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Performance-Based Design for Healthcare Facilities

Wilfrid Gbenankpon Djima, Abdullah Can Zulfikar and Cüneyt Tüzün

Abstract

Healthcare buildings are one of the most critical facilities in any country for their important roles just after an earthquake. In this context, working on the resistance of healthcare facilities against earthquake is of great importance for a probable future earthquake. However, in today's world, in either private or governmental agencies, buildings earthquake resistant design is not within the primary criteria such as social facilities and architectural details need for the residents. While the structural system in any building are often considered the most important in the performance, it represent approximately only 20% of the total building cost. Consequently, structural engineers should look the seismic performance in an extensive context, looking at all the systems of the building than just the damage to structural items and life-safety. So to response to this issue, a next generation of seismic performance-based design methodology and tools have been outlined in the FEMAP58 documents to allow engineers to query out the seismic performance of an entire building in terms of future life loss, facility repair cost and repair time and that we summarized and applied in this chapter for a six (6) story special moment frame healthcare building.

Keywords: Seismic Performance Assessment, Performance-Based Design, Earthquake Loss Assessment, Healthcare Facilities

1. Introduction

Many essential facilities such as hospital buildings are in high seismic zones throughout the world, and some of them were designed and built at a time without sufficient earthquake knowledge nor performed and are consequently susceptible to earthquakes.

The typical building design process is not performance-based. In the typical process, design professionals select, proportion, and detail building components to satisfy prescriptive criteria contained within the building code. Many of these criteria were developed with the intent to provide some level of seismic performance. However, the intended performance is often not obvious, and the actual ability of the resulting designs to provide the intended performance is seldom evaluated or understood.

Therefore, it has been noted in this period generation procedures some limitations in the: accuracy and reliability of available analytical procedures in predicting actual building response, the level of conservatism underlying the acceptance criteria, the inability to reliably and economically apply performance-based procedures to the design of new buildings and the need for alternative ways of communicating performance to stakeholders that is more meaningful and useful for decision-making

purposes [1]. Other limitations in the performance based-design procedure were also the non-account of non-structural equipment's very important economically but also regarding their behavior during an earthquake. For example, 50% of the injuries and 3% of the deaths in the 1999 Kocaeli Mw7.4 earthquake were caused by non-structural elements and 30% of the losses were found to be furniture, white goods, electronic equipment and other valuable items [2, 3]. In addition, in the 1989 Loma Prieta and 1994 Northridge earthquakes, 10 large hospitals were evacuated or had to be closed due to damage caused by non-structural elements (plumbing) [4, 5].

So, to fulfill the promise of performance-based engineering, FEMA started the development of next-generation performance-based design procedures to address the above limitations. By result, it has been finalized the FEMAP58 [1, 6, 7] guideline to count not only the structural damage but also non-structural damage in the performance assessment. Specifically, others research also focused on the study of the non-structural seismic behavior and assessment and for hospital building [8, 9].

This paper provides practical guidance principally on implementing the seismic performance assessment methodology set forth in FEMA P-58-1 and the guidelines for Seismic performance assessment of buildings, [1, 10], to assess the seismic performance of individual buildings based on their unique site with structural, non-structural, and occupancy characteristics, expressed in terms of the probability of incurring casualties, repair and replacement costs, repair time. The FEMA-P58-2 Implementation Guide [2] contains examples illustrating the performance assessment process, including selected calculation and data generation procedures, by using the selected electronic materials provided in Volume 3 – Supporting Electronic Materials and Background Documentation [7, 11].

This study does a nonlinear static analysis for an existing typical six (6) story hospital building following the Turkish Building Earthquake Code [6] and the ASCE 41 [9] provisions as well as ACI-318 for reinforced concrete and masonry structure [7, 8], aiming to provide a more realistic estimate of the seismic demands and economic-effective assessment strategy. The PACT (Performance Assessment Calculation Tool) is used in the analysis of the sample hospital building [12–14].

Many financial institutions including lenders, investment funds, and insurers use Probable Maximum Loss (PML), Scenario Expected Loss (SEL), and Scenario Upper Loss (SUL) as preferred performance measures. These performance measures are quantitative statements of probable building repair cost, typically expressed as a percentage of building replacement value [1]. Some building owners, developers, and tenants have also relied on these performance measures to quantify seismic performance. In this regard, it is believed that this study will be a sample study for evaluation of seismic performance of a typical hospital building and its probable consequences.

2. Building description

The building is a six-stories healthcare building with a moment frame structure that has plan dimensions of 36,57 m by 54,86 m (see **Figures 1** and **2**). Floor-to-floor height is 4.6 m at the lower story and 4 m at other stories (see **Figure 3**). The structure has reinforced concrete special moment frames around the building perimeter. The floors and roof are two-way post tensioned flat slabs (0.2 m thick) supported by the perimeter moment frame and interior reinforced concrete columns on a 9.14 m by 9.14 m grid (see **Figures 4** and **5**). When entering the building information into the PACT direction 1 is arbitrarily aligned with the North–South (Y) axis and direction 2 is aligned with the East–West (X) building axis.

Figure 1.
Architectural 2D view of the healthcare building.

Figure 2.
Architectural Façade view of the healthcare building.

Figure 3.
Floor plan of building.

Figure 4.
Typical elevation E-W view.

Figure 5.
3D view of the structural frame.

The building is designed and detailed according to the requirements of Turkish Building Codes 2018 [6, 8, 9]. Vulnerable non-structural building features include exterior glazing, gypsum board partitions, suspended acoustical ceilings, fire sprinkler system, traction elevator, concrete roof tiles on a perimeter mansard, hot and cold-water piping, and HVAC ducting.

3. Building performance model

The building performance model has been constructed in PACT by the following order:

- providing project information,
- building characteristics selecting fragility specifications and performance groups,
- identifying collapse fragility and collapse modes,
- and providing residual drift fragility

For this case study, information’s input is as follow (see PACT input in **Figures 6** and **7**):

- Number of Stories: 6.
- Total Replacement Cost: Estimated as $\$2500/\text{m}^2 \times 12960 \text{ m}^2$ or \$32,400,000.
- Replacement Time: Estimated as 825 days.
- Core and Shell Replacement Cost: Estimated as $\$1000/\text{m}^2 \times 12960 \text{ m}^2$ or \$12,960,000.
- Maximum Workers per Square Foot: Default value of 0.001 is used.

PACT Building Modeler - Paradox,LA Loss, Intensity (Tr=475yrs) *

File Edit Tools Help

Project Info Building Info Population Component Fragilities Performance Groups Collapse Fragility Structural Analysis Results Residual Drift Hazard Curve

Project ID: Paradox,LA Loss, Intensity (Tr=475yrs)

Building Description: Six (6) Story Reinforced Concrete SMF Frame, Healthcare Building, ASCE 7-05

Client: Sypo_2018

Engineer: Mr Wilfrid G. DJIMA

Cost Multipliers

Region Cost Multiplier: 1.00 Date Cost Multiplier: 1.00

All costs should be relative to 2011 national averages.

Solver Options

Solver Random Seed Value 5 (0 indicates use of new random seed value for each run)

Figure 6.
PACT project information tab.

PACT Building Modeler - Paradox,LA Loss, Intensity (Tr=475yrs) *

File Edit Tools Help

Project Info Building Info Population Component Fragilities Performance Groups Collapse Fragility Structural Analysis Results Residual Drift Hazard Curve

Number of Stories: 6

Total Replacement Cost (\$): 32,400,000 Replacement Time (days): 825.00 Total Loss Threshold (As Ratio of Total Replacement Cost)

Core and Shell Replacement Cost (\$): 12,960,000 Max Workers per sq. m.: 0.001 1

Most Typical Defaults

Floor Area (sq. m.): 2,090.00 Story Height (m.): 6

Floor Num	Floor Name	Story Height (m.):	Area (sq. m.):	Height Factor	Hazmat Factor	Occupancy Factor
1	Floor 1	4.60	2,090.00	1.08	1	2
2	Floor 2	4.00	2,090.00	1.08	1	2
3	Floor 3	4.00	2,090.00	1.08	1	2
4	Floor 4	4.00	2,090.00	1.08	1	2
5	Floor 5	4.00	2,090.00	1.08	1	2
6	Floor 6	4.00	2,090.00	1.08	1	2
7	Floor 2		2,090.00	1.08	1	2

Figure 7.
PACT building information t tab.

- Total Loss Threshold (as Ratio of Total Replacement Cost): Default value of 1.0 is used.
- Floor Area: 2090 m²
- Floor Height: 4 m Variation in floor height is input via the Floor Number drop down selector, which also permits input of non-typical floor areas.

Figures 8 and 9 show the PACT panel input for Population Modeling.

Figure 8.
PACT project population modeling tab graph.

Figure 9.
PACT healthcare population.

4. Structural components

4.1 Structural component fragility specification

The structural components are inputs based on the basic building characteristics previously described. The selection process proceeds progressively from foundations through super structure. The following information summarizes the structural components included in the performance assessment model.

For each floor, the number of special moment frame beam-column joints vulnerable to story drift in each building direction are entered for each of the pre-selected specifications. **Table 1** and **Figure 10** summarize the defining performance groups in PACT with A, B, C, D, E the building axes in X (2) direction and 1, 2, 3, 4, 5, 6, 7 in Y (1) direction. Input of the post-tensioned slab/column joint information is similarly inserted at each floor; however, these fragilities are input as non-directional. There are 15 joints per floor (**Table 2**).

4.2 Structural component performance group

The performance group definition process is repeated for each floor and for each direction (including non-directional) as shown in **Figures 11** and **12**. **Table 3** summarize the total number of performance group per floor.

Joint Location	Fragility Classification Number	Input Direction	Joint Location	Fragility Classification Number	Input Direction
A-1	B1041.002a	1	A-5	B1041.003b	2
A-2	B1041.002a	2	B-1	B1041.003b	1
A-6	B1041.002a	2	B-7	B1041.003b	1
A-7	B1041.002a	1	C-1	B1041.003b	1
E-1	B1041.002a	1	C-7	B1041.003b	1
E-2	B1041.002a	2	D-1	B1041.003b	1
E-6	B1041.002a	2	D-7	B1041.003b	1
E-7	B1041.002a	1	E-3	B1041.003b	2
A-3	B1041.003b	2	E-4	B1041.003b	2
A-4	B1041.003b	2	E-5	B1041.003b	2

Table 1.
Fragility group selections for the beam/column components.

Figure 10.
Illustration of reinforced concrete elements specification selections.

Fragility Classification Number	Direction	Number Per Floor
B1041.002a	1	4
B1041.002a	2	4
B1041.003b	1	6
B1041.003b	2	6

Table 2.
Performance group quantities for reinforced concrete elements.

Figure 11.
PACT entries for 1st floor.

Figure 12.
PACT entries for 1st floor structural performance, direction 1. Performance groups, direction 2.

5. Non-structural components

The process of identifying and selecting the type and distribution of the non-structural components can be greatly simplified using the *Normative Quantity Estimation Tool*, provided in Volume 3 of PACT. This tool can be used to generate a floor-by-floor listing of non-structural components with estimates of their performance group quantities with the simple input of building floor areas and occupancies as shown in **Figure 13**.

To use the Normative Quantity Estimation Tool, the building floors and occupancies are entered into the Building Definition Table in the Normative Quantity Estimation Tab. **Figure 14** illustrates input of this information for the example building.

Figure 15 [1] is an example of fragilities curves of reinforced concrete Special Moment Frame at different damage state details in [1] and **Figure 16** is an example of fragility curves of different types of hospital non-structural equipment from [15].

The **Figures 17** and **18** show the overview of the in-site fragility description for Special Moment Frame (SMF) and Electrical Equipment [1].

Story	w _x (kN)	h _x (m)	wh ^k _{x x}	C _{VX}	V _x (kN)	F _x (kN)	F _x (V)(Kn/ml)	Computed Displacement	Corresponding drift ratio
Roof	32741.24	24.6	805434.5	0.28	19116.4	5368.30	84.10	0.1201	0.002
5th	32741.24	20.6	674469.54	0.23	19116.4	4495.41	70.42	0.1121	0.003325
4th	32741.24	16.6	543504.58	0.19	19116.4	3622.51	56.75	0.0988	0.004075
3rd	32741.24	12.6	412539.62	0.14	19116.4	2749.62	43.07	0.0825	0.00595
2nd	32741.24	8.6	281574.66	0.10	19116.4	1876.72	29.40	0.0587	0.006275
1st	32741.24	4.6	150609.7	0.05	19116.4	1003.83	15.73	0.0336	0.00730434
<\$\$\$\$>			2868132.6	1		19116.40	—	—	—

Table 3.
Lumped weight distribution + lateral forces and story drift ratio.

Compile	Processing of Incomplete Data		Processing of Zero Data		Sum Fragility by Floor			
	☐ Ignore Incomplete Data	☐ Include Incomplete Data	☐ Exclude Zero Data	☐ List as Zero	Sum Components by Building			
	☐ Include Incomplete Data	☐ Include Zero Data	☐ Include Zero Data	☐ Not Typically Included*	Sum Components by Floor			
					List All Components			
COMPONENT SUMMARY MATRIX								
OCCUPANCY				Fragility Number	Fragility Name	Assumed Quantity per component	Quantity	
Type	Occupancy #	Floor Name	Component Area				Directional	Non Directional
TOP STANDARD INPUT								
HEALTHCARE	1	Roof	22500	None Found	Cladding - Gross Wall Area	--	--	--
HEALTHCARE	1	Roof	22500	B2022.001	B2022.001 Curtain Walls - Generic Midrise Stick-Built C	30 SF	105.00	--
HEALTHCARE	1	Roof	22500	B3011.011	B3011.011 Concrete tile roof, tiles secured and complete	100 SF	--	65.25
HEALTHCARE	1	Roof	22500	C1011.001a	C1011.001a Wall Partition, Type: Gypsum with metal studs	100 LF	23.63	--
HEALTHCARE	1	Roof	22500	C3021.001a	C3021.001a Generic Floor Covering - Flooding of Floor	User By	--	--
HEALTHCARE	1	Roof	22500	C3011.001a	C3011.001a Wall Partition, Type: Gypsum + Wallpaper, 1/2" Thick	100 LF	2.86	--
HEALTHCARE	1	Roof	22500	C3032.001a	C3032.001a Suspended Ceiling, SDC A,B,C, Area (A): A-	250 SF	--	72.00
HEALTHCARE	1	Roof	22500	C3032.001a	C3032.001a Suspended Ceiling, SDC A,B,C, Area (A): A-	250 SF	--	7.20
HEALTHCARE	1	Roof	22500	C3032.001a	C3032.001a Suspended Ceiling, SDC A,B,C, Area (A): A-	250 SF	--	7.20
HEALTHCARE	1	Roof	22500	C3032.001a	C3032.001a Suspended Ceiling, SDC A,B,C, Area (A): A-	250 SF	--	3.60
HEALTHCARE	1	Roof	22500	None Found	Fixed Casework	--	--	--
HEALTHCARE	1	Roof	22500	None Found	Fume Hoods	--	--	--

Figure 13. Normative quantity estimation tool, component summary matrix showing non-structural inventories.

Compile	Processing of Incomplete Data		Processing of Zero Data		Sum Fragility by Floor	
	☐ Ignore Incomplete Data	☐ Include Incomplete Data	☐ Exclude Zero Data	☐ List as Zero	☐ Sum Components by Building & Floor	☐ Sum Components by Floor
	☐ Include Incomplete Data	☐ Include Zero Data	☐ Not Typically Included	☐ List All Components		
1			2			

COMPONENT SUMMARY MATRIX								
OCCUPANCY				Fragility Number	Fragility Name	Assumed Quantity per component within PACT	Quantity	
Type	Occupancy #	Floor Name	Component Area (sq ft)				Directional	Non Directional
OF STANDARD INPUT								
HEALTHCARE	1	Roof	22500	None Found	Cladding - Gross Wall Area	--	--	--
HEALTHCARE	1	Roof	22500	B2022.001	B2022.001 Curtain Walls - Generic Midrise Stic	30 SF	105.00	--
HEALTHCARE	1	Roof	22500	B3011.011	B3011.011 Concrete tile roof, tiles secured and	100 SF	--	65.25
HEALTHCARE	1	Roof	22500	C1011.001a	C1011.001a Wall Partition, Type: Gypsum with	100 LF	23.63	--
HEALTHCARE	1	Roof	22500	C3021.001a	C3021.001a Generic Floor Covering - Flooding	User By	--	--
HEALTHCARE	1	Roof	22500	C3011.001a	C3011.001a Wall Partition, Type: Gypsum + Wi	100 LF	2.86	--
HEALTHCARE	1	Roof	22500	C3032.001a	C3032.001a Suspended Ceiling, SDC A,B,C, Are	250 SF	--	72.00
HEALTHCARE	1	Roof	22500	C3032.001a	C3032.001a Suspended Ceiling, SDC A,B,C, Are	250 SF	--	7.20
HEALTHCARE	1	Roof	22500	C3032.001a	C3032.001a Suspended Ceiling, SDC A,B,C, Are	250 SF	--	7.20
HEALTHCARE	1	Roof	22500	C3032.001a	C3032.001a Suspended Ceiling, SDC A,B,C, Are	250 SF	--	3.60
HEALTHCARE	1	Roof	22500	None Found	Fixed Casework	--	--	--
HEALTHCARE	1	Roof	22500	None Found	Fume Hoods	--	--	--
HEALTHCARE	1	Roof	22500	E2022.001	E2022.001 Modular office work stations,	1 EA	--	WT MISMA

Figure 14. Normative quantity estimation tool, building definition table.

Figure 15. Example fragility of SMF.

6. Collapse fragility and collapse mode

The collapse fragility is defined as having a median value $\hat{S}_a(T)$ and a dispersion. For this purpose, we have used the non-linear static analysis approach in SAP2000

Figure 16.
Fragility curves as a function of earthquake PGA.

Figure 17.
B1041.002a SMF Beam-to-Column joint fragility.

(**Figures 19 and 20**) and the SPO2IDA Tool in [1]. The building was modeled according to the Turkish Building Code 2018 for pushover static analysis in each building direction and the effective stiffness of reinforced concrete columns, beams and shear walls as defined in [6] Section 5 were applied.

Figure 21 illustrates the results of the pushover analysis for both building direction 1 and direction 2, which are identical.

After then, the coordinates of the pushover curves are input to the SPO2IDA Tool provided in [1] along with the building height (24.6 m or 80.71 feet), building weight (199235.85 kN or 44790.02 kips) and fundamental building period (1.96 seconds). Four control points are used to approximate the pushover curve as illustrated in **Figure 22**.

Figure 23 present the results of the SPO2IDA evaluation. The value of $\hat{S}_a(T)$ is estimated as 1.16 g.

Figure 18.
Electrical distribution.

Figure 19.
SAP2000 hinges application at beam.

The collapse fragility is thus defined as having a median value of $S_a(T)$ of 1.16 g and a dispersion of 0.6 as entered into the PACT Collapse Fragility panel (Figure 24).

The number of independent collapse modes which can occur and thus the probability of each is difficult to predict analytically. To figure out these data, the user must use judgment supported upon building type, structural system, experience, and analytical inferences. When using the simplified analysis approach, limited analytical information regarding potential collapse modes is out there. For this instance, just one mode of collapse is taken under consideration. More information's gained from numerous response history analyses can give additional insight into potential collapse modes.

Figure 20.
Plastic hinge map in X direction earthquake loading.

Figure 21.
Pushover curve developed by analysis.

7. Define earthquake Hazard

Ground motion prediction equations provide estimates of spectral response acceleration parameters for specified earthquake magnitude and site-to-source distance based on regression analyses of past strong motion recordings.

Most ground motion prediction equations provide geometric mean (geomean) spectral response accelerations represented by the quantity:

$$S_{gm} = \sqrt{S_x(T) * S_y(T)} \tag{1}$$

where S_x and S_y are orthogonal components of spectral response acceleration at period T . The x and y directions could represent the actual recorded orientations, or they could represent a rotated axis orientation.

Intensity-based assessments require a target acceleration response spectrum and suites of 11 pair of ground motions scaled for compatibility with this spectrum (see **Figure 25**). **Figure 26** represents the selected ground motion pairs with geomean spectra that are similar in shape to the target response spectrum.

To determine the building's fundamental translational periods in two orthogonal directions, modal analysis is performed. The fundamental periods in x - and y -directions are 1.94 sec. and 1.98 sec., respectively. Then, the average fundamental period of the building is considered as:

Figure 22. SPO2IDA tool, SPO tab.

$$\overline{T} = \frac{T_x + T_y}{2} = 1.96 \text{ sec} \tag{2}$$

8. Analyze building response

Simplified analysis is used to generate median estimates of peak transient drift, peak floor accelerations and residual drifts. Associated dispersions are generated using simplified analysis. Peak total floor velocities are not generated since none of the vulnerable building components use this demand parameter. A linear building model is constructed using the modeling criteria of [8], linear static procedure.

8.1 Estimate median story drift ratio

Firstly, we determined the pseudo lateral force by the formula:

$$V = C_1 C_2 S_a(T_1) W_1 \tag{3}$$

where C1 is an adjustment factor for inelastic displacements; C2 is an adjustment factor for cyclic degradation; Sa(T1) is the 5% damped spectral acceleration at the

Figure 23.
SPO2IDA tool, IDA tab.

fundamental period of the building, in the direction under consideration, for the selected level of ground shaking; and W_1 is the first modal effective weight in the direction under consideration, taken as not less than 80% of the total weight, W .

Figures 27 and 28 and Table 3 show the computed lateral displacement in X (2) direction and the corresponding drift ratio.

$$\Delta_i^* = H_{\Delta i}(S, T_1, h_i, H) \times \Delta_i \quad i = 1 \text{ to } N \quad (4)$$

where $H_{\Delta i}(S, T_1, h_i, H)$ is the drift modification factor for story i computed.

$$\ln(H_{\Delta i}) = a_0 + a_1 T_1 + a_2 S + a_3 \frac{h_{i+1}}{H} + a_4 \left(\frac{h_{i+1}}{H} \right)^2 + a_5 \left(\frac{h_{i+1}}{H} \right)^3, S \geq 1, i = 1 \text{ to } N \quad (5)$$

With

$$T_1 = 1.96s, H = 24.6m$$

Values of a_0 through a_5 for 6 stories or less in height are provided in [1] Table 5-4 by using the strength ratio given by:

Figure 24.
PACT collapse fragility tab.

Figure 25.
Selected 11 earthquake ground motions response spectrum scaled according to the design spectra.

$$S = \frac{S_a(T)V}{V_{y1}} \tag{6}$$

The value of V_{y1} is taken from the pushover analysis used to estimate the collapse fragility (see SPO2IDA input, **Figure 22**, Elastic Segment end point) (**Table 4**).

8.2 Estimate peak floor acceleration

At the base of the building, peak floor acceleration is taken as equal to the peak ground acceleration. At other floor levels, i , the estimated median peak floor acceleration, a^* (**Table 5**) relative to a fixed point in space, is derived from the peak ground acceleration using:

Figure 26.
Mean matched Spectrum.

Figure 27.
SAP2000 lateral force applied.

$$a_i^* = H_{ai}(S, T_1, h_i, H) \times PGA \quad i = 2 \text{ to } N + 1 \tag{7}$$

$$\ln(H_{ai}) = a_0 + a_1 T_1 + a_2 S + a_3 \frac{h_i + 1}{H} + a_4 \left(\frac{h_i + 1}{H} \right)^2 + a_5 \left(\frac{h_i + 1}{H} \right)^3, S \geq 1, i = 1 \text{ to } N \tag{8}$$

The coefficients of a_0 through a_5 for 6 stories or less in height are provided in [1] Table 5-4.

8.3 Estimate of dispersion for median story ratio, median peak floor acceleration, and median peak floor velocity

For intensity-based, separate values of total dispersion for drift ratio, β_{SD} , floor acceleration, β_{FA} , and floor velocity, β_{FV} , are needed.

Figure 28.
X-X deformed shape.

Story	Δ_i	$h_i + l/H$	$\ln H\Delta_i$	$H\Delta_i$	Δ^*i
1	0.0073043	0.1869919	0.2089634	1.2323998	0.0090019
2	0.006275	0.3495935	-0.009875	0.990174	0.0062133
3	0.00595	0.5121951	-0.107092	0.8984431	0.0053457
4	0.00595	0.6747967	-0.082688	0.9206379	0.0054778
5	0.004075	0.8373984	0.0633358	1.0653845	0.0043414
6	0.003325	1	0.3309807	1.3923329	0.0046295

Table 4.
Median story drift ratio estimates.

Story	PGA	$h_i + 1/H$	$\ln H\Delta_i$	$H\Delta_i$	a^*i
1	0.695	—	—	—	0.695
2	0.695	0.1869919	-0.357947	0.69911	0.4858814
3	0.695	0.3495935	-0.364289	0.6946906	0.48281
4	0.695	0.5121951	-0.37063	0.6902992	0.4797579
5	0.695	0.6747967	-0.376972	0.6859355	0.4767252
6	0.695	0.8373984	-0.383313	0.6815995	0.4737116
roof	0.695	1	-0.389655	0.6772908	0.4707171

Table 5.
Median floor acceleration estimates.

$$\beta_{SD} = \sqrt{\beta_{a\Delta}^2 + \beta_m^2} \tag{9}$$

$$\beta_{FA} = \sqrt{\beta_{aa}^2 + \beta_m^2} \tag{10}$$

$$\beta_{FV} = \sqrt{\beta_{a\Delta}^2 + \beta_m^2} \tag{11}$$

These are calculated based on [1] Table 5-6 values for analysis record- to-record dispersion for drift, $\beta_{a\Delta}$, acceleration, β_{aa} , and velocity, β_{av} , respectively, by interpolation approach.

9. Estimate median residual story drift ratio and dispersion

Since the requirements for direct simulation of residual drift are computationally complex and not practical for general implementation in design, the following equations were developed to estimate the median residual drift ratio, response of the structure:

$$\begin{aligned} \Delta_r &= 0 \text{ for } \Delta \leq \Delta_y \\ \{\Delta_r &= 0.3(\Delta - \Delta_y) \text{ for } \Delta_y < \Delta < 4\Delta_y\} \\ \Delta_r &= (\Delta - 3\Delta_y) \text{ for } \Delta \geq 4\Delta_y \end{aligned} \tag{12}$$

where Δ is the median story drift ratio calculated by analysis, and Δ_y is the median story drift ratio calculated at yield.

The peak transient drift ratios were estimated. The yield drift ratio is obtained from the capacity curve derived from the pushover analysis used to generate the story shear at yield (**Figure 29**).

At yield, the peak transient acceleration is determined by the equation for the building fundamental period between the range of 0.7 sec to 2 sec:

$$S_a(T) = \frac{S_a(1)}{T} = 0.755g \tag{13}$$

From the capacity curve, the corresponding roof displacement for the peak transient acceleration at yield then is 0.0045 m. Thus, the yield drift ratio is:

$$\Delta_y = \frac{0.0045}{24.6} = 0.0002 \tag{14}$$

The maximum transient drift ratio for the building occurs at the first story ($\Delta = 0.0090$).

$$\Delta_r = (0.0090 - 3 * 0.0002) = 0.0084$$

Figure 29.
Capacity curve from pushover analysis.

The median estimate of residual drift obtained from the simplified analysis method is assigned a dispersion of 0.8.

10. Input response and calculate performance

The median demand estimates for peak transient drift ratio, peak floor acceleration, and residual drift ratio are input to PACT for direction 1 and direction 2 in the Structural Analysis Results tab (see **Figures 30** and **31**). Then, PACT uses this information to make damage state assessments for all building components

Figure 30.
PACT peak transient drift ratio input tab.

Figure 31.
PACT residual drift tab.

contained in the building model. A Monte Carlo procedure is used to assess a range of possible outcomes as repair cost and repair time.

11. Review results and comments

As showed in the **Figure 32**, the estimated median repair cost is shown as \$2,710.445, which corresponds to 8.37% of the building’s total replacement cost. From the isograph on the **Figure 32**, it is seen that the yellow stick representing the performance group B2022.001 (Curtain Walls - Generic Midrise Stick-Built Curtain wall, Config: Monolithic, Lamination: Unknown, Glass Type: Unknown,

Figure 32.
PACT repair cost tab.

Figure 33.
PACT repair cost graph.

Figure 34.
PACT Casualties/ Deaths Results.

Figure 35.
PACT casualties / injuries.

Figure 36.
PACT repair cost tab with realizations.

Details: Aspect ratio = 6:5), explain its contribution to the most of the building total repair cost with approximately \$1.700.000.

Figures 33, 34, and 35 explain that 50% probability that repair cost will not exceed \$2.710.445, 145 injuries, 105 deaths.

The performance results of the PACT can be examined in numerous ways. Viewing results by realization reveals that collapse plays a more significant role than residual drift (see **Figure 36**). For approximately 56 of the 200 realizations of the collapse of the component B1049.031 Post-tensioned concrete flat slabs-columns with shear reinforcing and, 40 of the 200 realization for the performance group B3011.011 Concrete tile roof tile secured and compliant for damage being judged irreparable.

12. Conclusion

Performance assessment can provide useful information for many decisions associated with real property. These include: demonstrating equivalence of alternative design approaches, selecting appropriate design criteria for new buildings, determining if an existing building constitutes an acceptable risk for a particular planned use, whether or not it should be upgraded, and if so, to what level, performing benefit–cost studies to determine a reasonable investment for improved seismic resistance in a building, determining whether or not insurance is a cost-effective risk management technique.

In this study, a case study of a typical hospital building has been analyzed. The non-linear static pushover analysis results have showed that the collapse occurs at the building base in Mode-8. The linear static analysis results have demonstrated a maximum roof displacement of 7.69 cm. Consequently, the performance assessment that used the data from these analyses have shown a low repair cost of 8.37% (less than 40%). Thus, based on the past knowledge and recommendations that suggests 40% of the total building replacement cost can be a reasonable threshold for total loss of several buildings, the decision of retrofitting can be given for this case study since the repair cost is less than 40%.

The adaptation of the current study to the typical health-care facilities in many countries as Turkey is still on-going. It is believed that the results of this study will be valuable for the building owners, managers, insurance firms and for the process of benefit–cost performance and risk management.

Author details

Wilfrid Gbenankpon Djima, Abdullah Can Zulfikar and Cüneyt Tüzün
Department of Civil Engineering, Gebze Technical University, Kocaeli, Turkey

*Address all correspondence to: aczulfikar@gtu.edu.tr

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