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Seismic Vulnerability Studies of a G+17 storey building in Abu Dhabi - UAE using Fragility Curves

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ABSTRACT

The growth of tall buildings in the United Arab Emirates (UAE) has paved the way for a surge in interest in the country's seismic vulnerability investigation. The case study building comprises of shear walls and RC columns as its lateral force-resisting system. It is a newly constructed G+17 storey building and is about 78 meters high. The non-linear dynamic seismic analysis which is the time history modal analysis, also known as Fast Non-linear analysis was performed on the study building with about 45 earthquakes in 3 sets of hazard levels (2%, 5%, and 10% Probability of Exceedance [PE]) to generate the inter-story drift values. Based on the Performance-based approach given by FEMA 356, the Fragility curves are developed by creating the Probabilistic Seismic Design Modal. The resultant fragility curves are given in terms of 3 probabilities i.e., (1) Immediate Occupancy, (2) Life Safety, and (3) Collapse Prevention. The whole study depends on the idea that comparative sort of structures will have a similar likelihood of a given harm state for a given seismic force.

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NOMENCLATURE

a, b	Regression Coefficients	PGA	Peak Ground Acceleration
ACI	American Concrete Institute	PSDM	Probability Seismic Design Model
ASCE	American Society for Civil Engineers	R	Response Modification Factor
DL	Dead Load	R_JB	Joyner Boore Distance
C	Capacity of Structure	RSN	Record Sequence Number
Cd	Deflection Amplificaton	Sa	Spectral Acceleration
CP	Collapse Prevention	Ss	0.2 sec Spectral Acceleration
Cp_w	Windward Coefficient	S1	1 sec Spectral Acceleration
Cp1	Leeward Coefficient	SDL	Superimposed Dead Load
D	Seismic Demand which is considered as Θ_{max}	SLS	Serviceability Limit State
FNA	Fast Non-Linear Analysis	SRSS	Square Root of Sum of the Squares
G	Ground	T1	Fundamental Time Period
GCC	Gulf Cooperation Council	UAE	United Arab Emirates
GM	Ground Motion	UHS	Uniform Hazard Spectrum
GMPE	Ground Motion Prediction Equations	ULS	Ultimate Limit State
I	Occupancy Importance	Vs30	Shear Wave velocity
IM	Intensity Measure	**Greek Symbols**	
IO	Immediate Occupancy	Θ_{max}	Maximum Interstory Drift Ratio
ISDR	Interstory Drift Ratio	Φ	Standard Normal Cumulative Function
LL	Live Load	$\hat{C}$	Median structural drift capacity
LS	Life Safety	β_c	Aleatoric Uncertainty in Capacity
NGA	Next Generation of GM Attenuation Models	β_M	Epistemic Uncertainty in modelling
PE	Probability of Exceedance	**Subscripts**	
PEER	Pacific Earthquake Engineering Research Centre	C	Capacity
		M	Modelling

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1. INTRODUCTION

The contextual analysis building is a G+17 story building newly constructed structure in Abu Dhabi, UAE [1, 2] with flat slabs and shear walls, designed for response spectrum analysis. This chosen building could represent the modern constructions in GCC countries. Thereby the research on the Earthquake Reliability Assessment [3] of this structure would lay the foundation for the proper seismic design for similar kind of structures in GCC countries. The geology, tectonics and seismic source modal for UAE especially Abu Dhabi, were referred from various studies [4-8]. Based on the geological studies on UAE performed by various eminent researchers [9-17] who have provided the results in terms of Peak Ground Acceleration, Uniform Hazard Spectra and Deaggregation [18-21]; the relevant parameters (such as the PGA, Shear wave velocity (Vs30), Joyner Boore distance (R_JB), magnitude) required for the selection of the most appropriate earthquake for the vulnerability studies were obtained from Pacific Earthquake Engineering Research Centre [2,5]. The guidelines provided by NIST GCR 11-917-15 [22, 23] were followed to formulate the significant methodology to be adopted for the vulnerability studies. In accordance to this, a total of 45 ground motions [24] under 3 sets of hazard levels as 2, 5 and 10% [25, 26] Probability of Exceedance, were chosen to perform the Non-linear Dynamic Seismic Analysis which is Time History Modal Analysis, also known as Fast Non-Linear Analysis (www.csiamerica.com) on the case study building and hence to obtain the Interstory Drift Values.

The fragility curves gives the damage level as probabilities for a structure that tends to reach over the deformation limit for a given state of ground movement [27-29]. Depending upon the performance based probabilistic Approach given by FEMA 356 [30], the results were provided in terms of Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP).

The novelty of this research is that there has been no fragility curves derived so far for this newly constructed building in Abu Dhabi and not much seismic vulnerability studies is available for the GCC countries.

The objective is to study the seismic vulnerability of an existing high rise building, located in Abu Dhabi, UAE through fragility curves, thereby producing results that helps in suggesting seismic design protocols that could be adopted for similar High Rise Buildings with shear walls and columns as its lateral force resisting system.

2. CASE STUDY BUILDING

A newly constructed G+17 story building located in Abu Dhabi, UAE was selected as the case study building on which the vulnerability analysis is performed. This building is designed with Shear walls and Flat slabs.

2. 1. Structural Details The structural details of the case study building are elaborated in Table 1.

2. 2. Structural System Table 2 describes the four structural systems of the case study building. 3 D model of the building is developed in ETABS software as shown in Figure 1 and the typical floor plan is represented in Figure 2.

2. 3. Materials Used–Concrete Equation (1) gives the cylinder to cube strength relationship. Table 3 gives the conversed concrete strength (of cube & cylinder) and

TABLE 1. Structural System of G+17 storey (case study) building

Floors	Approximate Area
5 Basements (Parking)	5 x 1320 m^2
Podium 1	1320 m^2
Podium 2 (retail)	1275 m^2
1 office floor	1 x 830 m^2
2 - 17 typical floors	16 x 845 m^2
Roof	845 m^2
Upper roof	620 m^2

Height (excluding Basements) 78 m

The basement and typical floor heights are 3.3 m and 3.5 m respectively

RC Structures – Conventional Reinforced Concrete In Situ Construction

TABLE 2. Structural system of the case study building

Gravity System	• RC Flat slabs @ typical floors and basement floors • Transfer Beams @ Basement floors • Stair Flights and landings
Lateral system	• Shear walls and columns in both orthogonal directions – Building frame system • Lateral load is transferred to the shear walls by means of a horizontal diaphragm, i.e. the floor slabs • Thickness of walls – 300 mm to 400 mm • Core walls in basement levels – 300 mm to 400 mm
Raft Foundation	• Raft footing of 1.5m depth accompanied by few tension piles as per the foundation analysis. For the design of foundation, worst load combinations of earthquake forces as well as uplift water pressures are considered.
Typical Floor	• RC Flat slabs of Approximately 240 mm thick with local thickening of 280 mm rests on RC columns and walls

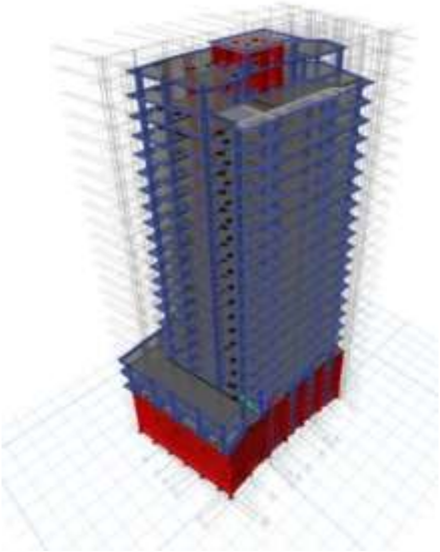

Figure 1. 3D model of the building in ETABs

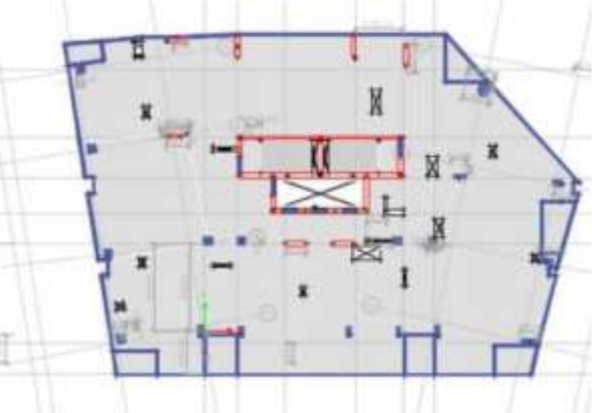

Figure 2. Typical floor model in ETABs

Young's modulus adopted in the design of the case study building.

$$\text{Cylinder strength} = 0.85 \times \text{Cube strength} \quad (1)$$

TABLE 3. Concrete Strength of cube and cylinder, and Young's modulus

Applicable	Cube Strength, f_{cu} (N/mm^2)	Cylinder Strength f_{ck} (N/mm^2)	Young's Modulus (kN/mm^2)
Foundations	60	51	38385
Slabs/ Beams/ Retaining Walls	45	38	33133
Foundations	60	51	38385
Slabs/ Beams/ Retaining Walls	45	38	33133

2. 4. Special Design Incorporated

The special design specifications are as follows:

Second Order Analysis (P - Δ): 1.2DL + 0.5LL
Construction Sequence Analysis : 1.0DL + 1.0SDL
Floor Diaphragm: Semi-rigid diaphragms
Stiffness Modifiers: Based on ACI 318 10.10.4.1 (The values are compiled in Table 4)

2. 5. Wind Load (As per ASCE7-05)

Wind Speed= 90 mph
Exposure type= B
Importance Factor= 1
Cpw= 0.8
Cp1= 0.5

2. 6. Static Earthquake Load (As per ASCE7-05)

R= 5
System Overstrength, Omega= 2.5
Cd= 4.5
I= 1
Ss= 0.6
S1= 0.18
Long-Period Transition Period= 8 sec
Site Class= C
Eccentricity Ratio= 0.05

2. 7. Response Spectrum

Seismic loads are considered in the analysis for both, equivalent static method and response spectrum method. As the considered case study building falls under the category of tall and irregular builing, the fundamental mode of vibration is not dominating the response. Hence dynamic analysis using Response Spectrum method is adopted. This building was designed based on Response Spectrum method as per ASCE 7-05 parameters which is indicated in Figure 3.

2. 8. Analysis

Modal analysis is performed to compute modal responses and they are combined using SRSS method to get maximum responses. For design of vertical elements (columns and shear walls), forces from response spectrum method are considered.

TABLE 4. Stiffness Modifiers incorporated in the design software model

Element	ULS	SLS
Columns	0.7	1.0
Walls (uncracked)	0.7	1.0
Beams	0.35	0.5
Slabs	0.25	0.35

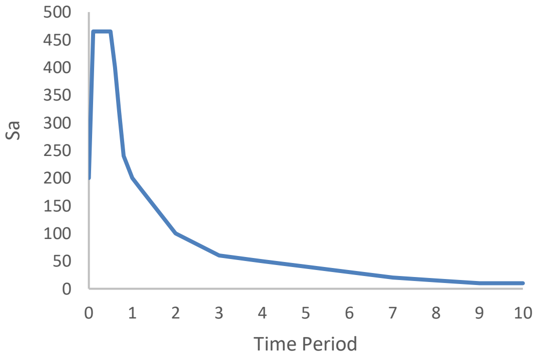

Figure 3. Response Spectrum Function as per ASCE 7-05

3. GROUND MOTION DATA

Three sets of earthquake data for 2, 5 and 10% probability of Exceedance (PE) of 50 years earthquakes which has the effective return periods of 475 years, 975 years and 2475 years respectively were selected for vulnerability studies [23, 31-33]. The target response spectrum for Abu Dhabi, U.A.E were taken from the paper [1] who have performed the seismic hazard assessment for UAE based on 7 GMPE's inclusive of 3 NGA. The interpolated values for the target spectrum of 5% PE was calculated. The three target RS for the three hazard levels are exhibited in Table 5 and its graphical representation is expressed by Figure 4. The ground motions required are selected, scaled and downloaded from PEER centre – NGA West 2 database.

The significant parameters required for the selection of most relevant earthquake data from PEER are sorted in Table 6. From Table 6, the time period for which the ground motions are to be scaled are set by the guidelines given by NIST GCR 11-917-15 [22], which is the period within $0.2T_1$ and $1.5T_1$, where T_1 is the Fundamental Time period of the Case Study Building. The value of T_1 is 4.99 s.

TABLE 5. Target response spectrum of Abu Dhabi for 2, 5 and 10% PE

Time (s)	**PGA of Abu Dhabi, UAE** **475 years (2% PE)**	 **975 years (5% PE)**	 **2475 years (10% PE)**
0	0.035	0.059	0.073
0.2	0.071	0.138	0.178
1	0.040	0.062	0.075
2	0.033	0.041	0.045
3	0.016	0.022	0.025
4	0.009	0.014	0.017

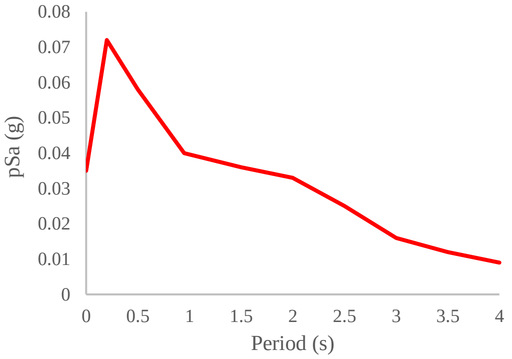

Figure 4a. Design target spectrum for 2% PE given in PEER database

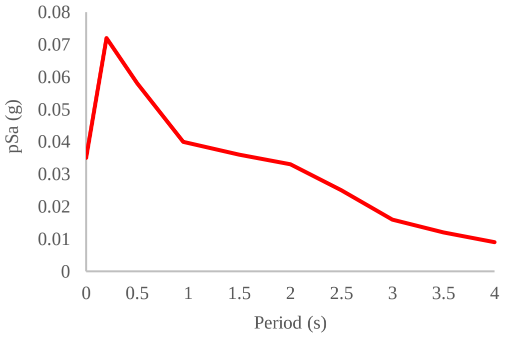

Figure 4b. Design target spectrum for 5% PE given in PEER database

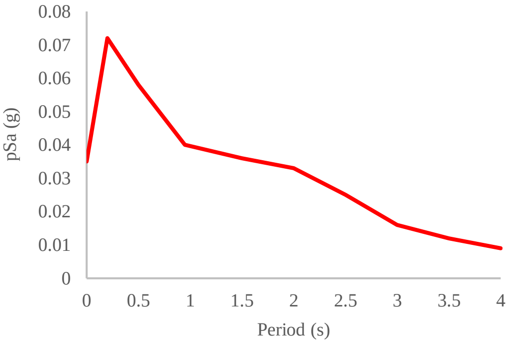

Figure 4c. Design target spectrum for 10% PE given in PEER database

In total 45 ground motions (GMs) are obtained from PEER database in terms of 3 sets as 15 GMs under each set. The ground motions have approxiamtely the same magnitude but different mechanism, distance and velocity. The GM data comprises of Acceleration, Displacement and velocity files in Horizontal-1, Horizontal-2 and Vertical direction. Among which the acceleration files in Horizontal-1, Horizontal-2 are required for the non-linear dynamic analysis. The scale factor generated from PEER database (Figure 5) for each ground motion after scaling was used for the time history analysis. Earthquake data obtained from PEER databaseand the scaled ground motions are represented in Tables 7and 8, respectively.

TABLE 6. Search Parameters in PEER

Parameter	Value	Source
Fault type	SS (Strike Slip) + Reverse	[12]
Magnitude (min, max)	4, 7	[1]
R_JB (Joyner Boore distance) [min, max]	60, 300 (Km)	
Rrup (Rupture Plane distance) [min, max]	60, 300 (Km)	Assumption
Shear Wave Velocity (Vs30) –for site class C [min, max]	366, 762 (m/s)	IBC 2012 [1]
Pulse	No Pulse-like Records	Assumption
Initial Scale factor [min, max]	0.5, 3	
Spectral Ordinate	SRSS (Square Root of Sum of Squares)	[19]
Damping Ratio	5%	
Scaling Method	Minimize MSE	
Period Ratio	1, 7.5	

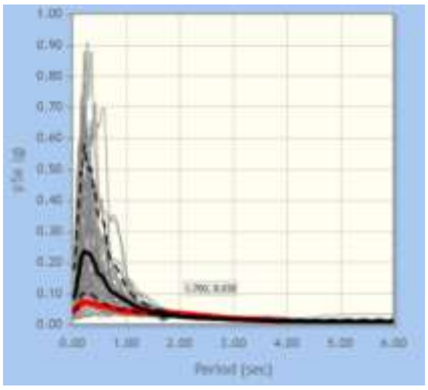

Figure 5a. Scaled spectra with Target spectrum for 2%

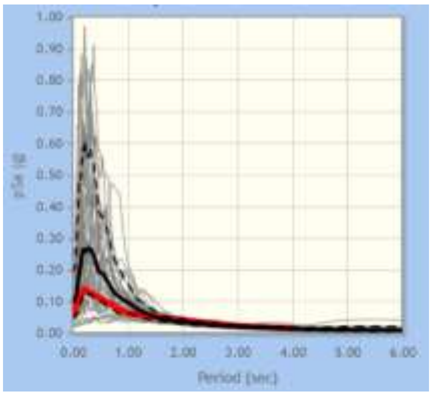

Figure 5b. Scaled spectra with Target spectrum for 5%

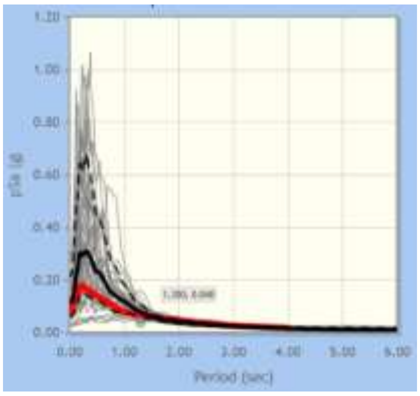

Figure 5c. Scaled spectra with Target spectrum for 10%

4. NONLINEAR DYNAMIC ANALYSIS & ISDR

A non-linear dynamic analysis – Time History Modal Analysis also known as Fast Non-Linear Analysis (FNA) was performed on the case study building for all 45 ground motions (GMs) using the commercially available software ETABS 2017. FNA method was chosen to be the most appropriate dynamic analysis since the newly constructed case study building was designed primarily as linear-elastic and consists of fairly limited predefined non-linear behaviours such as P-Δ ratio, torsional irregularities (geometric nonlinearities). The significant cases to be incorporated during the time history analysis in ETABS 2017 as per the guidelines given by Computers and Structures, Inc. (www.csiamerica.com) includes,

i. Mass Source Data: 25% Live Load + 100% Dead Load (ASCE 7-16)
ii. Modal Case Data: Ritz vector

Total Mass Participation Ratio (MPR) should be > 90% (ASCE 7-05 [12.9.1]). The sufficient number of modes required for the FNA method to attain 99% MPR is achieved by trial and error method.

The maximum Inter Story Drift Ratio (ISDR) was calculated from the resultant displacements from the analysis and the spectral acceleration at the fundamental time period ($T_1 = 4.99$ s) for each time history for 5% damping were tabulated in Table 9.

5. MODELLING OF FRAGILITIES

Fragility curve is a compelling device for weakness evaluation of basic frameworks. It gives gauges regarding probabilities of a structure to reach or surpass the restriction of deformation at given degrees of ground shaking [34-36]. At the end of the day, Fragility bends gives the probability of surpassing a recommended degree of harm for a wide scope of ground motion intensities. The modelling and derivation of fragility curve explained by Rajeev et al. [28, 29] was followed in this paper.

TABLE 7. Earthquake data obtained from PEER

Sl. No.	GMs (from PEER)	Year	Station Name	Magnitude	Mechanism	Rjb (Km)	Rrup (Km)	Vs30 (m/sec)
1	RSN17 Scalif	1952	San Luis Obispo	6	Strike slip	73.41	73.41	493.5
2	RSN39 Borrego	1968	Pasadena – CIT Athenaeum	6.63	Strike slip	207.14	207.14	415.13
3	RSN40 Boreggo	1968	San Onofre – So Cal Edison	6.63	Strike slip	129.11	129.11	442.88
4	RSN85 Sfern	1971	"San Juan Capistrano"	6.61	Reverse	108.01	108.01	459.37
5	RSN86 Sfern	1971	"San Onofre - So Cal Edison"	6.61	Reverse	124.79	124.79	442.88
6	RSN609 Whittier	1987	"Castaic - Hasley Canyon"	5.99	Reverse Obliq	64.56	64.96	421.05
7	RSN905 Big Bear	1992	"Featherly Park - Maint"	6.46	Strike slip	78.81	78.91	367.54
8	RSN911 Big Bear	1992	"LA - 1955 1/2 Purdue Ave. Bsmt"	6.46	Strike slip	140.22	140.28	379
9	RSN972 Northr	1994	"Featherly Park - Maint"	6.69	Reverse	82.01	82.32	367.54
10	RSN1037 Northr	1994	"Mojave - Oak Creek Canyon"	6.69	Reverse	75.54	75.8	422.73
11	RSN1109 Kobe	1995	"MZH"	6.9	Strike slip	69.04	70.26	609
12	RSN1112 Kobe	1995	"OKA"	6.9	Strike slip	86.93	86.94	609
13	RSN1630 Upland	1990	"Ocean Floor SEMS III"	5.63	Strike slip	71.72	71.73	659.6
14	RSN2078 Nenana	2002	"Anchorage - K2-18"	6.7	Strike slip	216.47	216.47	435.21
15	RSN2083 Nenana	2002	"Anchorage - NOAA Weather Fac."	6.7	Strike slip	275.47	275.47	390.32

TABLE 8. Scaled GMs for 2%, 5% and 10% PE

RSN	Earthquake Name	Scale Factor		
		2% PE	5%PE	10%PE
17	"Southern Calif"	1.91	1.6463	1.1985
39	"Borrego Mtn"	1.872	1.6135	1.1746
40	"Borrego Mtn"	1.3123	1.1311	0.8235
85	"San Fernando"	1.3674	1.1786	0.858
86	"San Fernando"	2.3585	2.0329	1.4799
609	"Whittier Narrows-01"	2.8532	2.4593	1.7903
905	"Big Bear-01"	1.8934	1.632	1.188
911	"Big Bear-01"	1.5696	1.3529	0.9849
972	"Northridge-01"	2.0657	1.7805	1.2962
1037	"Northridge-01"	2.6927	2.321	1.6896
1109	"Kobe_ Japan"	1.5064	1.2985	0.9452
1112	"Kobe_ Japan"	2.6419	2.2771	1.6577
1630	"Upland"	2.0608	1.7763	1.2931
2078	"Nenana Mountain_ Alaska"	2.1257	1.8322	1.3338
2083	"Nenana Mountain_ Alaska"	1.6706	1.44	1.0483

TABLE 9. The maximum ISDR and pSa (@ T_1) for 2%, 5% and 10% PE in 50 years which is equivalent to 475 years, 975 years and 2475 years return periods respectively for 5% damping

G+17 Story	Period (T_1) = 4.99 sec					
Ground Motion (PEER)	2% PE		5% PE		10% PE	
	Sa (T_1)	ISDR (%)	Sa (T_1)	ISDR (%)	Sa (T_1)	ISDR (%)
RSN17 Scalif	0.007	0.116	0.006	0.100	0.005	0.073
RSN39 Borrego	0.005	0.128	0.004	0.110	0.003	0.080
RSN40 Boreggo	0.011	0.216	0.009	0.186	0.007	0.136
RSN85 Sfern	0.010	0.203	0.009	0.175	0.006	0.127
RSN86 Sfern	0.011	0.185	0.009	0.160	0.007	0.116
RSN609 Whittier	0.003	0.075	0.003	0.065	0.002	0.047
RSN905 Big Bear	0.003	0.106	0.002	0.092	0.002	0.067
RSN911 Big Bear	0.003	0.092	0.003	0.080	0.002	0.058
RSN972 Northr	0.003	0.178	0.002	0.153	0.002	0.111

$$\text{Fragility} = P\,(D > C \mid IM) \qquad (2)$$

The above fragility equation (2) depicts, the probability that the D set on the structure is more noteworthy than

RSN1037 Northr	0.004	0.111	0.003	0.095	0.002	0.069
RSN1109 Kobe	0.007	0.249	0.006	0.161	0.005	0.117
RSN1112 Kobe	0.018	0.323	0.006	0.198	0.011	0.202
RSN1630 Upland	0.010	0.210	0.008	0.181	0.006	0.132
RSN2078 Nenana	0.006	0.076	0.005	0.108	0.004	0.079
RSN2083 Nenana	0.006	0.163	0.007	0.140	0.005	0.102

the limit C of the structure. This is administered by a picked IM which means the degree of seismic stacking and it depicts the spectral acceleration as intensity measure

A proposed conceivable approach to survey the fragility function is by creating a probabilistic distribution for the demand moulded on the IM, which is known as seismic demand model PSDM and convolving it with an appropriation for the limit. The demand on the structure is measured utilizing not many chose metric(s) (say inter story drift, ductility,). Cornell et al. [8] recommended that the estimate for the median demand can be spoken by a power model as Equation (3):

$$\hat{D} = aIM^{b} \qquad (3)$$

Where IM is the seismic intensity measure of choice, and both a & b are regression coefficients.

In this research both Θ_{max} and Sa are obtained for 5% damping.

5. 1. Structural Performance As briefly explained by Aiswarya et al. [30], as per FEMA 356 in the global-level seismic evaluation, the performance of the structure is quantified by the Interstory drift. The seismic evaluation approach as recommended by FEMA 356 uses three performance level which are Immediate Occupancy, Life Safety and Collapse Prevention. The global level Interstory drift limits for the three performance levels for RC building elements in FEMA 356 (ASCE 2000) is as mentioned in Table 10.

The expected damage states for the three performance levels [31, 32] are:

TABLE 10. Drift limits for the performance levels (FEMA365)

Structural Performance Level	Drift (%)
IO	1
LS	2
CP	4

- The IO level is characterized by the cut-off under which the structure can be securely occupied with no huge fix. It is portrayed by the estimation of Θ_{max} at which the casing enters the plastic range.
- The SD level (Significant Damage) creates at a mishappening at which huge harm is continued, yet a generous edge stays against nascent breakdown.
- The CP level is given by the purpose of nascent breakdown of the casing because of either extreme debasement in strength and associations or huge P-Δ impacts coming about because of exorbitant lateral deformations.

5. 2. Deriving Fragility Curves To construct the PSDM, nonlinear dynamic analysis shall be used. One of the method, “Cloud analysis” [30, 27], is a suitable method (although not the most precise). The advantage of this strategy is that it depends on the GM as they are recorded. By performing a simple linear regression of the logarithm of D against the logarithm of IM ($\hat{D} = aIM^{b}$), the PSDM parameters (a, b) could be obtained. The best power law equation was determined and is shown in Figure 6.

The appropriation of the demand about its median is regularly accepted to follow a two-boundary lognormal probability distribution. Accordingly, in the wake of assessing the scattering of the demand about its median, which is moulded upon the IM, the fragility can be given as shwn in Equation (4) and indicates the damage measure.

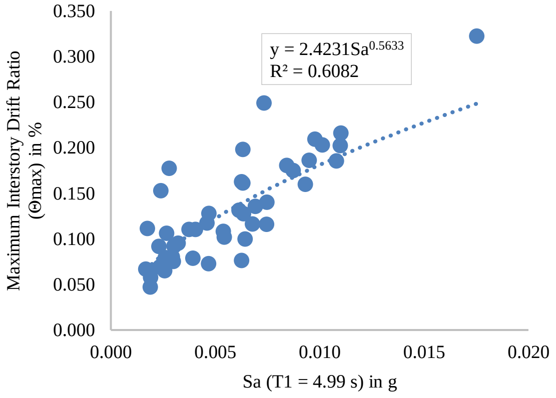

Figure 6. Probabilistic Seismic Demand Model (PSDM)

TABLE 11. PSDM parameters

PSDM PARAMETERS	
A	2.4231
b	0.5633
$\beta_{D\|IM}$	0.271

$$P(D > C \mid IM) = 1 - \Phi\left(\frac{\ln(\hat{C}) - \ln(a \cdot IM^{b})}{\sqrt{\beta^{2}_{D\mid IM} + \beta^{2}_{C} + \beta^{2}_{M}}}\right) \tag{4}$$

β_C - is taken as 0.2 for this study
β_M - is taken as 0.2 for this study

5. 3. Seismic Fragility Curve The seismic fragility curves of the case study building (G+17 story) is given by Figure 7. As per the Median Structural Capacity mentioned in Table 12, in contrast to Figure 7, interprets that the non linearity of the case study building does not overwhelm the general structural reaction.

TABLE 12. Median Structural Capacity for IO, LS & CP

	$\hat{C}$
IO	1
LS	2
CP	4

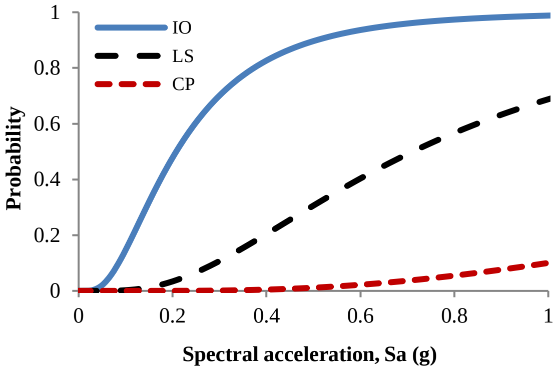

Figure 7. Fragility curve for the case study RC building

6. CONCLUSION

Seismic fragility curves were developed for the case study building. Vulnerability assessment of the building is executed using the developed fragility curves.

The vulnerability assessment of RCC multistorey building in this research is a useful tool for seismic retrofitting decisions, disaster response planning and evaluation of loss of functionality of the structures in GCC countries. Using the analytical approach, the seismic fragility curve was developed for the proposed case study building for which no fragility curves were developed before. This building was identified as a typical High Rise Building (G+17 storey) in Abu Dhabi, United Arab Emirates, in the region with Shear walls as the basic lateral load resisting system. The predictive tool for PSDM parameters (a, b, β) using response spectrum technique was created. As a result of analytical method fragility curves, the uncertainty in the ground motion does not dominate the overall structural response. The whole study is based on the idea that comparative sort of structures will have a similar likelihood of a given harm state for given seismic force.

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Persian Abstract

چکیده

بهبود سریع توسعه ساختمانهای بلند در امارات متحده عربی (امارات متحده عربی) ، زمینه را برای افزایش علاقه به تحقیقات خطر لرزه ای کشور فراهم کرده است. ساختمان مورد مطالعه شامل ستونهای دیوار برشی و RC به عنوان سیستم مقاومت در برابر نیروی جانبی آن است. این یک ساختمان داستانی G + 17 است که به تازگی ساخته شده و حدود ۷۸ متر ارتفاع دارد. تجزیه و تحلیل لرزه ای دینامیکی غیر خطی که همان تجزیه و تحلیل مد تاریخ است ، همچنین به عنوان تجزیه و تحلیل سریع غیر خطی سریع در حدود ۴۵ زلزله در ۳ مجموعه سطح خطر (۲ ، ۵ و ۱۰٪ احتمال افزایش [PE]) انجام می شود در ساختمان مطالعه برای تولید مقادیر رانش Interstory. بر اساس رویکرد مبتنی بر عملکرد ارائه شده توسط FEMA 356 ، منحنی های شکنندگی با ایجاد مدل طراحی لرزه ای احتمالی ایجاد می شوند. منحنی های شکنندگی حاصل از نظر ۳ احتمال ، به عنوان مثال ، (۱) اشغال فوری ، (۲) ایمنی زندگی و (۳) پیشگیری از سقوط. این بستگی به ایده ای دارد که نوع سازه های مقایسه ای احتمال مشابهی را برای یک حالت آسیب دیده برای نیروی لرزه ای معین داشته باشند.