Ground Motion Selection and Scaling Approach for Evaluation of Reinforced Concrete Frames against Sideway Collapse

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SUMMARY
Numerical analysis and design of various structural systems against collapse limit state is one of the most significant aims in PBEE concepts. One of the basic issues in predicting the collapse safety is the assessment of uncertainties due to ground motions characteristics and their effects on nonlinear structural response. Considering the difficulties in selection of representative ground motion records for quantitative prediction of damage probability and development of related fragility curves, the requirement of investigating an appropriate approach for selection and scaling a set of ground motions which include a limited number of records become apparent. The purpose of this research is to assess the seismic behavior of reinforced concrete frames at collapse limit state by accurate estimate of seismic fragility curves for different EDPs, using relatively limited numbers of records and investigating the sensitivity of results to the ground motion selection approach. A three-dimensional nonlinear finite element program, COM3, is used for performing of this study and all dynamic analyses will accomplish on 2D RC moment Frames.

Keywords: Ground Motion Selection, Incremental Dynamic Analysis, RC Frame, Collapse Limit State

1. INTRODUCTION

Numerical estimation of seismic response of different structural systems (inclusive Reinforced Concrete Frames) against Collapse is one of the most significant aims of recent studies in Performance Based Earthquake Engineering (PBEE). One of the basic factors of predicting the collapse safety is the assessment of uncertainties due to ground motions characteristics and their effects on nonlinear structural response. Recent researches has shown that ground motion characteristics due to the random nature, in comparison with other sources of uncertainty (such as material properties or design assumptions), has an important impact on the seismic response of the structural systems. Considering the main effects of uncertainties due to selection of appropriate ground motions (for Incremental Dynamic Analysis (IDA) time-consuming procedure) on the damage probability prediction and development of fragility curves for quantitative estimation of various structural performance levels, the necessity of investigating the development of fragility curves using a limited number of ground motion records become apparent.

These curves as an appropriate tool for evaluating the structural systems behavior and accurate estimating the probable damage, defines the probability of exceeding a specific Engineering Demand Parameter (EDP) for a given level of ground motion intensity, using time-history dynamic analysis results. This research discusses collapse probabilistic evaluation of reinforced concrete frames via accurate estimation of seismic fragility curves for a determinate EDP, using relatively limited numbers of records and then investigates the sensitivity of results to the ground motion selection method. The desirable purpose is to minimize the scatter in the structural response due to selected suite of ground motion records. Firstly, sample reinforced concrete frames are designed using Direct Displacement Based Design methodology (Priestley Method).

Then passing through modelling and performing the IDA process on the sample structures under selected and scaled representative records, related seismic fragility curves will develop. Afterwards, by specifying the optimum number and appropriate periodic range for records selection procedure, a limited number of proper records will select for each of the sample structures and then fragility curve that obtained by using of selected suite of ground motions will compare with fragility curve based on all of the existent records. COM3 finite element software is used for performing of this study and all Dynamic analysis will accomplish on 2D RC moment Frames.

2. GROUND MOTION RECORDS SELECTION PROCEDURE

In this research, the Dynamic Analyses are carried out using a records set containing Large Magnitude and Small Distance with characteristics of; Mw > 6.5, R < 30 km (LMSR). This records bin has proposed by Shome and Cornell with soil type C (in NEHRP). The ground motion set has collected from Pacific Earthquake Engineering Research Center (PEER) strong motion database. Characteristics of the selected records set are tabulated in table 2.1. Figure 1 illustrates the records displacement spectra (for damping ratio of 5%) and the 50th percentile (median) of all records displacement spectra, respectively.

Table 2.1. Candidate ground motion records set (LMSR)

Record ID	Event	M	R (Km)	Station	PGA(g)		Selected Component
					X	Y	
FOR	Mendocino	7.1	23.6	Fortuna	0.114	0.116	Y
RIO	Mendocino	7.1	18.5	Rio Dell Overpass	0.459	0.385	X
1061	Duzce	7.1	15.6	Lamont 1061	0.134	0.107	X
FAR	Northridge	6.7	23.9	N Faring Rd	0.273	0.242	X
FLE	Northridge	6.7	29.5	Fletcher Dr	0.162	0.24	Y
G06	Loma Prieta	6.9	19.9	Gilroy Array #6	0.170	0.126	X
AND	Loma Prieta	6.9	21.4	Anderson Dam	0.240	0.244	Y
ADL	Loma Prieta	6.9	21.4	Anderson Dam	0.077	0.064	X
CLD	Loma Prieta	6.9	22.3	Coyote Lake Dam	0.179	0.160	X
ORR090	Northridge	6.7	22.6	Castaic-Old Ridge	0.514	0.568	Y
BLD	Northridge	6.7	31.3	LA-Baldwin Hills	0.168	0.239	Y
MU2	Northridge	6.7	20.8	Beverly Hills	0.444	0.617	Y
TUJ	Northridge	6.7	24	Big Tujunga	0.245	0.163	X
CCN	Northridge	6.7	25.7	Canyon Country	0.222	0.256	Y
CHL	Northridge	6.7	23.7	LA- Chalon Rd	0.185	0.225	Y
GLE	Northridge	6.7	17.7	Sunland	0.157	0.127	X
HOW	Northridge	6.7	20	Burbank-Howard	0.163	0.120	X
WIL	Northridge	6.7	25.7	Hollywood	0.246	0.136	X
VAS	Northridge	6.7	24.2	Vasquez Rocks	0.139	0.151	Y
SORR	San Fernando	6.6	24.9	Castaic-Old Ridge	0.268	0.324	Y

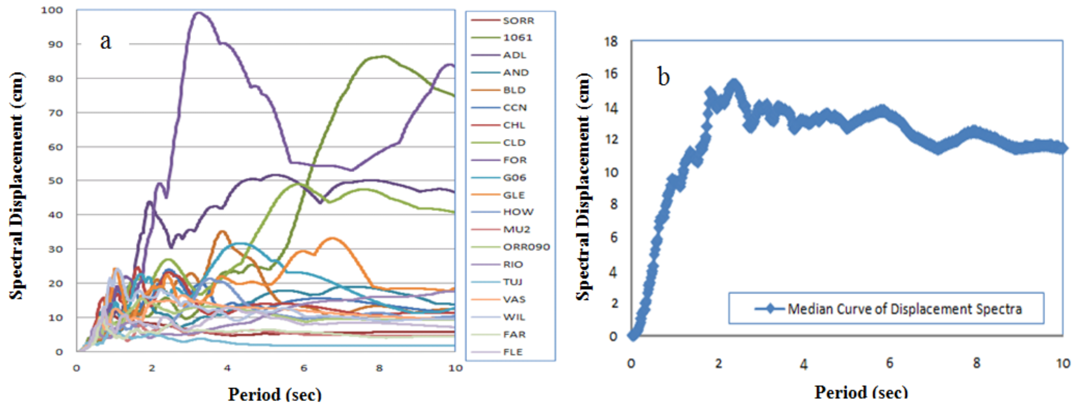

Figure 1. (a) ground motion records displacement spectra (5% Damping); (b) 50th percentile of all records displacement spectra

3. MODELING, ANALYZING AND DESIGNING OF SAMPLE STRUCTURES

To investigate the modelling of collapse probability and developing the fragility curves under selected suite of ground motion records, two single-bay reinforced concrete moment frames with 4 and 6 stories were chosen in this section. The bay size and stories height of all frames is respectively equal to 5.0 and 4.0 meters. Characteristics of studied frames are mentioned in the table below.

Table 3.1. Characteristics of studied Structures

Concrete Compressive Modulus	250(kg/cm2)	Importance Factor	1
Steel Yielding Modulus	4000(kg/cm2)	Live Load Factor	0.20
Elasticity Modulus of Steel	2000000(kg/cm2)	Design Acceleration	0.35
Live Load of Floors	1000 (kg/m)	Dead Load of Floors	4000(kg/m)

Firstly, sample structures were designed based on Displacement-Based Design procedure (Priestley Method) for concrete moment frames, using EC8 Design Displacement Spectrum that was modified by effective damping (ξ_{eff}). After calculating the base shear quantities according to resultant consequences, the optimum sections of sample frames were determined. In the next step, all frames were modelled and analyzed under selected suite of ground motion records to reach global collapse, using COM3 Software. The structural members were modelled using Fiber element in COM3. Each node of this element has six degrees of freedom (3 rotational and 3 transitional). Modelling the concrete frames members are performed using appropriate cells and stirrups details.

4. MODELING THE COLLAPSE PROBABILITY AND DEVELOPING THE FRAGILITY CURVES OF REINFORCED CONCRETE FRAMES

To estimate the structural collapse capacity, firstly the concrete frames are analyzed under chosen ground motion records set and the dispersion of the responses obtained by dynamic analyses is quantified. The 2D nonlinear dynamic analyses are performed using the ground motion component that has the maximum PGA for each of the twenty records in the LMSR set. Then the Peak Ground Acceleration (PGA) is chosen as the intensity measure and the relative intensity values are increased according to FEMA 350 recommendations for performing the IDA procedure. Considering the dispersion of nonlinear dynamic analyses results, Fragility curves can be utilized to quantitatively estimate the collapse capacity of the structures. Developing the fragility curves has two steps. As a first step, the median and standard deviation of collapse capacity are computed using the lognormal Probability Density Function (PDF) of the structural collapse capacity (generally the structural collapse probability has lognormal distribution). The second step is to develop the collapse fragility curve using the computed values of median and standard deviation and the lognormal Cumulative

Distribution Function (CDF) which describes the collapse probability (Equation 4.1).

$$P\left[Collapse \middle| IM\right] = \varphi\left[\frac{\ln(IM) - \ln(\mu)}{\sigma}\right] \qquad (4.1)$$

Where IM is the ground motion Intensity Measure, μ and σ are the median and standard deviation of the structural collapse capacity and φ is the standard normal distribution function. Considering the effect of the 5% linear elastic spectral acceleration at the fundamental period of the structure (Sa (T_1)) on reducing the dispersion of dynamic analyses curves, this parameter is considered as an appropriate IM for expressing the fragility curves. Incremental Dynamic Analysis results and fragility curves of sample concrete frames are seen in Figures 2 and 3, respectively.

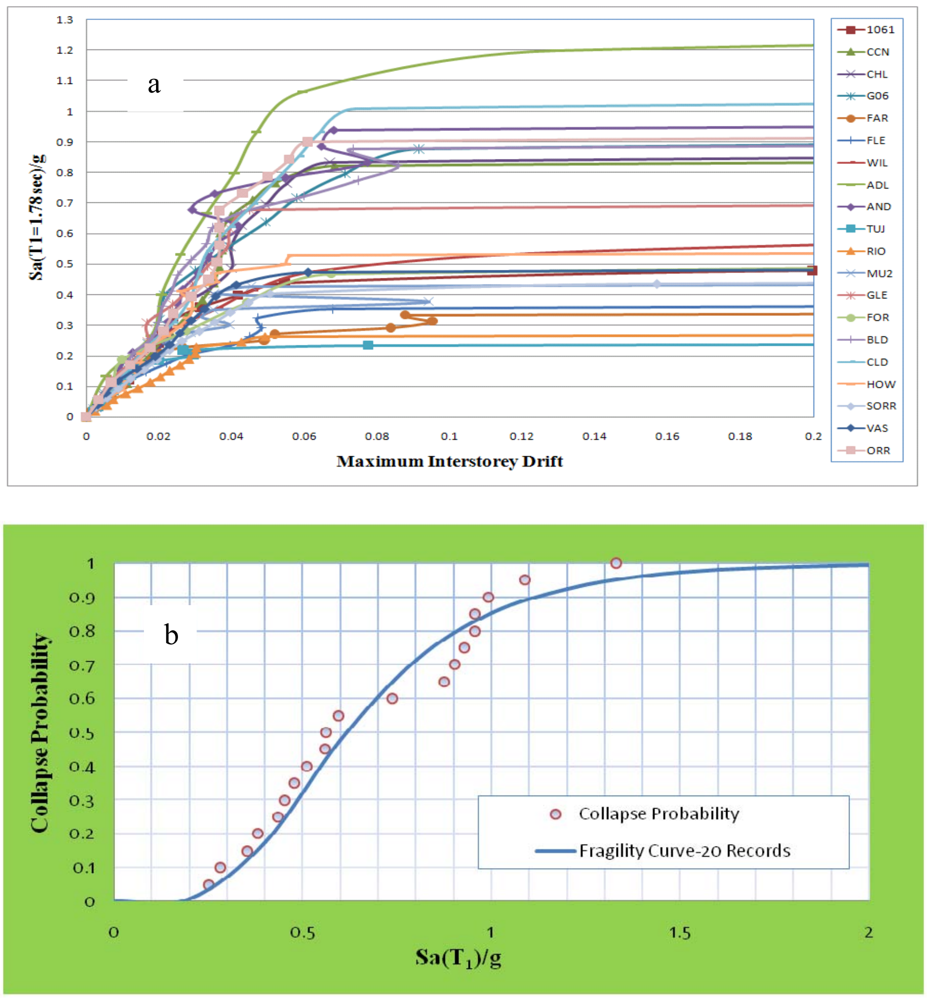

Figure 2. (a) 20 IDA curves obtained by LMSR set for 4 stories concrete frame; (b) Collapse fragility curve of 4 stories concrete frame

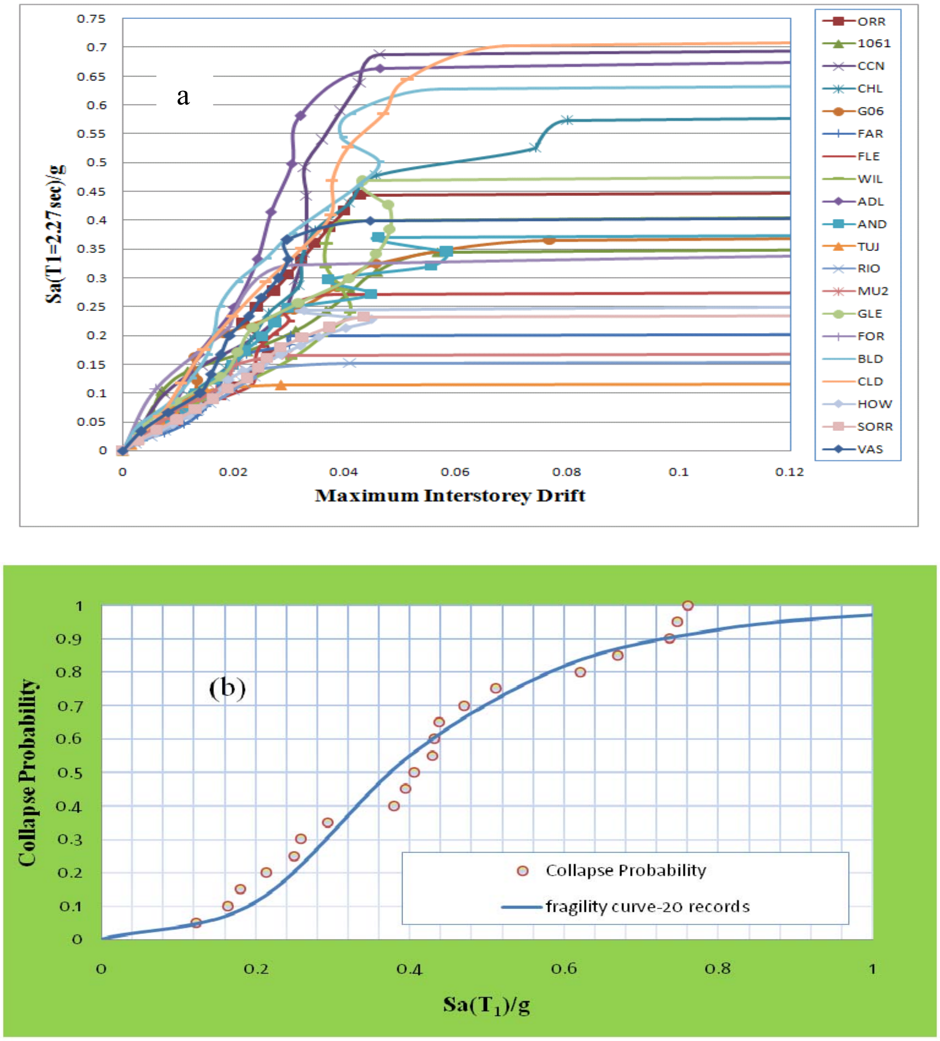

Figure 3. (a) 20 IDA curves obtained by LMSR set for 6 stories concrete frame; (b) Collapse fragility curve of 6 stories concrete frame

5. ESTIMATING THE STRUCTURAL COLLAPSE CAPACITY THROUGH CONVERTING THE PUSHOVER CAPACITY CURVE (SPO) TO IDA CURVE

Calculation of the collapse PGA coefficients is essential for estimation of the structural collapse capacity, through performing the dynamic analyses. In order to estimate the Sa (T_1) coefficients, corresponding to the structural collapse drift limit, the Nonlinear Static Pushover curve and Capacity Spectrum (ADRS) of the structure can be applied for determination of acceleration values near collapse limit. Determining the IM (Sa (T_1)) values corresponding to the structural collapse limit capacity can be reduced the IDA essential calculations and decreased the number of required ground motion records for developing the seismic fragility curves. For this purpose, at first, the concrete frames should be analyzed using Nonlinear Static Pushover (NSP) procedure and the resulted SPO curve should become bilinear according to FEMA356 recommendations. After this, the ductility parameter (μ) is calculated from dividing the maximum displacement of each point (within collapse range) by the yield displacement of the structure (which is obtained from the bilinear SPO curve). Then the effective damping (ζ_{eff}) is calculated for all curve points, using the resulting ductility parameter. In the next step, the collapse spectral acceleration values of a particular record, is obtained based on the structural capacity spectrum (which is plotted in terms of spectral acceleration and spectral displacement according to ATC-40 recommendations). For computing the related PGA coefficient for each selected point within the collapse range, it is essential to multiply all points of the acceleration spectrum of a definite record by a specific coefficient (It should be noted that the acceleration spectrum of each record is plotted in terms of the damping values of the selected points within the collapse range). This coefficient is the value that coincides the related acceleration spectrum (which its damping is equal to the damping of the selected point) with the mentioned point. Thus it is evident that this coefficient should be obtained based on trial and error for all of the points. The resulting coefficient for each point is equal to the analytic value of the spectral acceleration (obtained from IDA process), which is corresponding to the drift of that point. So, it is possible to estimate the values of the IDA curve with providing sufficient accuracy. This estimation, specially, is of importance for the points within collapse range and can reduce the number of required dynamic analyses. In relation to calculating the effective period, it should be noted that, based on the conventional Capacity Spectrum Method (ATC-40), the secant period (capacity spectrum slope) is used as the effective linear period of the SDOF system to determine the maximum displacement. According to FEMA 440, the real effective period, T_{eff}, is generally shorter than the secant period, T_{sec}, which defined by the point on the capacity curve corresponding to the maximum displacement. Results of computing the Sa (T_1) coefficients for estimating the IDA curves points under selected records set are illustrated for 4 and 6 stories concrete frames in Figures 4.a and 5.a, respectively. Figures 4.b and 5.b shows the approximated and real median (50th percentile) curves of IDA results which compared for sample concrete frames. Additionally, a comparison between the approximated and real fragility curves has done in Figures 6 and 7 for 4 and 6 stories concrete frames, respectively.

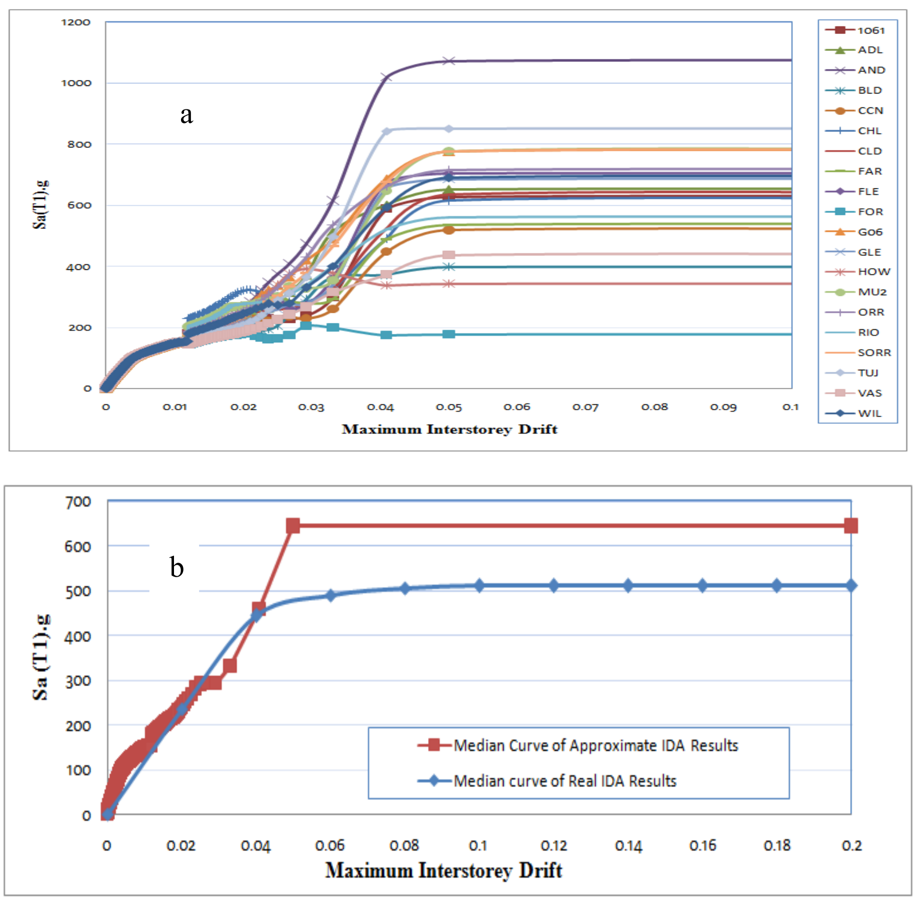

Figure 4. (a) Set of IDA estimated curves for 4 storey concrete frame, (b) Comparing the approximated and real median (50th percentile) curve of IDA results for 4- storey concrete frame

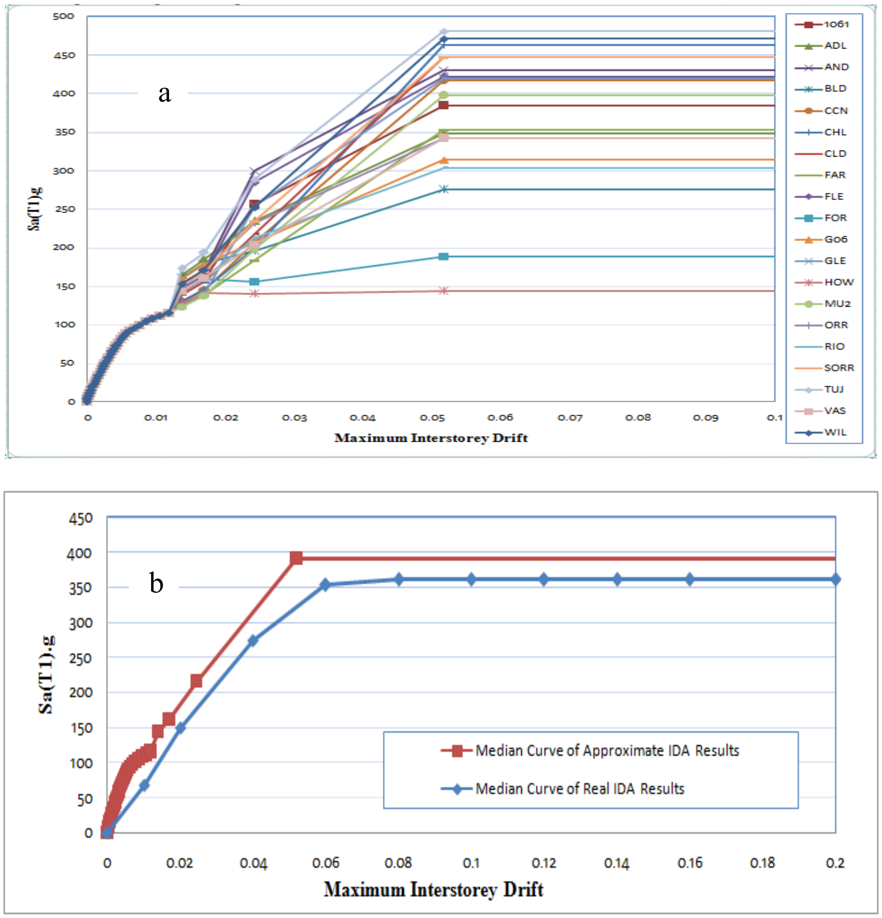

Figure 5. (a) Set of IDA estimated curves for 6 storey concrete frame, (b) Comparing the approximated and real median (50th percentile) curve of IDA results for 6- storey concrete frame

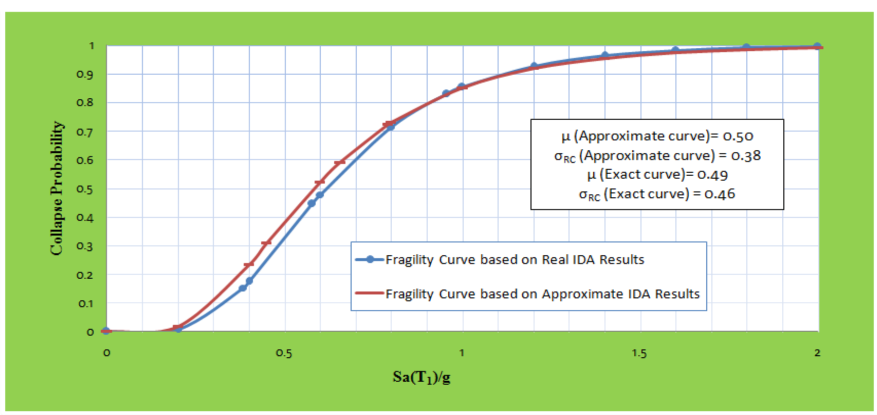

Figure 6. Comparison between the approximated and real fragility curves for 4 storey concrete frame

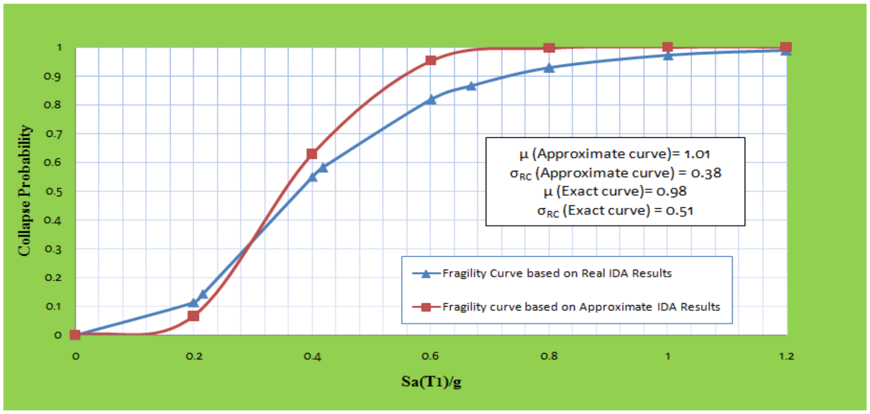

Figure 7. Comparison between the approximated and real fragility curves for 6 storey concrete frame

Comparison between results of the approximated and real median IDA curves for sample concrete frames shows that converting the structural pushover capacity curve to IDA curves is an appropriate approach to estimate the collapse capacity of the structures and also, is a useful technique for decreasing number of the required dynamic analyses to obtain the acceleration (Sa (T_1)) values near collapse limit.

6. SELECTION OF A LIMITED NUMBER OF RECORDS FOR DEVELOPING THE COLLAPSE FRAGILITY CURVES

Considering the fundamental parameters of fragility curves (Mean (μ) and Standard Deviation (σ) values), following, using the result of approximated fragility curves of sample 4 and 6 stories concrete frames, seven appropriate ground motion records are selected based on matching the Mean and Standard Deviation values of the selected suite with their corresponding values (μ and σ) in the LMSR set and the fragility curve obtained by selected records (7 records) that compared with the fragility curve resulted from all records of LMSR set. To make sure that the selected records set is appropriate, analysis results of the sample concrete frames under selected records using IDA process and Mean curve of IDA results obtained from selected ground motion records, is compared with Mean curve of IDA results based on all records of LMSR set. Comparison of the resultant curves has illustrated in figures 8, 9, 10 and 11 for the concrete frames under investigation.

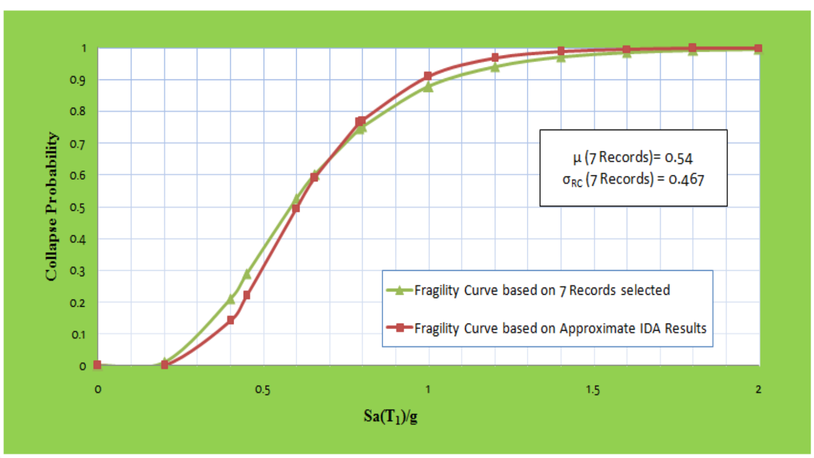

Figure 8. Comparison of the estimated fragility curve based on 7 selected records and approximated fragility curve which obtained by all records of LMSR set for 4 storey concrete frame

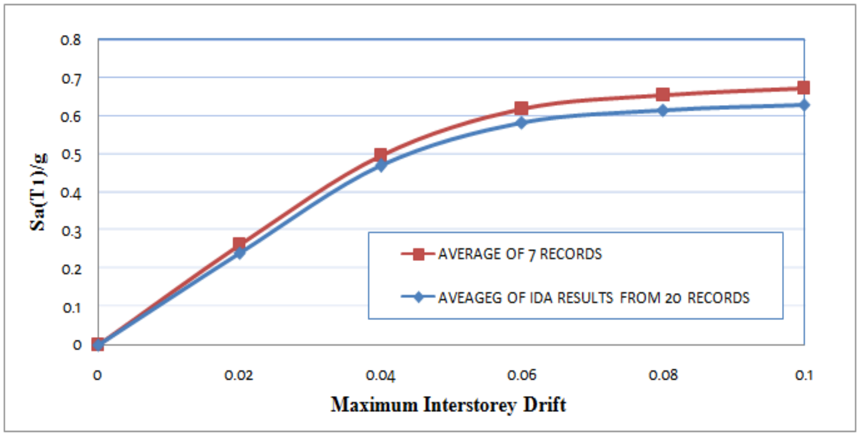

Figure 9. Comparison between the Mean IDA curve based on 7 selected records and Mean IDA curve which obtained by all records of LMSR set for 4 storey concrete frame

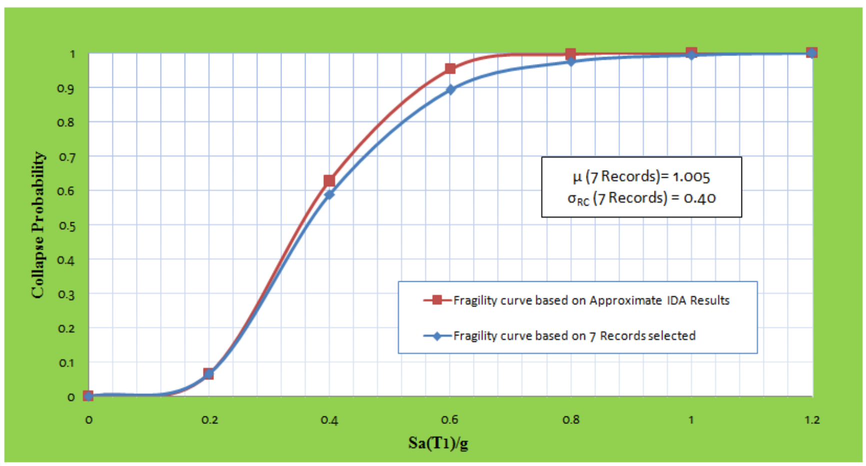

Figure 10. Comparison of the estimated fragility curve based on 7 selected records and approximated fragility curve which obtained by all records of LMSR set for 6 storey concrete frame

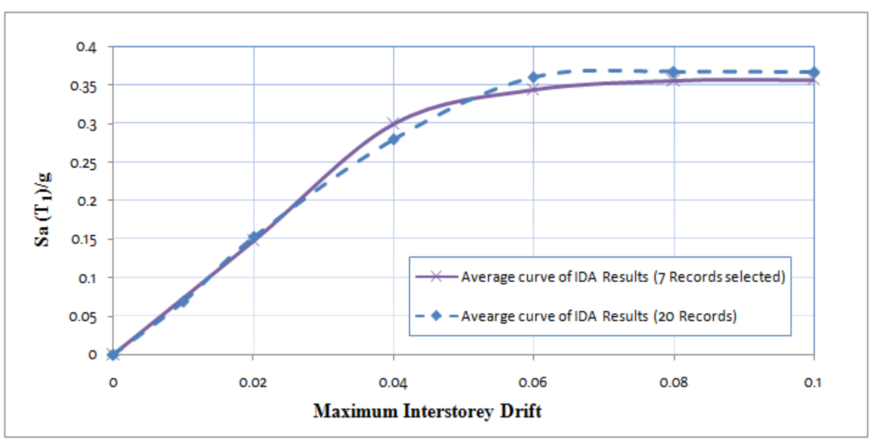

Figure 11. Comparison between the Mean IDA curve based on 7 selected records and Mean IDA curve which obtained by all records of LMSR set for 6 storey concrete frame

7. CONCLUSIONS

In this research, to properly select and scale Ground Motion Records (for Safely Seismic Designing the Reinforced Concrete Frames at Collapse Limit State), the Collapse Probability of Reinforced Concrete Frames under investigation were modeled. According to resultant IDA curves of sample concrete frames and using the approximated collapse fragility curves, an appropriate methodology was developed for selecting and scaling a limited number of ground motion records. The results from studied structures showed that it is possible to decrease number of the required dynamic analyses for estimating the structural collapse capacity, via approximation of the collapse fragility curve (which is obtained from converting the Pushover capacity curve to IDA curves). Based on the results of the proposed method, it is concluded that obtaining the estimated IDA curves (which is computationally beneficial and time-saving compared to perform the Incremental Dynamic Analyses) can be utilized for properly selection of a limited number of ground motion records.

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