Earthquake loss estimation for an educational reinforced concrete building by using FEMA P-58 methodology

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Abstract. The costs of damages in both social and economic aspects are increased as a result of several significant earthquakes worldwide, the economic and social losses are a function of damage of the buildings because the buildings are vulnerable to earthquake damage [1]. In this study a probabilistic methodology FEMA P-58 is applied for seismic performance assessment for Iraqi educational reinforced concrete building in order to calculate the performance in terms of two aspects, the first one is the direct economic losses which include repair costs and repair time and the second one is social losses which include casualties and injuries. This methodology is prepared by ATC, the American Applied Technology Council and its prepared for Federal Emergency Management Agency (FEMA) in 2012. The study is a continuation of other research papers related to applying the same method to the same building that the researcher undertook for the purpose of evaluating the performance of the building when exposed to earthquake and calculating the losses resulting from these damages by choosing different aspects of each research in terms of the method of simplified analysis or the calculation of damages and losses.

1. Introduction

1.1. FEMA P-58 methodology

Performance-based earthquake engineering (PBEE) present design, evaluation, construction, observation the function and repair or maintenance of engineered facilities whose performance under popular and extreme loads responds to the various needs and objectives of owners–users and society [2]. FEMA P-58 used PBEE framework and in order to apply it for a specific building, many data should be collected to achieve an accurate result. 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 nonstructural 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 [3]. The case study building has moment frame reinforced concrete structure, the simplified analysis described in FEMA P-58 is used in this paper to obtain the results. The PACT software which is provided by ACT team and considered the main tool in the methodology to calculate the estimated
economic and social losses is used in this study. PACT tool is freeware that used in the earthquake-related loss estimation through performance based probability estimates. This tools have been built using the same PEER framework. PACT software has more to offer than the many other similar tools due to its higher number of fragility curve, and consequence functions, higher transparency and user friendliness. In general, the FEMA P-58 method results vary more between buildings, since it has the ability to quantify the effects of building-specific (and site-specific) features to provide a more detailed risk assessment for the individual, and it also provides additional detailed building-specific risk information such as what specific components are expected to be damage and contribute most to losses, building repair time estimates, etc.

1.2. Earthquake hazard in Iraq
Concrete buildings are the predominant types of structural systems in Iraq. Modern single family residential buildings are predominantly two story reinforced concrete buildings. Old houses are one story reinforced concrete or masonry structures. Multi-storey residual, Industrial and commercial buildings range from three stories to twenty stories with the majority in the range of four to ten stories.
Steel structures constitutes a small percentage of the buildings used in Iraq, they are mainly used for industrial hangers and warehouses. Most modern reinforced concrete buildings can be classified as ordinary moment frames (OMF). According to The Global Facility for Disaster Reduction and Recovery (GFDRR) [4], in Iraq earthquake hazard is classified as medium according to the information that is currently available. This means that there is a 10% chance of potentially-damaging earthquake shaking in your project area in the next 50 years [4]. Majdi [1] suggested an earthquake hazard mitigation program to Iraqi decision makers by introducing Iraq’s situation in earthquake hazard and providing an insight into the achievements that may be gained by implementing a proposed program of earthquake hazard mitigation. Most of Iraqi buildings have moment frame system and reinforced concrete structure, they designed according to American code, but sometimes they erected following the experiences without using any standard or code. Therefore, the needs of study the expected damages and estimated losses caused by seismic activities for reinforced concrete buildings would be very useful for designers, owners and decision makers.

2. Evaluation of the ground motions
2.1. Probabilistic Seismic Hazard Analysis
Performance assessment can utilize site-specific characterization of ground shaking associated with different probabilities of exceedance. Such characterizations are routinely performed using probabilistic seismic hazard assessment (PSHA), where probability distributions are determined for the magnitude of each possible earthquake on each source, the location of each earthquake in or along each source, fM(m), and the fR(r), prediction of the response parameter of interest P(pga > pga’ | m,r). Kramer [5] describes this as a five-step process depicted in Figure 1.
Farman and Said [6] studied the Probabilistic Seismic Hazard Assessment (PSHA) for Iraq and found that the probabilities of occurring earthquakes increase towards the east-northeast and north due to the continued tectonic boundary convergence between the Arabian, Iranian and Turkish plates which produces intense earthquake activity.
2.2. Selection of ground motions

According to FEMA P-58 methodology, the earthquake ground shaking is characterized by target acceleration response spectra, its intensity can be represented by any user-defined acceleration response spectrum (e.g., a code design spectrum). Said and Farman [7] developed contour maps for Iraq of spectral accelerations at 0.2 and 1.0 s and PGA for a return period of 2475 years as shown in figure 2.

Figure 1. Step process for PSHA

Figure 2. Spectral accelerations for a return period of 2475 years on Site Class B, in units of (g), at a) 0.2 sec, b) 1.0 sec (Said and Farman)

FEMA P-58 provides a detailed description and procedure in order to select target intensities and ground motions records. Earthquake ground shaking is characterized by target acceleration response spectra. For nonlinear response history analysis, shaking effects are assessed by simultaneously evaluating response to orthogonal pairs of horizontal ground motion components [3]. Intensity is defined as The severity of ground shaking as represented by a 5%-damped, elastic acceleration response spectrum, or the 5% damped spectral response acceleration at a specific natural period of vibration. The methodology recommended at least eight target intensity levels.
In this study, structural analysis results are input for eight ground shaking intensities and twelve ground motions for each intensity level. Site hazard was evaluated for the eight intensity levels suggested by the FEMA P-58 Methodology. The selection of ground motion (GM) records is based on the following considerations:

- Range between 0.14 and 0.70 (FEMA recommendations between 0.14 and 1.4)
- From Database of Iranian Road, Housing and Urban Development Research Center (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 1.

| Max | max | max | max | max | max | max | max | max | max | max |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| PGA | PGA1 | PGA2 | PGA3 | PGA4 | PGA5 | PGA6 | PGA7 | PGA8 | PGA9 | PGA10 |
| 0.146 | 0.1756 | 0.193 | 0.194 | 0.24418 | 0.2755 | 0.315 | 0.349 | 0.351 | 0.3674 | 0.4188 |

### 3. Building characteristics

The selected building is located at the entrance of the Al-Mustaqbal University College at the North east as shown in the Figure 3, and it is a multi-story building consists of four storeys in order to satisfy the students and staff requirement. The building was constructed on 2018 as an in-situ concrete frame that filled bricks masonry by using ordinary Portland cement and different size steel bars with local sand and gravel and water, the bricks was local one. It is 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 more than fifty persons and the highest students’ number during the registration period is about (500-1000) per day.

![Figure 3. Location of the case study building in MUC](image-url)
4. Building basic data

The architectural information of the building is presenting in table 2: Basic information of the building

| Description      | Quantity | Dimensions (m) |
|------------------|----------|----------------|
| Spans            | 4        | 20             |
| Bays             | 3        | 15             |
| Stories          | 4        | 3              |
| Ground level     | 1        | 2.5            |

Floors area, height and occupancy

| No | Floor       | Area (m2) | Height (m) | occupancy                  |
|----|-------------|-----------|------------|----------------------------|
| 1  | GF          | 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       |                             |

The costs of the construction are given in table 3, the core and shell replacement cost represents replacement of the basic building structure, exterior enclosure, and mechanical, electrical, and plumbing infrastructure that is typically present in a building before occupant improvements are made [3]. Total replacement cost includes replacement of the core, shell, and all occupant improvements and contents. This value is assumed in this study as 67% of the total cost of the building. The parameters that use to calculate repair time are replacement time and the maximum workers per square unit (square feet or square meter). The replacement time, is defined as a time necessary to replace a building that has been damaged beyond the point of practicable repair, including time associated with demolition and removal of debris, it estimated according to the experience. The replacement time in days taken as 240 and the maximum workers per square meter is 0.028580. FEMA P-58 used to calculate repair time. Values for this parameter should range from 0.0005 (one worker per 2,000 square feet) to 0.004 (1 worker per 250 square feet) as listed in table 3.

| Cost USD/m² | 420         |
|-------------|-------------|
| Core and Shell replacement per USD/ m² | 280         |
| Total replacement cost USD | 579600     |
| Core and Shell replacement USD | 386400     |
| Replacement time (days) | 240         |
| Maximum Workers per Square meter | 0.028580    |
5. Modelling of the Building

Figures 4 and 5 illustrated the floor plan and the elevation view of the structure respectively.

Figure 4. Floor plan of the building
6. Project information

The following input data in table 4, 5 and 6 of the project are given in PACT software which also includes declaration of some parameters used in project information.

| Table 4. General  Project information of the building |
|---------------------------------------------------|
| **Project ID** | Registration Building |
| **Building description** | Registration and Administration building in Al-Mustaqbal University College |
| **Client** | Al-Mustaqbal University College |
| **Engineer** | Ali Majdi |

| Table 5. Region cost parameters and solver random seed value |
|-------------------------------------------------------------|
| **Region Cost Multiplier** | 1.10 fields to adjust provided component repair cost consequence functions to appropriate present values. |
| **Date Cost Multiplier** | 1.00 |
| **Solver Random Seed Value** | 5 initiate all internally programmed sequences of random number generation utilized in performance assessment. If a Solver Random Seed Value of zero is used, PACT will randomly seed each generation sequence. This will result in different values for performance assessment results each time the same problem |
is executed even if there are no changes to the input. While the results of these assessments can be expected to be similar, users should input a single digit non-zero integer to avoid seeing anomalous changes in predicted performance when multiple evaluations of the same building are performed. Note that if a sufficiently large number of realizations is used, this effect is negligible.

Table 6. Parameters used in building info that given in PACT

| Parameter              | Value | Resource                          | Description                                                                                                                                 |
|------------------------|-------|-----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|
| Total loss threshold.  | 0.75  | FEMA P-58/ Vol. 1 and 2           | is the ratio of repair cost to replacement cost at which a decision will likely be made to replace the building rather than repair it. FEMA uses a value of 0.5 for this loss ratio when determining whether post-earthquake repair should be funded. PACT uses a default value of 1.0 to maximize the amount of assessment information that will be obtained in an assessment. It suggests that when repair costs exceed 40% of replacement costs, many owners will choose to demolish the existing building and replace it with a new one. |
| Height Factor          | 1     | FEMA P-58/ Vol.2 / Table 2-1      |                                                                                                                                              |
| Hazmat Factor          | 1     | FEMA P-58/ Vol.2                  | used to reflect the variable hazardous material premiums, 1.00 for modern buildings without significant hazardous material content to 1.20 for buildings that contain significant amounts of hazardous material |
| Occupancy Factor       | 1.1   | FEMA P-58/ Vol.2 / Table 2-2      | Occupied / Education K-12                                                                                                                   |

7. Population model
The population data of the building is given in PACT according to estimated values of occupancy hourly, weekly and monthly. The monthly and daily population model are illustrated in figures 6 and 7 respectively.

Figure 6. Monthly population model

Figure 7. Daily population model
8. Results of simplified analysis

By using PACT software and after input all data described in the previous section and also the details of the structural and nonstructural components, the following results are obtained applying the simplified analysis following the procedure of FEMA P-58 methodology:

8.1. Repair cost

Curves of repair cost graphically for each intensity represents the relation between:
- Performance groups and cost in USD
- Costs in USD and their probability (Lognormal fitted curves & binned values)
- Annualized Repair cost and the annual probability
- Intensity number & repair cost in USD and annual probability (3D)

These curves are shown in the figures from 8 and 17.

Figure 8. Repair cost for Intensity 1

Figure 9. Repair cost for Intensity 2
Figure 10. Repair cost for Intensity 3

Figure 11. Repair cost for Intensity 4

Figure 12. Repair cost for Intensity 5

Figure 13. Repair cost for Intensity 6
Figure 14. Repair cost for Intensity 7

Figure 15. Repair cost for Intensity 8

Figure 16. Annualized Repair cost for all intensities
8.2. Repair time

Curves of repair time graphically for each intensity represents the relation between:
- Time in days and performance groups for each floor
- Time in days and their probability (Lognormal fitted curves & binned values) for each intensity
- Annualized Repair time and the annual probability
- Intensity number & repair time in days and annual probability (3D)

These curves are shown in the figures from 18 and 27

![Figure 17. Repair cost curve](image)

![Figure 18. Repair time for Intensity 1](image)

![Figure 19. Repair time for intensity 2](image)
Figure 20. Repair time for Intensity 3

Figure 21. Repair time for Intensity 4

Figure 22. Repair time for Intensity 5

Figure 23. Repair time for Intensity 6
Figure 24. Repair time for Intensity 7

Figure 25. Repair time for Intensity 8

Figure 26. Annualized total Repair time for all intensities
8.3. Casualties

Curves of casualties (Deaths and serious injuries) graphically for each intensity represents the relation between:
- Number of casualties and their probability (Lognormal fitted curves & binned values) for each intensity, as shown in the figures 28 and 29 for intensities 7 and 8.
- Annualized number of fatalities and the annual probability, as shown in the figures 30 and 31.

Intensity number & casualties and annual probability. As shown in the figures 32 and 33.

Figure 27. Repair time curves for all intensities

Figure 28. Deaths and injuries for Intensity 7
Figure 29. Deaths and injuries for Intensity 7

Figure 30. Annualized fatalities for all intensities
Figure 31. Annualized injuries for all intensities

Figure 32. Fatality curves for all intensities
9. Discussion and conclusion

In this paper FEMA P-58 methodology is used in order to estimate the earthquake losses for four storey reinforced concrete educational building in Al-Hilla city in the middle of Iraq. FEMA P-58 method provides detailed building-specific risk information such as what specific components are expected to be damage and contribute most to losses, building repair time. The output of this method obtained from PACT software and represented by calculate performance, exactly repair cost, repair time, casualties (Fatalities and injuries).

From results obtained from this study it could be concluded that any details of the case study building includes it’s site, analysis method, plan, construction details, etc influences the results of the earthquake consequences.

The simplified analysis is performed in this study in order to calculate the performances or consequences for each intensity level of the eight target acceleration response spectra according to the procedure described in FEMA-P58. The results obtained are very clear to the owner and decision makers. PACT used Monte Carlo probabilistic approach to obtain the results of the consequences of the earthquake. In this study 500 realizations are selected. The results that obtained could be highlighted as following:

- Repair cost: take in to account the worst case for realization for each intensity and which performance level are related with this case in both directions. As example the wall partition is more sensitive and cause losses and collapsed in many intensities. In intensity 8 it expected a full collapse for the building. The annualized total for 15821 USD.

- Repair time: by using similar approach in repair cost according to worst case of realizations, the results here are related with each floors and it could be concluded that the most damages (and repair time needed) is happened in upper floor and in the performance level of wall partitions. Also here shows the analysis that the building will be collapsed in intensity 8. The annualized total is about 2.08 days.

- Casualties: the worst case of intensity 8 is estimated about 36 deaths and 4 injuries and the annualized fatalities is 0.0012.
Collapse did not occur during any of the analyses for intensities 1, 2, 3, 4, or 5. However, for intensities 6, 7, and 8, collapse, indicated by lack of analysis convergence, did occur for some of the analyses.

References

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