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Applying ATC FEMA P-58 Approach and Nonlinear History Analysis to Estimate Economic and Social Losses due Earthquake for Reinforced Concrete Building in Iraq

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Abstract:- This research study investigates the estimated economic and social losses of reinforced concrete moment resisting frame building by using FEMA P-58, the next-generation Seismic Performance Assessment methodology for Buildings developed by American Applied Technology Council (ATC), in 2012). Dynamic time history, using twelve ground motion records from near and far-fault regions, has been used to perform the seismic analysis of the considered model configurations. The typical buildings are vulnerable to earthquake damage, therefore it could be considered that the economic and social losses are a function of damage of the buildings. Damages vary according to ability of building to resist ground motion and other aspects such as geographic differences of ground motion. In the current paper, the probabilistic approach FEMA P-58 with nonlinear time history analysis applied to calculate the consequences of the seismic activities, these consequences are presented by repair time, repair cost and casualties. PACT (Performance Assessment Calculation Tool) is used to calculate performance or the losses, these are repair cost, repair time and casualties, PACT is a main tool in FEMA P-58 methodology. The CSI Software ETABS is applied in this study for 3-D modeling and obtaining drift ratio. The building used as a case study is an educational reinforced concrete building in Al-Mustaqbal university college in Al-Hilla city, Babylon governorate.

***Keywords**:- FEMA P-58, PACT, Earthquake Loss Estimation, Time History Analysis, Ground Motion Selection, Residual Drift.*

I. INTRODUCTION

The performance objective of FEMA P-58 is based on the level of damage experienced by a building and the probable results of the damage including possible loss of occupancy, reconstruction the building or repair time, repair costs and fatalities & injuries or casualties.

Performance-Based Seismic Design (PBSD) concept is used by FEMA P-58 and it utilized several measures of performances that enable the decision makers to easily understood. FEMA P-58 is published in seven volumes including detailed procedure, explanations, data base and tools. It considered not just structural and nonstructural aspects, but also occupancy of the building and environmental factors as well.

The methodology has very useful tools that enable clear implementation of it, the main tool that used in is PACT (Performance Assessment Calculation Tool). It helps users for accumulation of building performance models and it linked with the Monte Carlo analysis to carry out recurring calculations. It provides models for ten different types of buildings depending on its occupancy. These include Education (k-12): High Schools, healthcare, hospitality, residential buildings. PACT uses NISTIR 6389 classification systems to identify and categorized fragility curve according to the types of component, this based on the UNIFORMAT II classification system and it has six main categories and four sub levels.

Volume one in FEMA P-58 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 methodology has limitations and uncertainties, the main limitations that it takes into account the losses within the building without consider the likelihood kinds of losses such as power, water and sewage services, in addition the damages and casualties outside the building when damage leads to debris that falls in the surrounding area are neglected, finally it not takes into account the probable significant impacts such us initiation of fire and release of 1 dangerous materials.

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The methodology classified the structural and nonstructural components in main two groups, these are fragility group which are present of components which have similar construction characteristics, including details of construction, details of manufacture, and installation techniques; potential modes of damage; probability of incurring these damage modes, when subjected to earthquake demands and potential consequences resulting from damage.

Performance groups are a sub-categorization of fragility groups. A performance group is a subset of fragility group components that are subjected to the same earthquake demands (e.g., story drift, floor acceleration, or velocity, in a particular direction, at a particular floor level).

The collapse fragility function which expresses the possibility of collapse the building, in one or modes, as a function ground motion intensity. The developing of this function is performing once the building performance model has been developed and input into PACT.

Collapse fragility functions include definition of the median spectral response acceleration at the building's effective fundamental period Ŝa (T) and a dispersion β associated with collapse, the possible collapse modes (expressed as a percentage of each floor area impacted by collapse and the number of stories involved in the collapse), the probability of each collapse mode given that collapse occurs, and the probability of incurring serious injuries and fatalities in an area of collapse.

II. GROUND MOTIONS SELECTION

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 (1996) describes this as a four-step process enumerated below and depicted in Figure 3.

The selection of ground motion records are based on 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. PGA	
max PGA1	0.1461
max PGA2	0.17565
max PGA3	0.1936
max PGA4	0.1948
max PGA5	0.24419
max PGA6	0.27555
max PGA7	0.3152
max PGA8	0.349
max PGA9	0.3513
max PGA10	0.3674
max PGA11	0.4188
max PGA12	0.6977

Table 1: PGA of the selected Ground motion records

III. 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 4, 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 seize 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.

Figures 1, 2 and 3 shows pictures and location of the building, floor plans and elevation view and distribution of beams and columns respectively.

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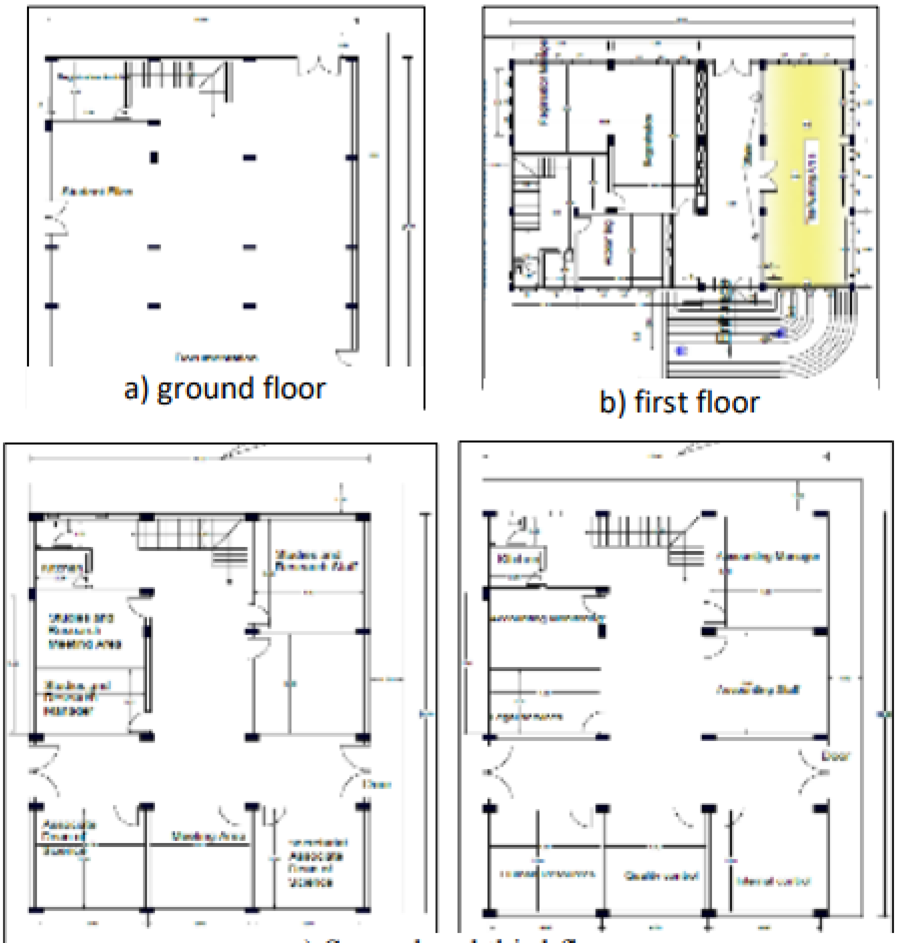
Fig 1: Case study building and its location n MUC



c) Second and third floor

Fig 2: Plans of the floors

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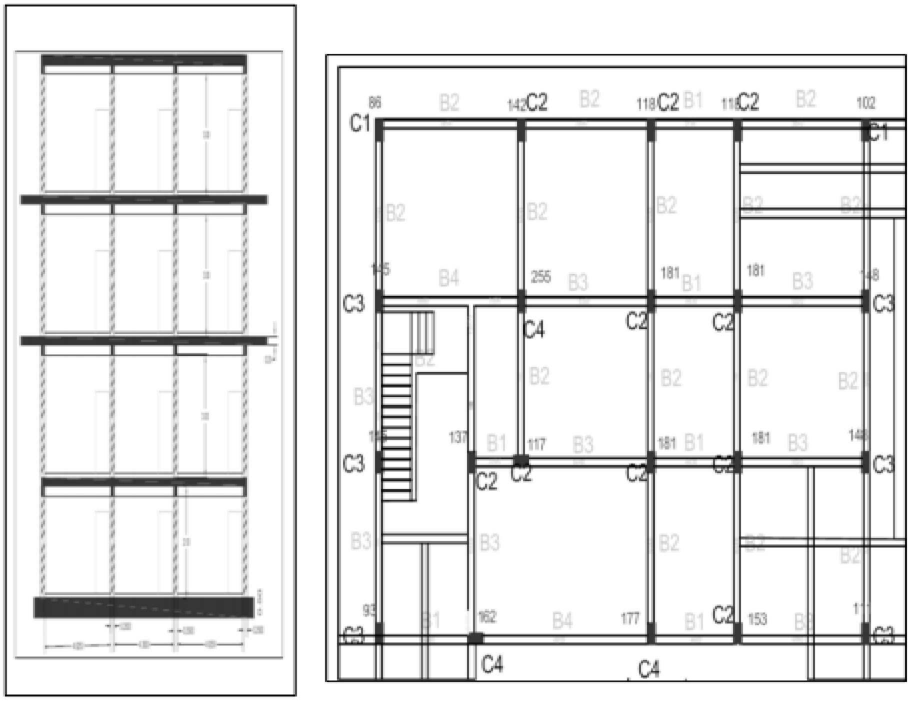

Fig 3: Side view and distribution of beams and columns

IV. PROJECT INFORMATION

The following input data in table 2 of the project are given in PACT software. And its also includes declarations of the parameters used in project information.

Project ID		Registration Building
Building description		Registration and Administration building in Al-Mustaqbal University College Located in Al-Hilla, Babylon
Client		Al-Mustaqbal University College
Engineer		Ali Majdi
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 2: General Project information of the building

V. BUILDING INFO (PACT)

The general information of the building such as spans, bays stories, areas, heights and occupancy are given in table 3. The details of the cost for construct the building according to Iraqi actual market are given in tables 4. Table 5 consists of the parameters used in building info that given in PACT software.

Description			Quantity		Dimensions (m)
Spans (total)			4		20
Bays (total)			3		15
Stories			4		3
Ground level			1		2.5
Floors area, height and occupancy					
No	Floor	Area (m^2)		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	

Table 3: General information of the building

Cost USD/m^2	420
Core and Shell replacement per USD/ m^2	280
Total replacement cost USD	579600
Core and Shell replacement USD	386400
Replacement time (days)	240
Maximum Workers per Square meter	0.028580

Table 4: Costs and other details that required 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

Table 5: Parameters used in building info that given in PACT

VI. POPULATION MODEL

FEMA P-58 provide data base of the population models according to the occupancy of the building and enable the user to modify it as the project requirements. For the case study building the results of daily and monthly population are illustrated in figures 4 and 5 respectively.

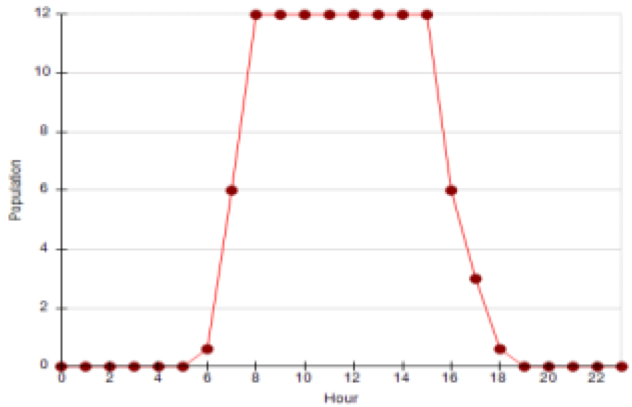

Fig 4: Daily population char

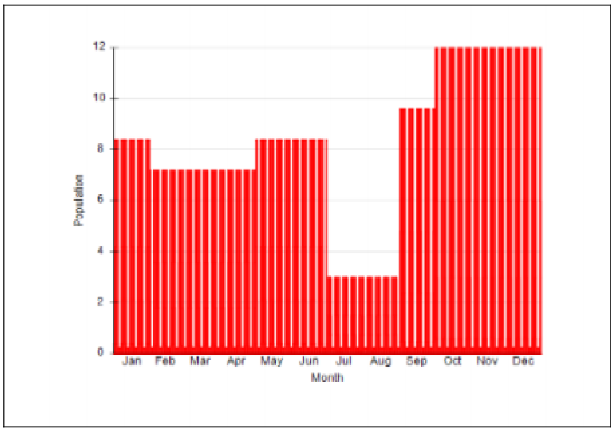

Fig 5 Monthly population chart

VII. STRUCTURAL ANALYSIS RESULTS

In this step, the required parameters in order to developing collapse fragilities are given as follows:

Parameter	Value
Number of demand vector	12
Number of Realisation	200
Non-Dir. factor	1.2
Modelling dispersion β_m	0.354
Construction dispersion β_c	0.25
For collapse	
Direction	1 and 2
Demand type	Drift ratio

Table 5: parameters required for time history analysis

The Modal Dispersion βm could be obtained from the following equation:

$$\beta_m = \sqrt{\beta_c^{\ 2} + \beta_q^{\ 2}}$$

Where:
βc is dispersion of construction quality
Bq: is dispersion of analytical model quality.
βm : should not be taken greater than 0.5.

The values of the above parameters could be obtained from tables 3-1 and 3-2 in volume two of FEMA P-58 that describe the implementation of the methodology. The following input values that given in PACT are calculated by following the procedure described in volume one and two of FEMA P-58, The following results nonlinear analysis are obtained for all eight target acceleration response spectra by following the procedure described in FEMA P-58 and given in PACT software in order to calculate the performance of repair costs, repair time, casualties, injuries.

A. *Residual Drift:*

The residual drift (RD) fragility function is a lognormal function representing the probability that the building experiences irreparable residual drift at each intensity. The residual drift and dispersion defining the function were calculated and it illustrated in figure 6.

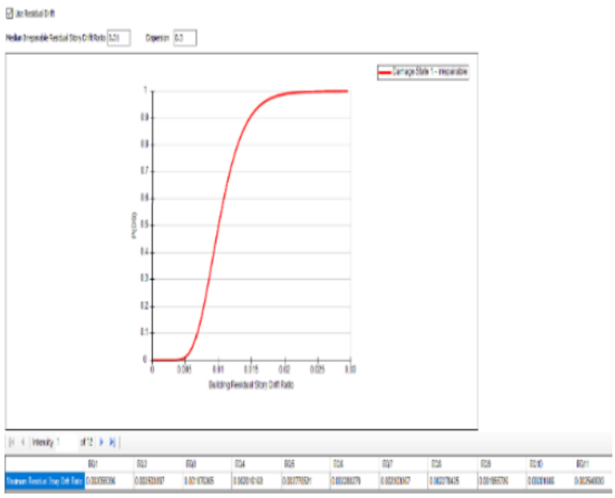

Fig 6: Residual drift

B. *Hazard curve*

The hazard curve for each building was defined using the USGS Hazard Curve Application tool imbedded into PACT. Figure 7 shows the hazard curve that obtained from PACT for the case study in this paper.

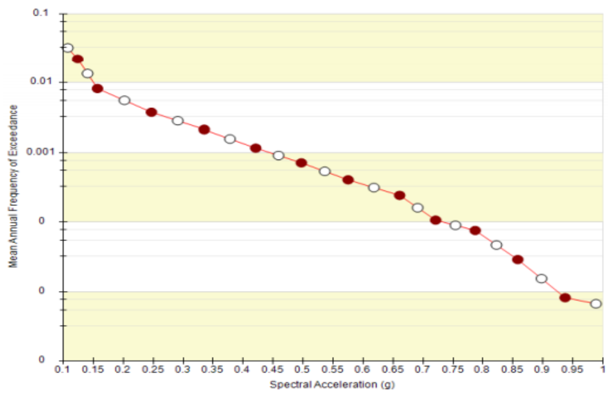

Fig 7: Hazard Curve

VIII. REPAIR COST

The figures 8, 9 and 10 illustrated annualized total repair cost, total repair cost of realizations for nonlinear analysis and repair cost curves respectively.

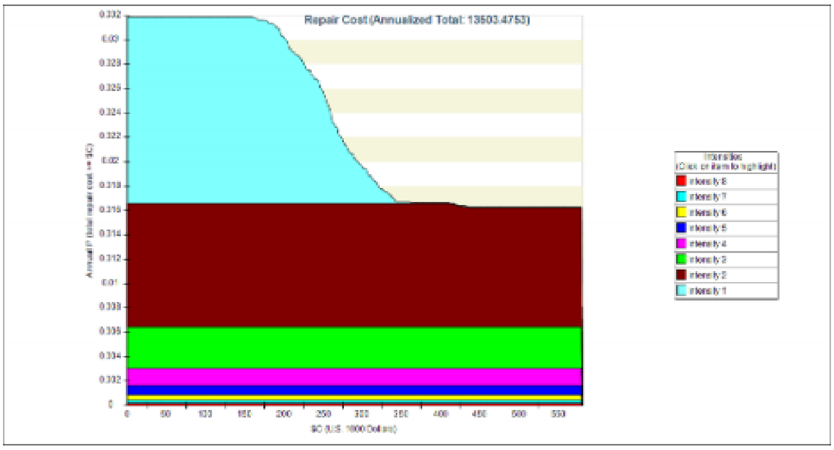

Fig 8: Annualized total repair cost

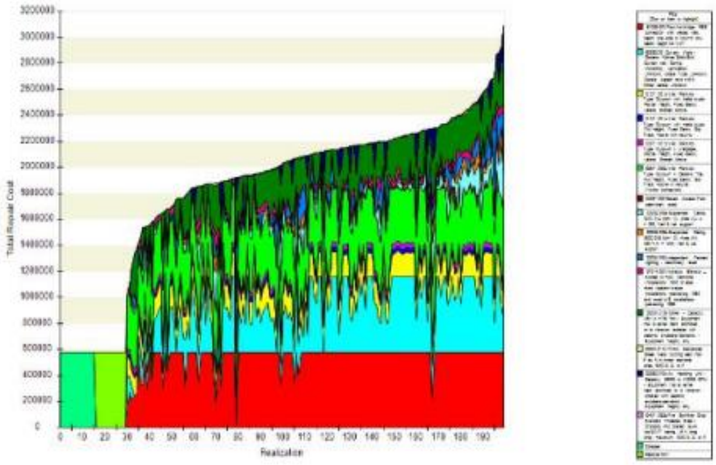

Fig 9: Total repair cost of realizations

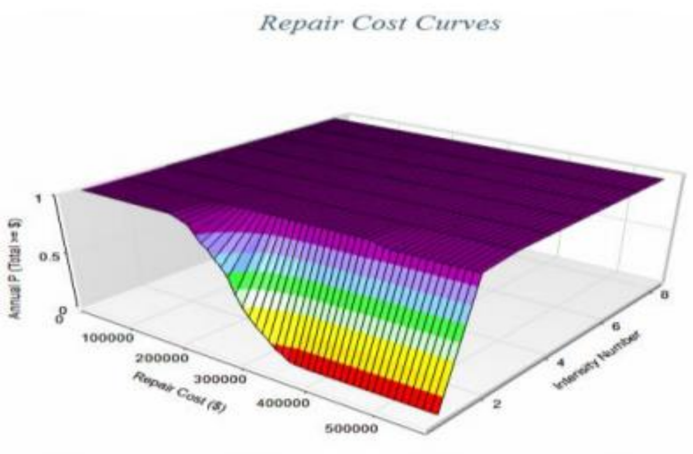

Fig 10: Repair cost curves

Figure 11 shows the estimated repair cost for each intensity;

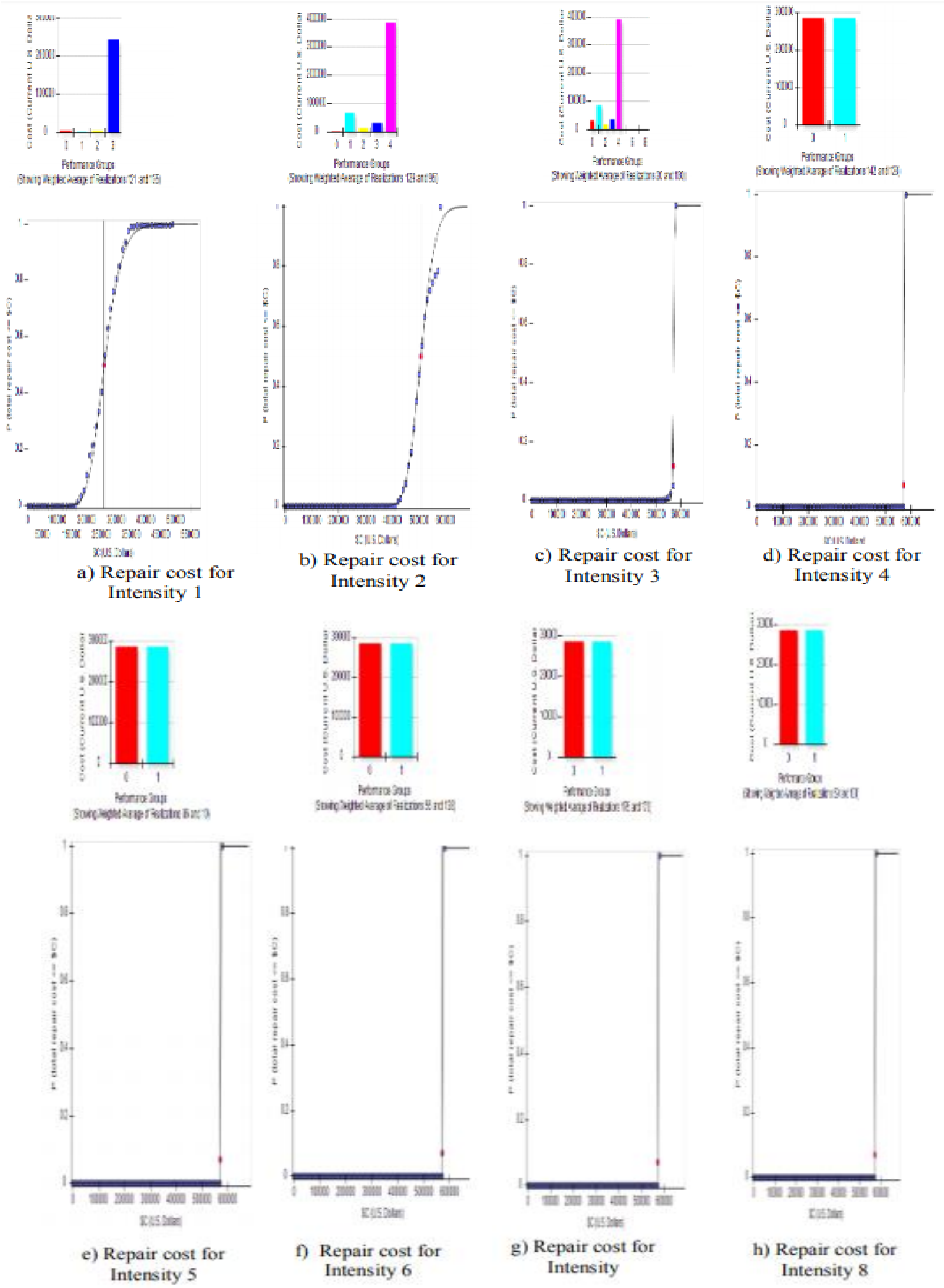

Fig 11: Repair cost for each intensity

IX. REPAIR TIME

The figures 12, 13 and 14 illustrated annualized total repair time, total repair time of realizations for and repair time curves respectively.

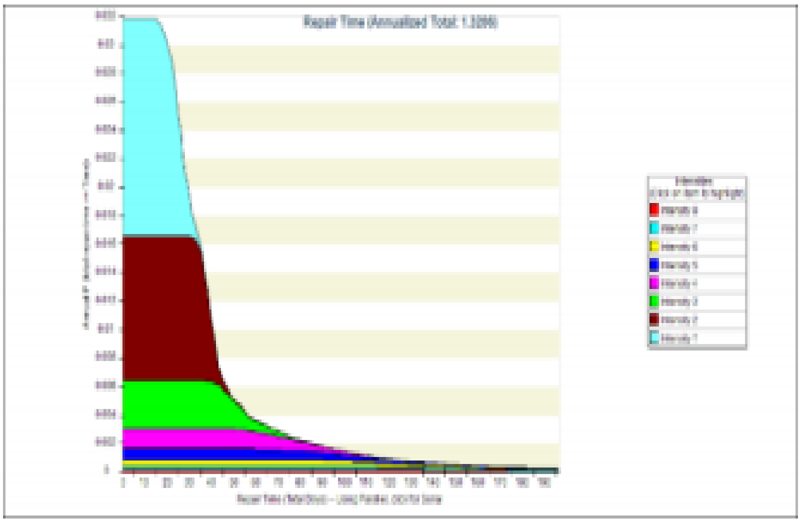

Fig 12 :Annualized total repair time

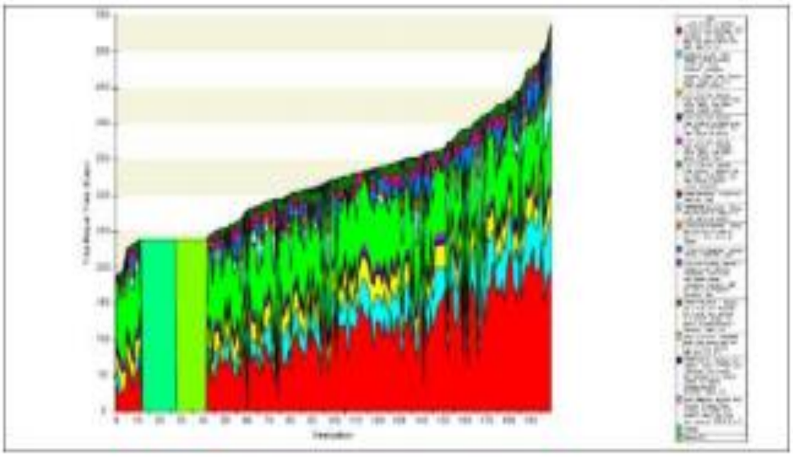

Fig 13: Repair time according to realizations

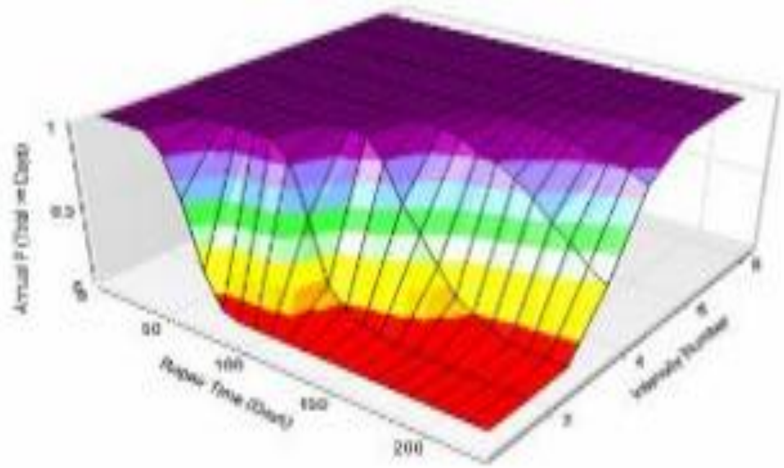

Fig 14: Repair time curves

Figure 15 shows the estimated repair time for each intensity;

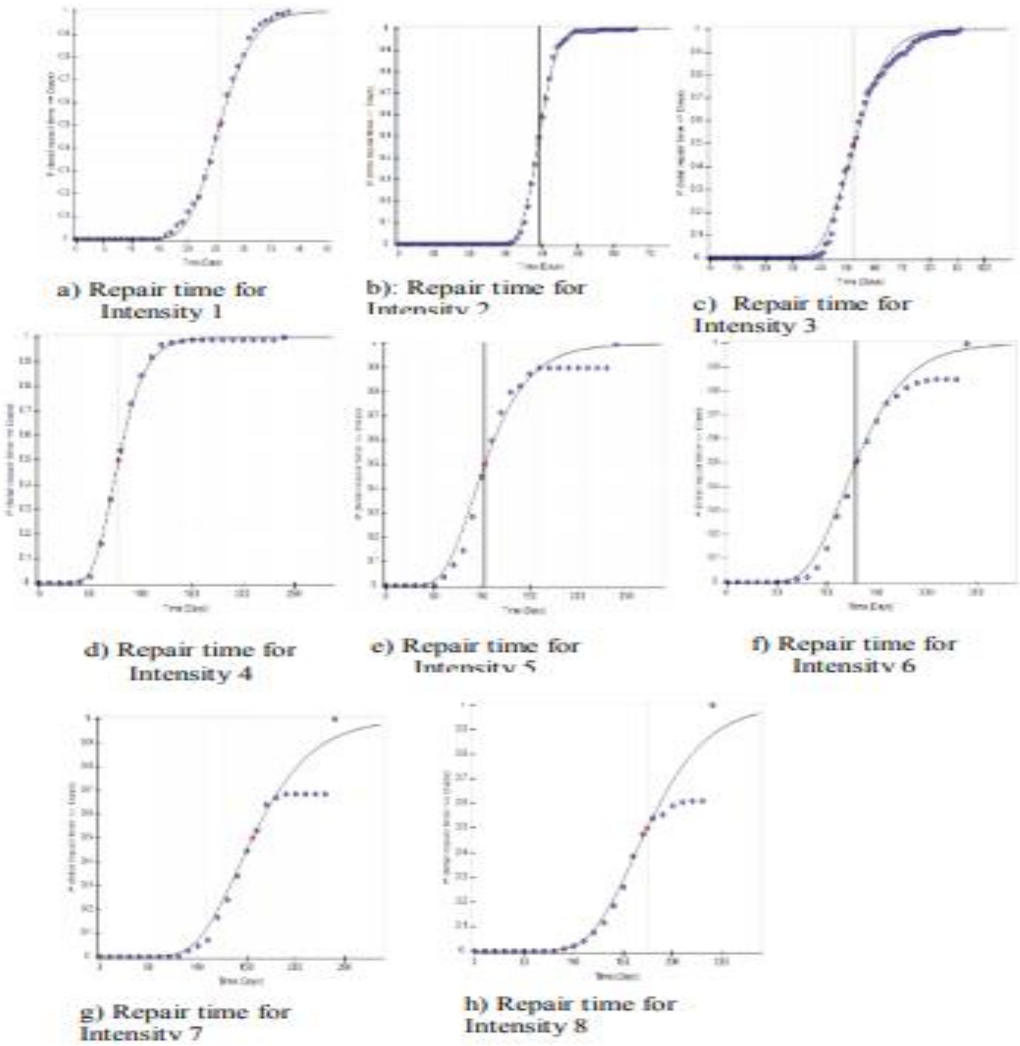

Fig 15: Estimated repair time for each intensity

X. CASUALTIES

The figures 16 through 22 shows the outcomes of estimated casualties including fatalities and injuries in different type of presentation.

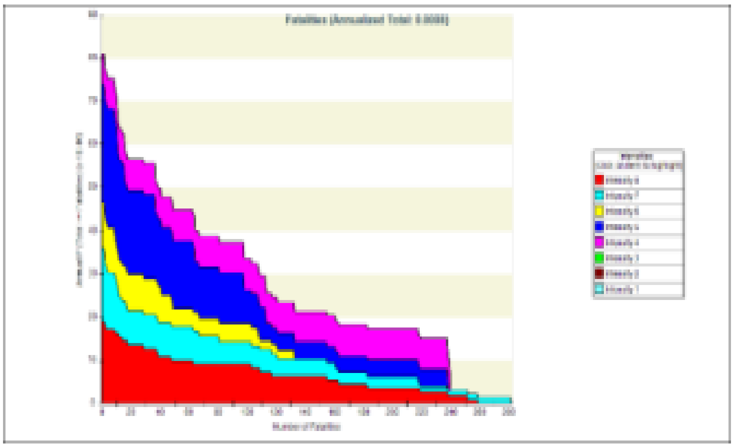

Fig 16: Annualized total fatalities

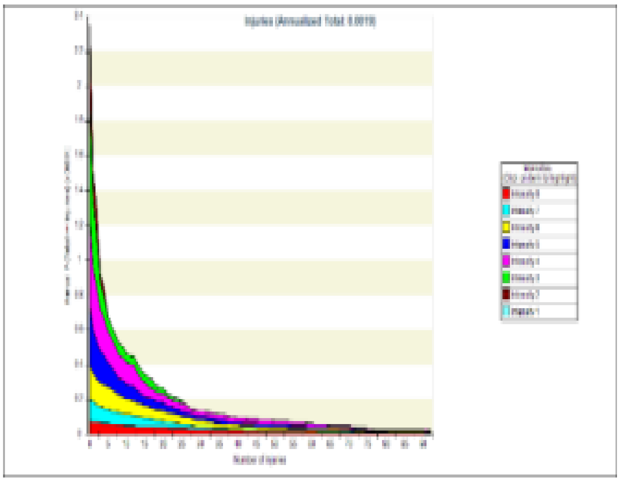

Fig 17: Annualized total injuries

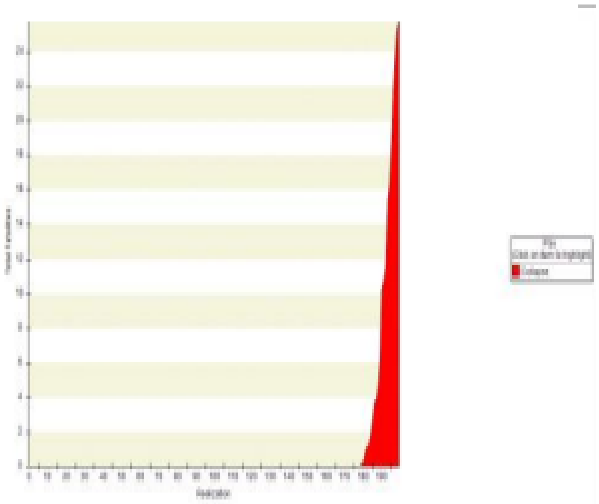

Fig 18: Total fatalities according to realizations

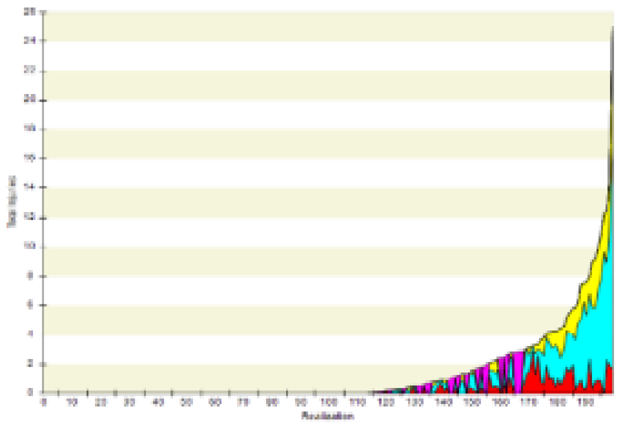

Fig 19: Total injuries according to realizations

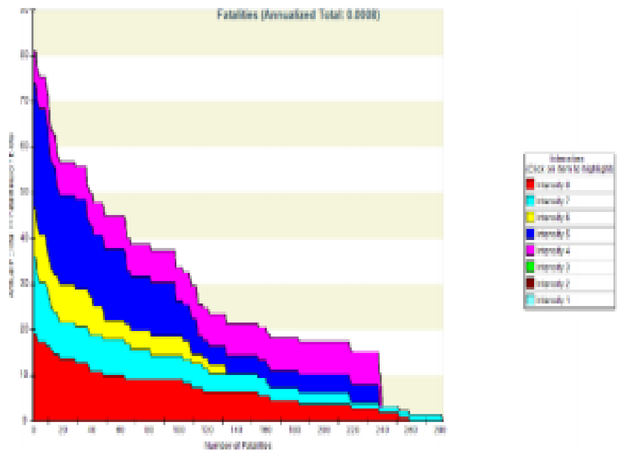

Fig 20: Fatality curves

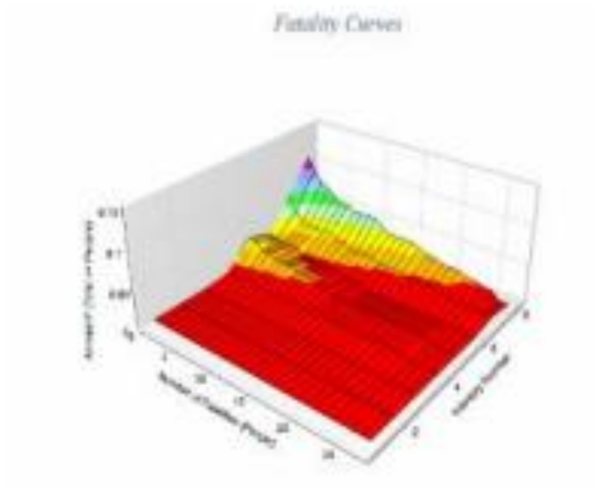

Fig 21 :3D- Fatality curves

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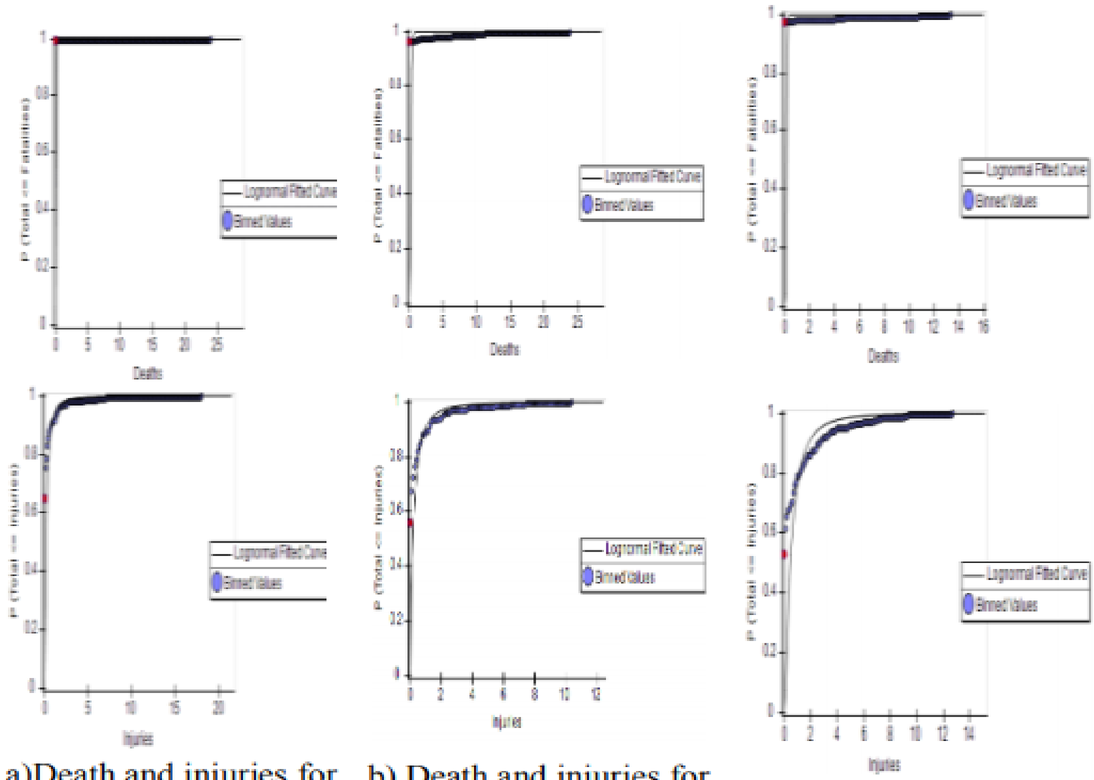
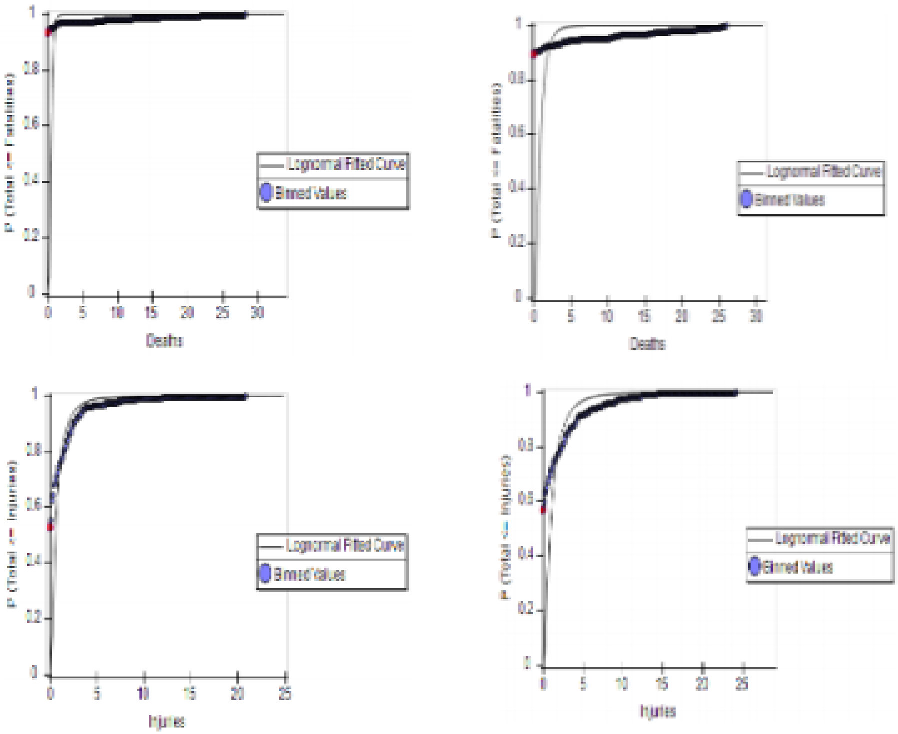


a)Death and injuries for Intensity 4

b) Death and injuries for Intensity 5

c)Death and injuries for Intensity 6



e) Death and injuries for Intensity 7

f) Death and injuries for Intensity 8

Fig 22: Estimated Death and injuries for Intensity 4,5,6,7 and 8

XI. 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), unsafe placards as well as environmental aspects like carbon emissions and embodied energy. In this paper estimated repair cost, repair time and casualties are performed using time history analysis, the computation of unsafe placards and environmental aspects is out of scope of this study.

Applying of PACT tool, the freeware that used in the earthquake-related loss estimation through performance based probability estimates is done to calculate the consequences of the damages due earthquake shaking for twelve peak ground acceleration records. 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. 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.

As mentioned before, time history analysis is performed in this study, 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 200 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 was about 13503 USD.
- Repair time: by using similar approach in repair cost according to worst case of realizations, the a)Death and injuries for Intensity 4 b) Death and injuries for Intensity 5 c)Death and injuries for Intensity 6 e) Death and injuries for Intensity 7 f) Death and injuries for Intensity 8 Figure 22: Estimated Death and injuries for Intensity 4,5,6,7 and 8 7 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 was 1.32 days.
- Casualties: the worst case of intensity 8 was about 27 deaths and 24 injuries, the annualized fatalities 0.0008.

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