

EVALUATION OF SEISMIC RESILIENCE OF A DUAL SYSTEM CONCRETE BUILDING FOLLOWING FEMA P58

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ABSTRACT

Earthquake resilience of buildings is a major concern for urban areas in Bangladesh, where rapid urbanization and seismic vulnerability present significant challenges. This study focuses on evaluating the repair cost and repair time of a dual system reinforced concrete building under seismic loading, where the values were obtained through the FEMA P-58 performance-based assessment framework using fragility and consequence functions in the Performance Assessment Calculation Tool (PACT), following structural response analysis in ETABS and seismic demand estimation through SPO2IDA. A three-story multi-unit residential building located in Dhaka, and designed in accordance with the Bangladesh National Building Code (BNBC 2020) was selected as the case study. The building was evaluated under eight earthquake intensity levels, with spectral acceleration values ranging from 0.13g to 0.2g. The findings indicate that the building demonstrates high economic and functional resilience. At lower seismic intensities, the structure experienced negligible damage requiring no repair intervention. Even at the maximum intensity of 0.2g, the repair cost was limited to only 1.44% of the total replacement cost, while the maximum downtime recorded was 6.1 days. These small values demonstrate that the building can be restored with minimal financial burden and returned to operational use within a week following an extreme seismic event. The results highlight that dual system concrete buildings designed according to BNBC 2020 can achieve rapid recovery with low repair costs and minimum disruption, making them a resilient and sustainable solution for seismic-prone regions such as Dhaka.

Keywords: PACT, Repair cost, Repair time, Seismic resilience, FEMA P-58

1. INTRODUCTION

Earthquakes have been recognized as one of the most destructive natural hazards, causing significant human and economic losses around the world. (Hamburger, 2014). Over the last couple of decades, there has been a big shift toward performance-based earthquake engineering (PBEE) to quantify the resilience of structures against seismic events. (FEMA, 2018; Porter, 2003). This is especially crucial in developing nations like Bangladesh, where rapid urban growth and the construction of multi-story reinforced concrete (RC) buildings in areas prone to moderate-to-high seismic activity make it vital to assess repair costs and timelines for restoring functionality and ensuring economic stability after an earthquake (MoDMR Atlas, 2015). Consequently, a detailed investigation of these parameters has become vital to assess the financial feasibility and recovery performance of existing and newly designed buildings.

Numerous studies have been conducted worldwide where post-earthquake losses and downtime were estimated using different PBEE methodologies. The FEMA P-58 framework was introduced to enable the probabilistic estimation of repair cost, repair time, and casualties. Through this methodology, earthquake-induced damage was linked directly to decision-oriented loss metrics, and it was demonstrated that median losses could be predicted with a reasonable degree of confidence for a given hazard level. (Porter, 2003). It was applied to reinforced concrete (RC) buildings in Italy, where expected annual losses (EALs) ranging from 0.5% to 1.5% of the total replacement cost were reported, depending on construction age and detailing quality. It was also found that non-structural components contributed most to total repair cost and repair time. (Cardone & Perrone, 2017). The framework was further extended to a regional scale, revealing that repair costs dominated total earthquake-induced losses (Zeng et al., 2016). Similarly, FEMA P-58 was used for hospitals and steel systems, where downtime reductions of up to 60% and repair cost savings of about 35% were achieved through improved design measures (Jarrett et al., 2015; Yu et al., 2019). In contrast, within the Bangladeshi context, very limited studies have been performed on PBEE-based resilience assessment. Typical RC building was conducted vulnerability analysis and found that most mid-rise RC frames in Dhaka were at high risk of moderate damage under design-level earthquakes (Rahman Abir & Hossain, 2024). Urban RC structures were assessed, and concluded that dual system buildings exhibited greater seismic resilience and shorter functional recovery times than moment-resisting frames alone (Hasan et al., 2025). Despite these contributions, most previous research was carried out for foreign construction typologies or old structural systems. Therefore, a distinct research gap has been identified in the evaluation of cost- and time-based seismic performance of modern dual-system RC buildings designed under current Bangladesh National Building Code (BNBC 2020) provisions, which justifies the present study.

This study aims to identify the expected repair cost and repair time of a dual-system reinforced concrete building in Dhaka, Bangladesh, under different seismic intensities. The analysis considered various intensities and the component-level fragilities. The findings were used to evaluate the building's economic and time-based resilience, focusing on the link between ground motion intensity, repair costs, and downtime.

By measuring annual repair costs and downtime, this study supports the development of cost-effective, resilient design principles and encourages decisions based on seismic risk in Bangladesh. The results are expected to assist engineers, policymakers, and urban planners in improving recovery plans after earthquakes, lowering financial losses, and ensuring public safety for long-term growth in cities.

2. METHODOLOGY

The analysis was carried out following the probabilistic framework of FEMA P-58 (2018), which involves a four-step process for estimating economic losses and repair time.

2.1 Structural Modeling and Analysis

A three-story dual system reinforced concrete (RC) building was modeled in ETABS 2017 using finite element-based analysis. The building measures 240 ft in length, 60 ft in width, and 45 ft in total height above the foundation, with each story being 13 ft high, as shown in Figure 1. It featured 12 bays along the longitudinal direction and 6 bays along the transverse direction, each spaced 20 ft apart. The structure included ordinary RC shear walls and intermediate moment-resisting frames, designed according to BNBC 2020 provisions. The shear walls at the building ends had an aspect ratio of 1.95, classifying them as squat walls.

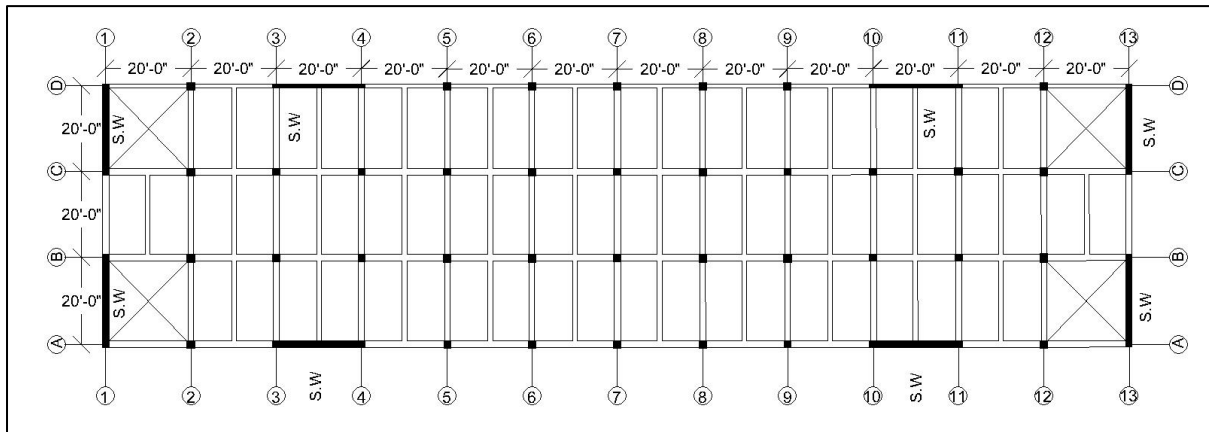


Figure 1: Layout plan of the model

A static pushover analysis was performed to determine the lateral strength and deformation capacity, while response spectrum analysis was conducted to evaluate inter-story drift and floor acceleration. The fundamental period (T_1) was found to be 0.35s, and the building weight was estimated as 27,939.8 kips. Median spectral acceleration (S_a) values were derived using the SPO2IDA tools for a range of earthquake intensities from 0.13g to 0.20g.

2.2 Damage Assessment

The structural responses obtained from the analysis (inter-story drift and acceleration) were used to estimate potential damage states for both structural and non-structural components. Fragility functions, representing the probability of reaching specific damage states, were assigned to components such as beam-column joints, infill walls, and mechanical systems. The fragility data were obtained from the FEMA P-58 component database and modified to reflect local construction characteristics. The median story drift ratios for the top story were observed up to 0.00084, confirming elastic behavior under design-level shaking.

2.3 Loss Estimation

The Performance Assessment Calculation Tool (PACT) of FEMA P-58 was used to compute the repair cost and repair time associated with each damage scenario. The consequences functions were applied to translate component-level damage into economic losses. The parallel repair cost assumption was adopted, where all damaged components across different floors were assumed to be repaired simultaneously. The repair cost was normalized as a percentage of the total replacement value to facilitate comparison across intensity levels.

2.4 Aggregation and Evaluation

The component-level losses were aggregated at the building level to obtain the total repair cost and downtime. The analysis was conducted for eight ground motion intensity levels (0.13 g to 0.20 g). For each intensity, median repair cost and median repair time were derived at a 50% non-exceedance probability. The annualized loss was computed using the Mean Annual Frequency of Exceedance

(MAFE) approach, integrating expected losses across all hazard levels. Finally, the results were used to evaluate the time- and cost-based seismic resilience of the building in terms of annualized repair cost (USD/year) and downtime (days/year).

3. RESULT AND DISCUSSION

3.1 PACT Results

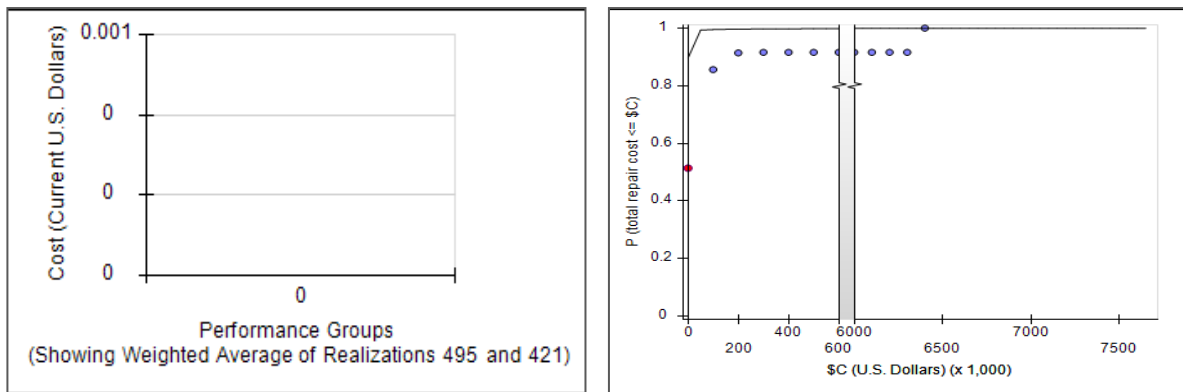
Performance Assessment Calculation Tool (PACT) is a computational tool developed under FEMA P-58 that quantifies earthquake-induced losses through a methodological framework combining both deterministic and probabilistic approaches. In this study, the building's losses are evaluated for eight different levels of earthquake intensity

3.1.1 Repair Cost

The cost of repairing a building to its former pre-earthquake condition or the cost of a destroyed building is known as the repair cost. The structure is said to need repair in case the cost is below a given percentage of the overall value of replacement; in other cases, it gets replaced. This portion in this study is assumed to be half of the total cost of replacement.

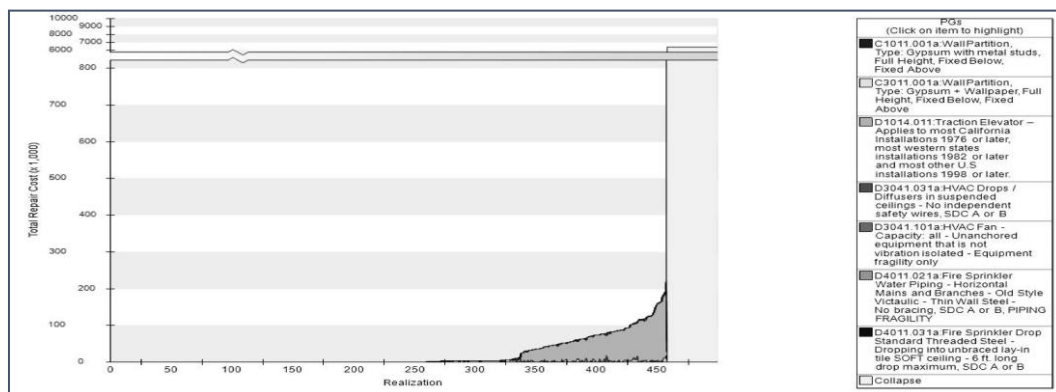
3.1.1.1 Repair Cost Analysis for Intensity 1 (0.13g)

For an intensity of 0.13g, the repair cost results are presented in the following Figure 2.



(a) Repair cost distribution for performance groups

(b) Repair cost probability distribution



(c) Graphical representation of performance group contributors to repair cost

Figure 2: Graphical representation of repair cost analysis for intensity 1 (0.13g)

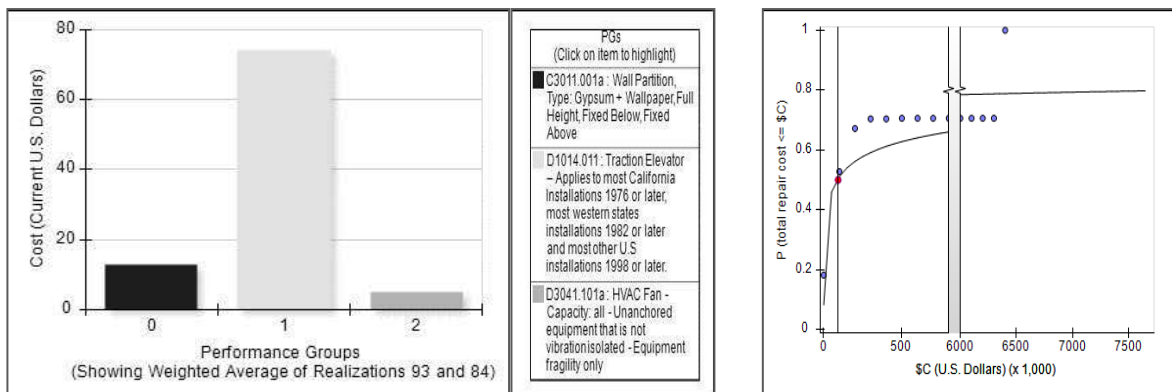
Figure 2 (b) shows that no repair cost is required up to a median value of 0.514, indicating that the building remains undamaged before this threshold. Hence, no performance group contributes to the repair cost as seen in Figure 2 (a). The graphical representation of performance group contributors in Figure 2 (c) indicates that collapse occurred for realizations 431–500, while realizations 0–430 did not collapse, confirming that under this intensity level, the structure remains safe and does not require any repair before reaching the threshold response.

3.1.1.2 Repair Cost Analysis for Intensity 2-7 (0.14-0.19g)

Likewise, following the analysis of results on intensity levels 2 to 7 (0.14g to 0.19g), it can be seen that the cost of repair also rises gradually with the increase in the intensity of the ground motion. The actual cost at 0.14g (intensity 2) was approximately BDT 1.15 million dollars (\$13,541), which is approximately 0.21% of the total cost of replacement, principally as a result of light damage in interior walls and elevator parts. When the intensity went to 0.15g (intensity 3), the repair cost marginally increased to about BDT 1.21 million (\$14,286) which is equivalent to 0.22% of the entire building replacement cost. When the intensity was 0.16g (intensity 4), the cost of repair was almost BDT 3.10 million (\$36,538), comprising 0.57% of the total replacement value. In the case of 0.17g (intensity 5), the demand for repair was higher; costs amounted to approximately BDT 4.06 million (\$47,849), which is 0.75% of the total replacement cost of the building. At 0.18g (intensity 6), the cost of repair was about BDT 5.52 million (\$65,053), which is 1.02% of the total replacement cost of the building. Lastly, with the intensity of 0.19g (intensity 7), the cost of repair increased even more to approximately BDT 5.64 million (\$66,474) or 1.04% of the replacement price.

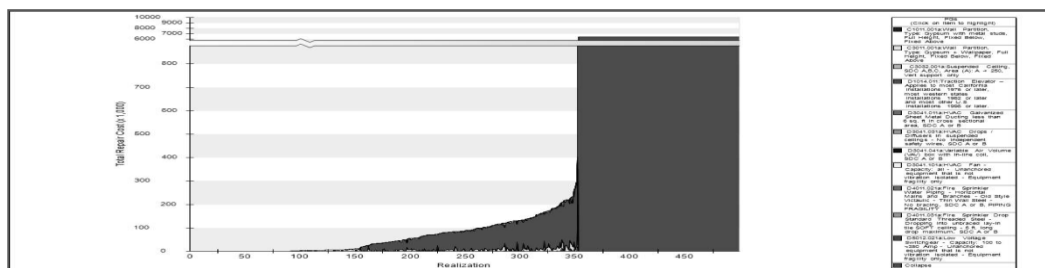
3.1.1.3 Repair Cost Analysis for Intensity 8 (0.2g)

For an intensity of 0.2g, the repair cost distribution and performance group contributions are presented in the following Figure 3.



(a) Distribution of repair costs among performance groups

(b) Repair cost probability distribution



(c) Graphical representation of performance group contributors to repair cost

Figure 3: Graphical representation of repair cost analysis for intensity 8 (0.20g)

Figure 3 (b) indicates that a repair value of BDT 7.8 million (\$91907) would be needed at a non-exceedance probability of 0.5, indicating a value of 1.44% of the entire building replacement cost. More than this point, it is more cost-effective to replace than repair. According to Figure 3 (a), the performance groups C3011.001a (Wall Partition), D1014.011 (Traction Elevator), and D3041.101a (HVAC Fan) are the most important in terms of the total repair price. The performance analysis of performance groups, Figure 3 (c), indicates that collapse has occurred in the realizations 326-500, but realizations 0-325 do not collapse, indicating that significant damage only starts above this threshold value.

Figure 4 shows the time-based results (stacked area) and loss area charts modified according to the Mean Annual Frequency of Exceedance (MAFE) of the repair cost in regard to the obtained results.

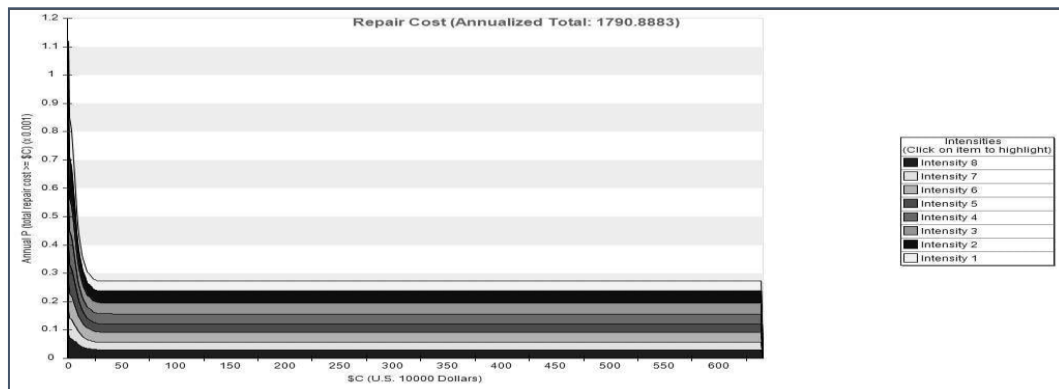


Figure 4: Time-based result

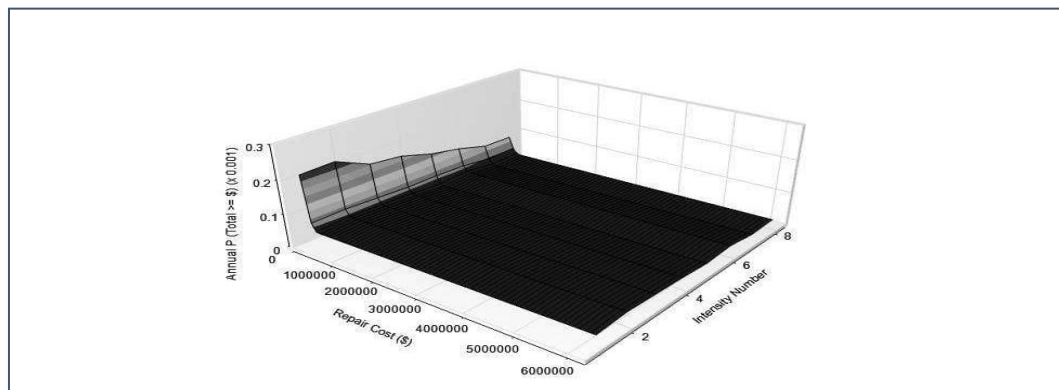


Figure 5: Loss area chart

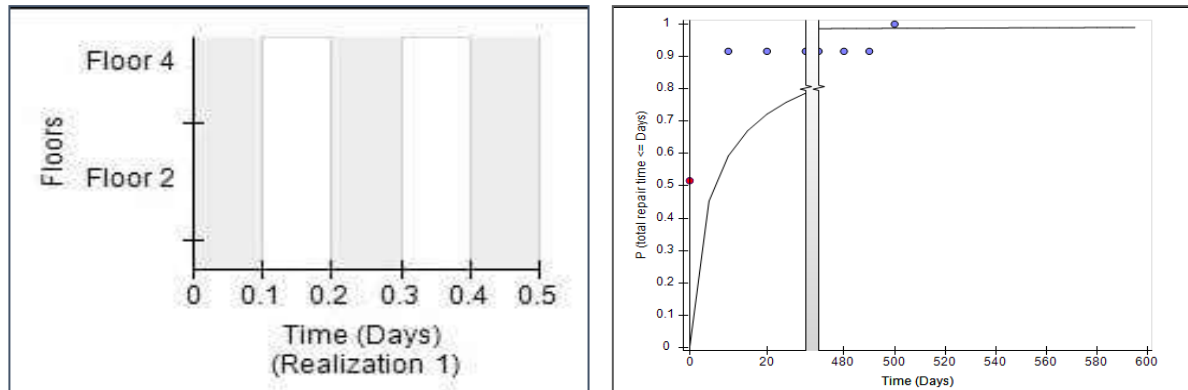
The probability of collapse of the building under the analysis, as calculated annually, is 0.024%, and the probability of total loss caused by residual drift is 0, which shows that the building is resilient to earthquakes.

3.1.2 Repair Time

Repair time is the duration required to restore a damaged building to its original condition, excluding the time needed for design, approval, funding, contractor mobilization, and project completion. The damaged components require a specific time for replacement. In this study, parallel repair time is considered, meaning all floors are repaired simultaneously.

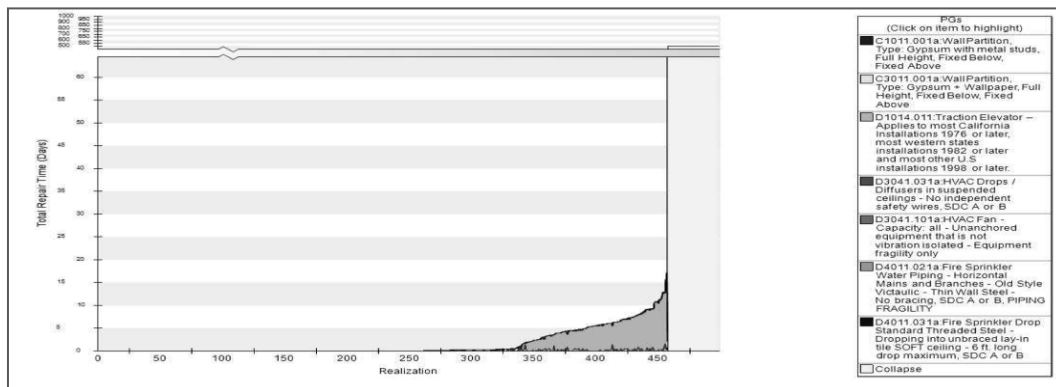
3.1.2.1 Repair Time Analysis for Intensity 1 (0.13g)

For an intensity of 0.13g (intensity 1), the repair time results are presented in Figure 6. Figure 6(b) represents that no repair time is required up to a median value of 0.516, indicating that the building remains undamaged before this threshold. Hence, no performance group contributes to the repair time as seen in Figure 6(a). The graphical representation of contributors in Figure 6(c) indicates that collapse occurred for realizations 451-500, while realizations 0-450 did not collapse, confirming that under this intensity level, the structure remains safe and does not require any repair time before reaching the threshold response.



(a) Distribution of repair time among performance groups

(b) Repair time probability distribution



(c) Graphical representation of performance group contributors to repair time

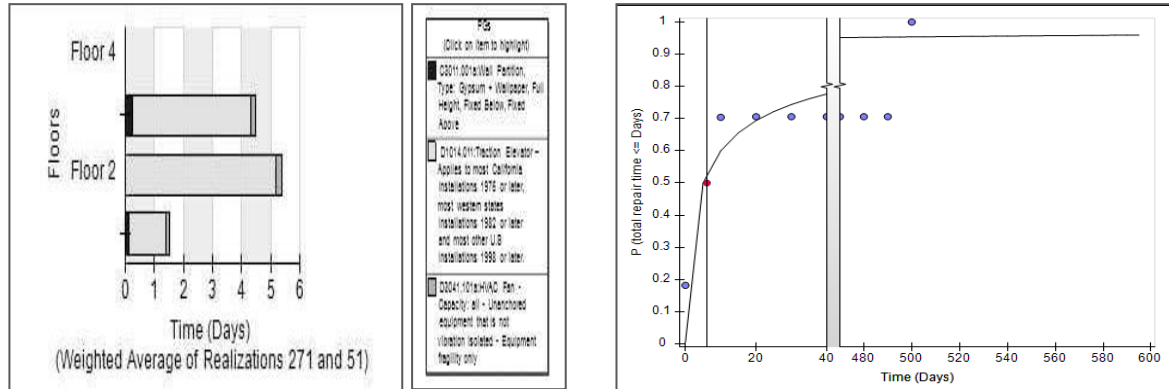
Figure 6: Graphical representation of repair time analysis for intensity 1 (0.13g)

3.1.2.2 Repair Cost Analysis for Intensity 2-7 (0.14-0.19g)

Similarly, after analyzing the results for intensity levels 2 to 7 (0.14g to 0.19g), it is observed that the repair time gradually increases with the rise in ground motion intensity. At 0.14g (intensity 2), the required repair time was 1.2 days, reflecting the building's high resilience with only minor non-structural damage. At 0.14g (intensity 3), the downtime slightly increased to 1.21 days, due to small cracks and localized damage in interior partitions and mechanical components. For 0.16g (intensity 4), the repair time rose to 3.05 days, showing more visible non-structural distress. At 0.17g (intensity 5), downtime reached 3.42 days, caused by increased damage. For 0.18g (intensity 6), the building required 4.92 days for full repair, mainly due to extended replacement of interior finishes, partitions, and elevator machinery. Finally, at 0.19g (intensity 7), the total repair time increased to 4.64 days, reflecting moderate damage. Despite the rising downtime, the structure remained within repairable limits and maintained high seismic resilience throughout these intensity levels.

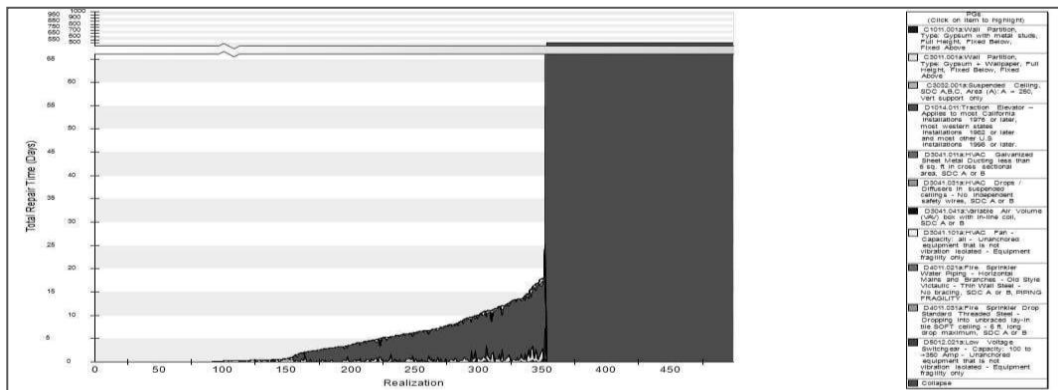
3.1.2.3 Repair time Analysis for Intensity 8 (0.20g)

For an intensity of 0.2g, the repair time results are presented in Figure 7. Figure 7(a) presents that the building requires a repair time of 6.1 days up to a non-exceedance probability of 0.5, indicating that the structure can be restored within a short duration, demonstrating high resilience.



(a) Distribution of repair time among performance groups

(b) Repair time probability distribution



(c) Graphical representation of performance group contributors to repair time

Figure 7: Graphical representation of repair time analysis for intensity 8 (0.20g)

The performance groups that contribute most to the repair time are elevator systems (56%) and ventilation equipment (30%), as shown in Figure 7(b). The repair activity distribution across different floors and the probability plots justify this observation. The graphical representation in Figure 7(c) shows that collapse occurred for realizations 331-500, while realizations 0-330 remained undamaged, confirming that under this intensity level, the structure sustains repairable damage and can be restored efficiently within the stated downtime.

Time-based results (stacked area) and loss area charts adjusted based on the mean annual frequency of exceedance (MAFE) for repair time based on the obtained results are shown below in Figures 8 and 9.

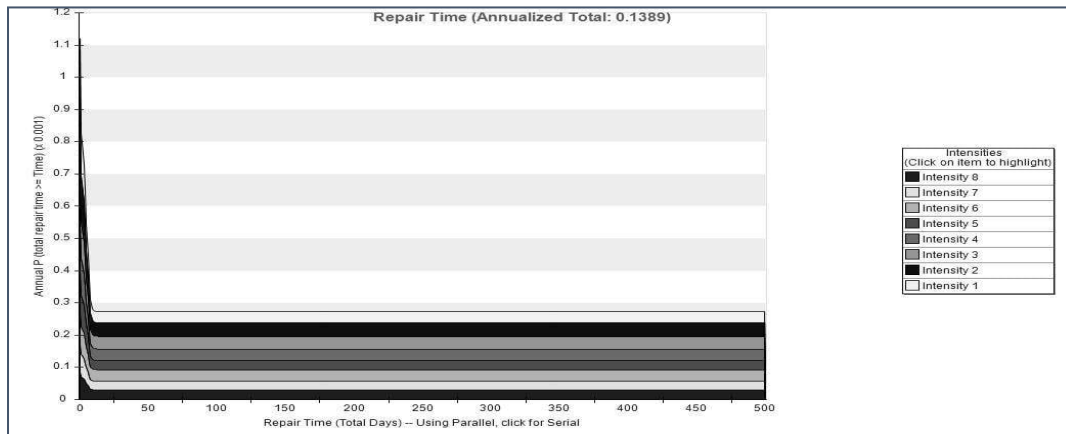


Figure 8: Time-based result

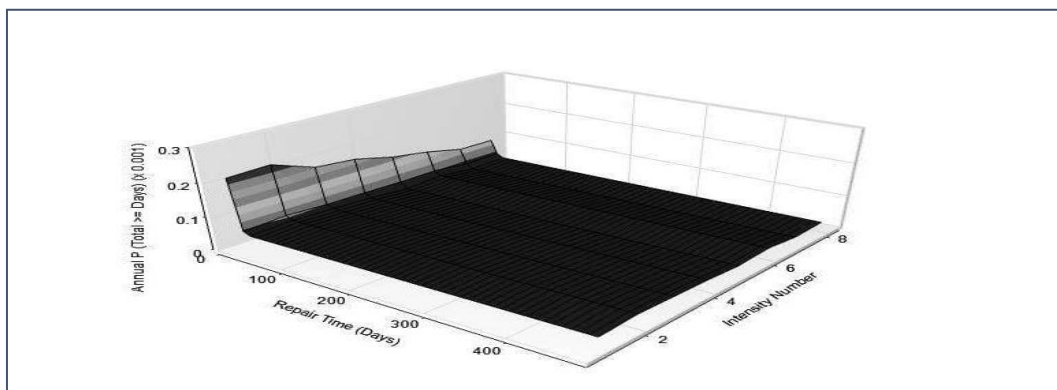


Figure 9: Loss area chart

4. CONCLUSION

At the lowest seismic intensity of 0.13g, the building exhibited no observable damage, resulting in zero repair cost and downtime, with no associated casualties or environmental impacts. When the intensity increased, the extent of both structural and non-structural damage rose progressively, leading to higher repair costs and longer restoration durations. The highest level of damage occurred at 0.2g, where the repair cost was estimated at BDT 7.8 million (USD 91,907), representing only 1.44% of the total replacement cost, while the corresponding downtime was limited to 6.1 days. These results exhibit the building's high seismic resilience and its ability to rapidly regain operational functionality following an earthquake. Time-based assessment further indicated an annualized repair cost of only USD 1790.9, reflecting minimal long-term maintenance demand. The structural response remained predominantly elastic, confirming that the building is repairable up to a residual drift ratio of 1.25%, thereby ensuring efficient post-earthquake recovery with negligible economic and functional disruptions.

DECLARATION OF USE OF AI

We hereby declare that artificial intelligence (AI) tools were used in this research work solely as a supportive aid to enhance clarity, language quality, and grammatical checking of the manuscript. The core ideas, analysis, methodology, interpretation of results, and conclusions are entirely our own. All academic judgments, originality, and responsibility for the content rest fully with the authors. The use of AI was conducted ethically and in compliance with academic integrity and institutional guidelines.

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