7-10)}
\]

\[
h_x = \text{total height} = 11.5 \text{ m}
\]

\[
C = 0.75 \quad , \quad x = ( \text{table10, 12.8-2 in ASCE/SEI 7-10})
\]

\[
T_1 = 0.7 \text{ sec}
\]

6. INCREMENTAL DYNAMIC ANALYSIS (IDA)

Incremental dynamic analysis involves scaling each ground motion in a suite until it causes collapse (Or exceeding other performance level) of the structure [14]. This process produces a set of IM values associated with the onset of collapse for each ground motion. The probability of collapse at a given IM level, x, can then be estimated as the fraction of records for which collapse occurs at a level lower than x. According to IDA curve, the relationship between drift ratio and ground motions can be determined. Then, this relationship is utilized to determine performance level of a structure. This relationship also shows a range of behaviour with large variation from each record. IDA must be considered the first step before developing fragility curves.

In this report the following steps are performed to develop incremental dynamic analysis for the case study building:

Step 1: Selection of ground motion records
These are selected based on following considerations:
- Range between 0.14 and 0.70 (The motions were selected to match the CMS over the period range of interest (0.2T1 to 2.5 T1)
- From Database of Iranian Road, Housing and Urban Development Research Centre (BHRC)
- Different locations and stations of selected GM are in the border between Iraq and Iran in order to simulate the reality of the probable earthquake as much as possible.
- 12 GMs are selected according to above; they are listed with their maximum PGA in table 2:

| Table 2. maximum PGA of selected ground motion |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| PGA 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Value 0.315 | 0.351 | 0.195 | 0.194 | 0.35 | 0.367 | 0.698 | 0.146 | 0.2756 | 0.24419 | 0.1757 | 0.419 |
The results obtained from these IDA analyses are shown in figures 11 & 12.

![IDA curves for all selected ground motions.](image1)

**Figure 11.** IDA curves for all selected ground motions.

![IDA curves for 16%, 50%, median and 90%.](image2)

**Figure 12.** IDA curves for 16%, 50%, median and 90%.

### 7. FRAGILITY ANALYSIS

It could be defined as a fragility function as a probabilistic relationship between the frequency of failure of a component of a nuclear power plant and peak ground acceleration in an earthquake. Fragility analysis is the analysis for seismic loss estimation in built environments. They represent the probability of exceeding a damage limit state for a given structure type subjected to seismic excitation. In the literature there are various type of fragility analysis available. The damage limit states in fragilities may be defined as global drift ratio (maximum roof drift normalized by the building height), inter-story drift ratio (maximum lateral displacement between two consecutive stories normalized by the story height) or story shear force etc. Fragility curves involve uncertainties associated with structural capacity, damage limit state definition and records of ground motion accelerations. Fragility curve shows probability to express level of damage at specified ground motion records. Some parameters, such as PGA, spectral acceleration, and peak ground velocity, can be used to develop fragility curve. FEMA P-58 provide a spreadsheet tool in to develop fragility curve by selecting PGA as a reference of the performance levels. Mean and standard deviation of PGA are necessary to develop fragility curve. These parameters were calculated for every point.
7.1. Performance levels

The first step in performance-based seismic design is to define the objective, or performance level. FEMA P-58 used the levels from Vision 2000 report as illustrated in table 3.

Table 3. Values of maximum drift for the building

| Height of Building (m) | OP Limit Drift % | IO Limit Drift % | LS Limit Drift % | NC Limit Drift % | OP max. Disp. (m) | IO max. Disp. (m) | LS max. Disp. (m) | NC max. Disp. (m) | No. of analysis |
|------------------------|------------------|------------------|------------------|------------------|-------------------|------------------|------------------|------------------|----------------|
| 11.5                   | 0.12%            | 0.30%            | 0.90%            | 1.50%            | 0.0138            | 0.0345           | 0.1035           | 0.1725           | 12             |

7.2. Fragility Curves

By applying the above procedure to obtain the fragility curve for a specific performance level, the results are obtained and illustrated in figures 13 through 17. as following:

Figure 13. Fragility curve for OP level.
Figure 14. Result of fragility function for IO level

Figure 15. Result of fragility function for LS level.

Figure 16. Result of fragility function for NC level
8. DISCUSSION AND CONCLUSION

- FEMA P-58 methodology is used in order to evaluate seismic damages to educational reinforced concrete building.
- Recommendations in new Iraqi seismic code and ASCE/SEI 7-10 are followed to obtain some important parameters like soil classifications, design category, occupancy factor.
- A performance model for the building is performed including all structural and nonstructural components according to their fragility and performance groups.
- Four performance levels are defined in this approach: Operational (OP), immediate occupancy (IO), life safety (LS) and near collapse (NS).
- A static nonlinear analysis (pushover) is developed in order to estimate seismic structural deformations and evaluate the seismic capacity of the building.
- An incremental dynamic analysis (IDA) is developed by using twelve ground motions and scaling them from 0.1g to 1.5g with 0.1g interval.
- The selection of the ground motions is done with consideration the recommendation in FEMA P-58 and from Iranian database to simulate the future earthquakes as much as possible.
- To obtain the outcomes of evaluation the building to seismic damages and according to performance levels, the procedure of fragility curve is performed for each level.
- As illustrated in figure 14, from results of fragility curves for all performance levels, and when the record of 0.3g as a reference of all these curves, it could be concluded that there is no probability – according to the results- that building reach NC and LS levels in case and there is just 2% probability to reach IO level in the same case. The probability that building reach OP level with no or limited damages is about 45% in case of 0.3g.
- Just in case of ground motions above 1.2g started the probability to reach LS and NC levels, and there is no probability for that according to earthquake catalogue in the region (Low seismicity region)

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