

Comparison of Linear and Nonlinear Seismic Behavior of 2D and 3D RC Buildings

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Abstract

This study compared displacement demands obtained from linear and nonlinear time history analyses of 2D and 3D models to investigate how 2D models reflect 3-D models. Estimates of 2D and 3D linear and 2D nonlinear models were also compared to that of 3D nonlinear model to visualize success of linear and 2D nonlinear models in seismic displacement estimates of RC buildings. A total of 288 dynamic analyses were performed with 12 different records taking into account two principal directions of 10-, 15- and 20-storey buildings. Outcomes of the current study imply that 2D representation of 3D models needs careful modelling. Buildings are usually designed according to related earthquake code considering both gravity and seismic loads. Then, an interior frame is used for 2D modelling. The periods of 3D and 2D models need to be closer for proper representation. Another observation is that the 2D linear elastic models do not properly represent the 3D nonlinear models. Thus, it is recommended to use 3D models when linear modelling is preferred. Since 2D nonlinear models represent reasonably well their 3D nonlinear ones, 2D modelling can be preferred for buildings with no irregularity due to extensive labor and time required for 3D nonlinear models.

Keywords: displacement demands, 2D and 3D frame models, linear and nonlinear analyses, time history analysis, ground motions with forward directivity effects.

1. Introduction

Displacement demand estimates of building stock in earthquake prone countries are essential for seismic performance evaluation. Static or dynamic analysis can be used in estimating displacement demands of structures. Although nonlinear time history analysis provides precise estimates, it may cause labor and time loss. Therefore static (pushover) analyses or nonlinear time-history analyses of “equivalent” SDOF system reflecting 3D models are preferred for their simplicity in estimating displacement demands of structures. Also, linear time history analyses are used for estimates of seismic displacement demands.

In this study, three structures selected as 10-, 15- and 20-storey are considered to represent mid-rise reinforced concrete buildings. These buildings are modelled as three dimensional (3D) frame elements without shear walls in SAP2000 [1]. In addition, two dimensional (2D) models were derived from the interior frames in two principal directions of 3D models. In total, 27 models as three 3D and six 2D models for each building were created. 12 past earthquakes records with forward directivity are selected for using linear and nonlinear time-history analysis. In part 1 of the study, displacement demands obtained from linear and nonlinear time history analyses of 2D and 3D



models were compared to investigate how 2D models reflect 3-D models. In part 2 of the study, the estimates of 2D and 3D linear and 2D nonlinear models were compared to that of 3D nonlinear model in order to visualize success of linear and 2D nonlinear models in seismic displacement estimates of RC buildings. A total of 288 dynamic analyses were performed with 12 different earthquakes records taking into account the two principal directions of 10-, 15- and 20-storey buildings. The outcomes and findings of the study are useful to better understand the consequences and issues in implication of 2D and 3D linear and 2D nonlinear models.

2. Description of buildings and modeling approach

10, 15 and 20-storey reinforced concrete buildings were taken into consideration as mid-rise buildings for this study. Building models have double symmetry axis; consists of a typical beam-column RC frame system with no shear walls. The plan view of the 3D models and the 2D models derived from the inner axes of this model were given in Fig 1. The selected buildings are designed according to modern Turkish Earthquake Code (TEC-2007) considering both gravity and seismic loads [2]. A design ground acceleration of 0.40g assuming the highest seismicity zone and soil class Z3 that is similar to the class C soil of FEMA-356 is assumed [3]. Compressive concrete strength value of 35 MPa is considered while the yield strength of both longitudinal and transverse reinforcement is assumed to be 420 MPa. The period values of the dominant vibration mode of the models are given in Table 1. Nonlinear models have been developed to investigate how the linear models reflect the nonlinear models. Nonlinear behavior was achieved through plastic hinges defined at both ends of beams and columns. The plastic hinge length in the critical sections was calculated as half ($h / 2$) of the cross section height in the relevant direction as specified in TEC-2007 for the Mander confined concrete model [4-5]. The software SEMAp is used for moment-curvature analyses of RC sections reflecting their material properties longitudinal and transverse steel content, and axial load level of the critical sections [6]. Using the curvature values obtained as a result of the analyses, the rotation values of the critical points given in Figure 2 were calculated [7]. SAP2000 is used for linear and nonlinear analyses [1]. Newmark mean acceleration method is used for linear and nonlinear time history analyses in SAP2000. Effective stiffness values for all linear and nonlinear models are obtained per 2007 Turkish Earthquake Code; 0.4EI for beams and values between 0.4EI and 0.8EI depending on axial load level for column elements [2, 8, 9]

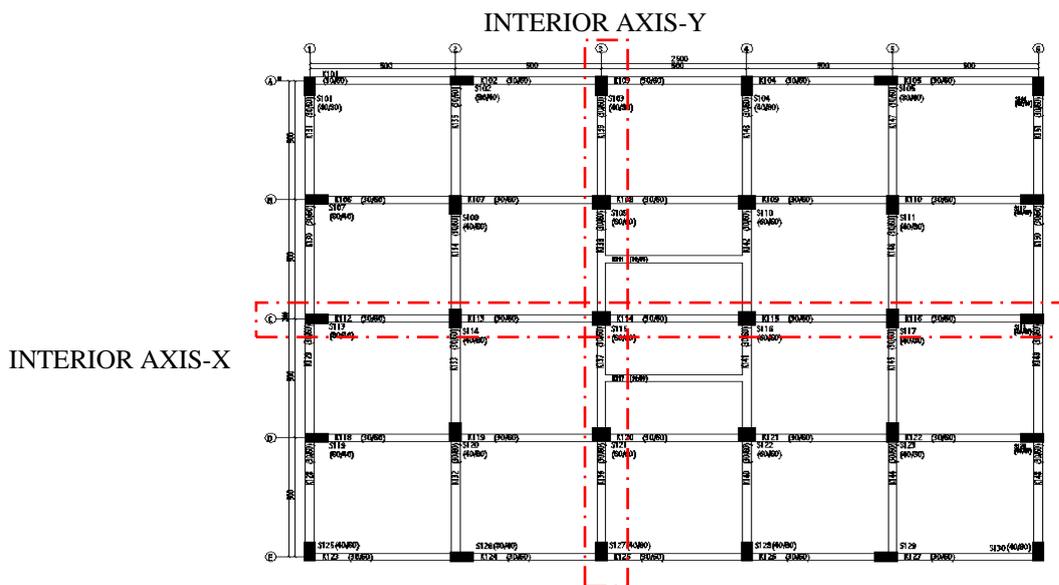


Fig.1. Plan view of the considered buildings (Selected frame models are also marked.)

Table 1. The dominant vibration periods in the relevant direction of the models used in the study (T_1)

Models	T_1 (s)	Models	T_1 (s)	Models	T_1 (s)
10S-2D-X	1.37	15S-2D-X	2.11	20S-2D-X	2.35
10S-2D-Y	1.31	15S-2D-Y	1.97	20S-2D-Y	2.15
10S-3D-X	1.35	15S-3D-X	1.76	20S-3D-X	1.97
10S-3D-Y	1.31	15S-3D-Y	1.71	20S-3D-Y	1.87

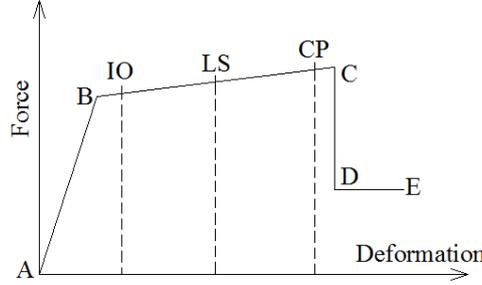


Fig.2. Typical strength-deformation relation

3. Ground motions

A total of 12 earthquake records with forward directivity effect were used in the study. Forward directivity produces ground motion which contains large amplitudes and short durations [10-11]. Because of this, acceleration records with forward directivity can cause very serious demand increases in structures near the fault, as they carry relatively large velocity pulse effects [8, 9, 12]. Such acceleration records take part in some sources as earthquakes carrying pulse effect "near source" [13].

Table 2. Earthquake acceleration records used in the study and their characteristics

No	Earthquake	Date	Station	Component	PGA (g)	PGV (mm/s)	Vs30 (m/s)
1	Cape Men.	25.04.1992	Petrolia	090	0.662	897	712.8
2	Duzce	12.11.1999	Bolu	090	0.822	621	326.0
3	Erzincan	13.03.1992	Erzincan10	EW	0.496	643	274.5
4	Imperial V.	15.10.1979	Brawley Air	315	0.220	389	208.7
5	Kobe	16.01.1995	Takatori	090	0.616	1207	256.0
6	Kocaeli	17.08.1999	Duzce	270	0.358	464	276.0
7	Kocaeli	17.08.1999	Gebze	000	0.244	503	792.0
8	Landers	28.06.1992	Lucerne	275	0.721	976	684.9
9	Loma Pri.	18.10.1989	Los Gatos Lex	090	0.508	728	1070.3
10	Morgan Hill	24.04.1984	C. Lake Dam	285	1.298	808	597.1
11	Northridge	17.01.1994	Newhall F.	360	0.590	972	269.1
12	Northridge	17.01.1994	Sylmar Ol	090	0.604	782	440.5

The characteristics of earthquake records used in this study are given in Table 2 [14]. Although there is a limited number of records with forward directivity in the literature, ground motion records with considerably large PGA band have been used. Elastic acceleration spectrum for the 5% damping ratio of the selected records are given in Figure 3. In addition, the average of acceleration records and response spectrum provided in Turkish Earthquake Code-2007 according to design earthquake with 10% probability of exceedance in 50 years for Z3 type soil was plotted. Despite the fact that the

selected records have a very broad scatter, it seems that it is very close to the spectrum plotted according to TEC-2007.

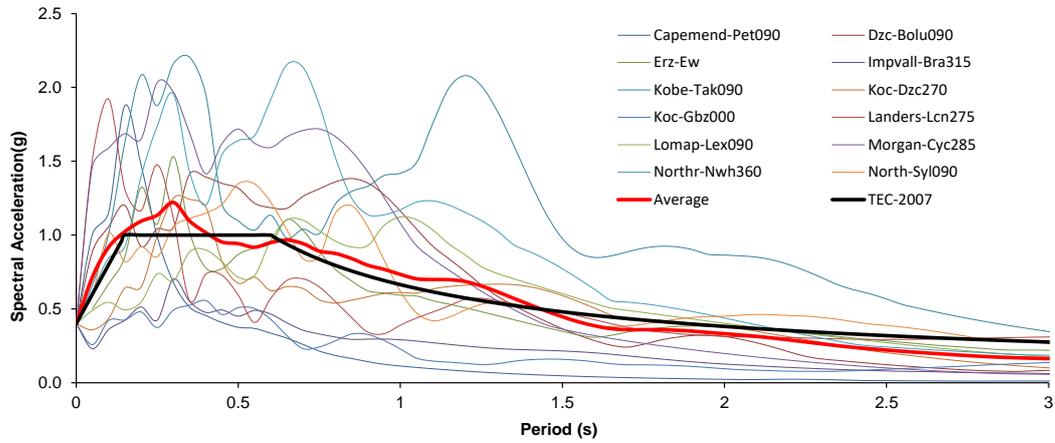


Fig.3. Elastic acceleration spectrum for 5% damping of earthquake acceleration records used in the study

4. Evaluation seismic demand

Seismic demand estimates of 288 linear and nonlinear time history analyses are compared. Building models used in the study are labeled as number of floor, type of model (2D or 3D), type of behavior (L: linear or N: nonlinear), and direction taken into account for analysis. For example, 10S-2DL-X and 10S-2DN-X represent the x-direction analysis result of a 10-storey two-dimensional linear and nonlinear model, respectively. Roof level displacement and interstory drift demands are used as seismic evaluation parameters.

Roof displacements are normalized by building height and called “roof drift ratio” while interstory displacement demands are normalized by story heights and called “interstory drift ratio”. Roof and interstory drift ratio demands are provided Tables 3 and 4, respectively.

Table 3. Roof drift ratio demands of 10-, 15- and 20-storey linear building models (%)

Earthquake	10-storey building				15-storey building				20-storey building			
	2D-L		3D-L		2D-L		3D-L		2D-L		3D-L	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
Cap-Pet090	0.16	0.16	0.15	0.15	0.09	0.09	0.09	0.09	0.07	0.07	0.06	0.07
Dzc-Bolu090	1.03	1.05	1.03	1.05	0.92	0.88	0.55	0.52	0.54	0.61	0.67	0.63
Erz-Ew	0.89	0.86	0.88	0.86	1.18	1.03	0.61	0.58	0.93	0.82	0.77	0.71
Impvall-Bra315	0.50	0.46	0.49	0.46	0.36	0.38	0.31	0.32	0.25	0.28	0.28	0.29
Kobe-Tak090	3.01	3.31	3.12	3.28	2.82	2.47	1.78	1.67	2.02	2.15	1.86	1.80
Koc-Dzc270	1.44	1.32	1.39	1.31	1.05	1.04	0.78	0.76	0.77	0.83	0.80	0.77
Koc-Gbz000	0.34	0.28	0.32	0.28	0.29	0.28	0.23	0.24	0.28	0.23	0.20	0.21
Landers-Lcn275	1.09	1.00	1.07	1.02	1.06	0.92	0.72	0.69	0.91	0.84	0.70	0.65
Lomap-Lex090	1.48	1.40	1.45	1.40	1.33	1.22	0.96	0.92	1.04	0.99	0.91	0.87
Morgan-Cyc285	0.95	0.98	0.97	0.99	0.60	0.62	0.57	0.57	0.41	0.46	0.46	0.47
Northr-Nwh360	2.00	1.86	1.96	1.86	1.19	1.27	1.02	0.99	0.88	0.94	0.95	0.96
Northr-Syl090	1.05	1.07	1.07	1.05	1.59	1.39	0.81	0.73	1.36	1.19	1.04	0.94
Maximum	3.01	3.31	3.12	3.28	2.82	2.47	1.78	1.67	2.02	2.15	1.86	1.80
Minimum	0.16	0.16	0.15	0.15	0.09	0.09	0.09	0.09	0.07	0.07	0.06	0.07
Average	1.16	1.14	1.16	1.14	1.04	0.97	0.70	0.67	0.79	0.78	0.72	0.70

Table 4. Interstory drift ratio demands of 10-, 15- and 20-storey linear building models (%)

Earthquake	10-storey building				15-storey building				20-storey building			
	2D-L		3D-L		2D-L		3D-L		2D-L		3D-L	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
Cap-Pet090	0.37	0.35	0.31	0.29	0.33	0.28	0.22	0.27	0.23	0.21	0.17	0.16
Dzc-Bolu090	1.37	1.48	1.42	1.47	1.46	1.07	0.94	0.96	1.22	1.07	0.94	0.82
Erz-Ew	1.20	1.18	1.18	1.17	1.85	1.82	1.12	0.94	1.39	1.51	1.34	1.19
Impvall-Bra315	0.64	0.57	0.62	0.58	0.56	0.52	0.53	0.53	0.46	0.42	0.38	0.40
Kobe-Tak090	3.93	4.54	4.20	4.49	3.87	3.43	2.44	2.36	2.58	2.72	2.60	2.31
Koc-Dzc270	1.78	1.73	1.79	1.73	1.63	1.66	1.13	1.10	1.11	1.20	1.20	1.10
Koc-Gbz000	0.51	0.43	0.49	0.43	0.48	0.43	0.41	0.38	0.45	0.33	0.33	0.35
Landers-Lcn275	1.49	1.56	1.50	1.23	1.43	1.28	1.01	0.81	1.35	1.05	0.69	0.60
Lomap-Lex090	1.85	1.86	1.87	1.84	1.80	1.67	1.36	1.31	1.48	1.37	1.18	1.12
Morgan-Cyc285	1.37	1.47	1.38	1.43	1.74	1.27	1.27	1.10	1.32	1.16	0.95	0.93
Northr-Nwh360	2.69	2.66	2.68	2.69	2.09	1.70	1.71	1.48	1.40	1.47	1.42	1.34
Northr-Syl090	1.55	1.45	1.52	1.45	2.11	1.81	1.08	1.00	2.00	1.62	1.33	1.21
Maximum	3.93	4.54	4.20	4.49	3.87	3.43	2.44	2.36	2.58	2.72	2.60	2.31
Minimum	0.37	0.35	0.31	0.29	0.33	0.28	0.22	0.27	0.23	0.21	0.17	0.16
Average	1.56	1.61	1.58	1.57	1.61	1.41	1.10	1.02	1.25	1.18	1.04	0.96

Roof drift ratios of each building subjected to 12 earthquake records for linear elastic analyses are plotted in Figure 4. It is obvious that 10-storey models have higher scatters for both 2D and 3D models. The comparison of 3D and 2D models shown in Figures 4a and 4b clearly points out that the 2D models have higher scatters. The ratios of maximum and minimum roof drifts are 21.6, 31.3 and 30.3 for 10-, 15- and 20-storey buildings, respectively. The difference in demands is an indication of different damage levels caused by ground motion records on the same buildings.

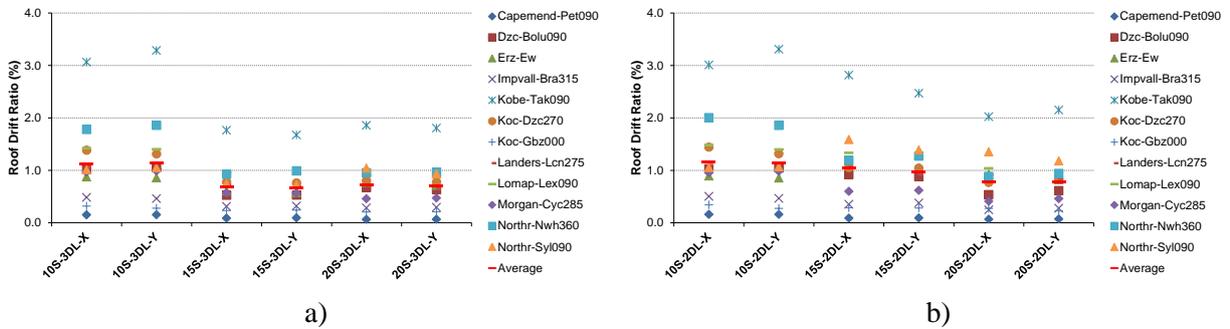


Fig.4. Roof drift ratios of 10-, 15- and 20-storey buildings as linear modelled 3D and 2D (%)

When the average roof drift ratios are considered, the highest seismic risk is seen in 10-storey buildings. As shown in Figure 5, the spectral acceleration values corresponding to the period values of 10-storey buildings are higher than that of the other buildings in most of earthquake records, especially for strong ones (for example: Kobe-Tak090, Northr-Nwh360, Lomap-Lex090). The higher seismic acceleration demand for 10-storey buildings explains their higher displacement demands.

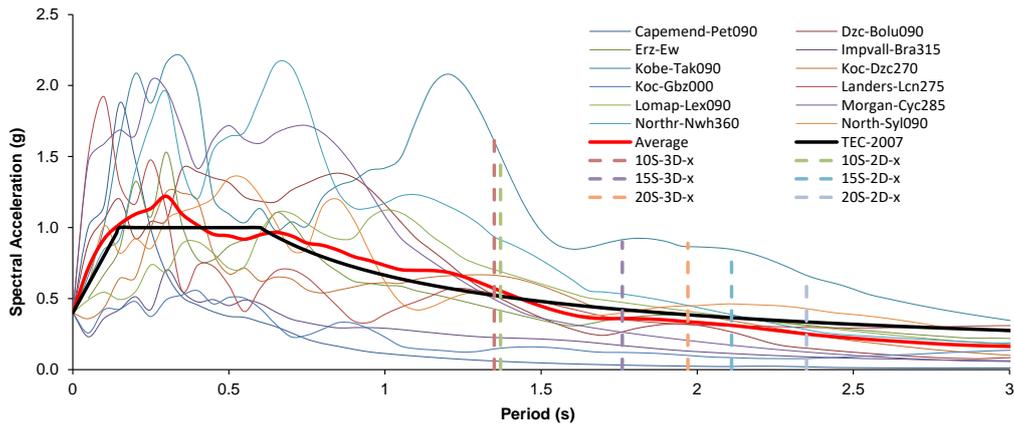


Fig.5. The spectral acceleration values corresponding to the period values of 10-, 15- and 20- storey buildings

Figure 6 plots interstory drift ratios of each building subjected to 12 earthquake records for linear elastic analyses. The scatter in 2D models is more apparent than that of 3D models. Among the building sets, the highest scatter for the interstory drifts is observed in the 10-storey buildings.

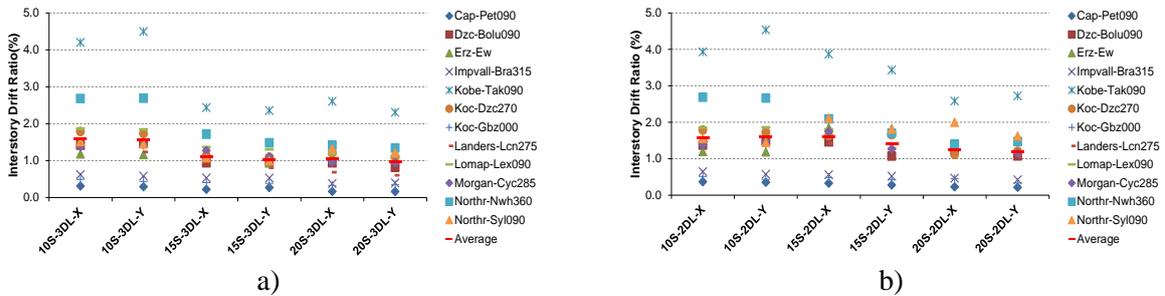


Fig.6. Interstory drift ratios of 10-, 15- and 20-storey buildings as linear modelled 3D and 2D (%)

Figure 7 compares the average roof and interstory drift ratios of 2D and 3D models to see how 2D linear models reflect 3D linear models. The figure obviously indicates that the 2D linear models of 10-storey buildings perfectly represent their 3D models. Although the 2D models of 20-storey models are quite reasonable, the 2D models of 15-storey estimate about 40% higher demands compared to the 3D models. The comparison of 2D and 3D model estimates obviously shows that the 2D linear models reflect their 3D models for 10- and 20-storey buildings. However, it is difficult to say similar observation for 15-storey buildings.

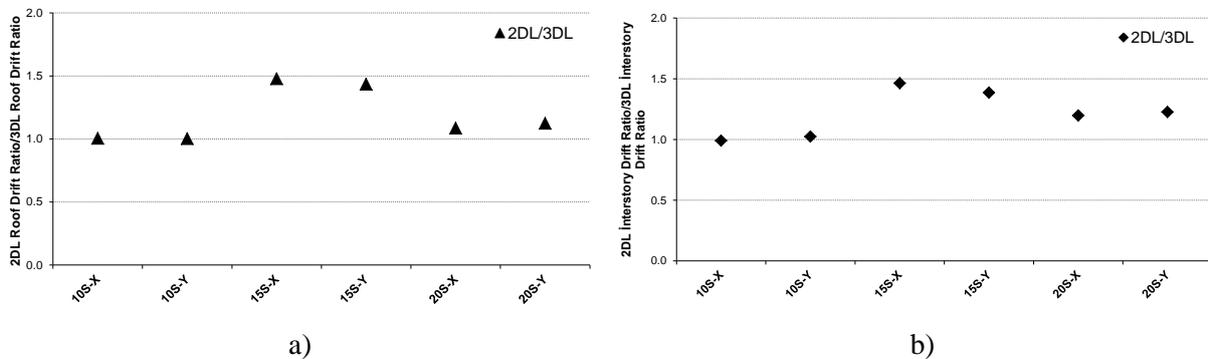


Fig.7. Comparison of roof and interstory drift ratios of 10-, 15- and 20-storey buildings for linear 2D and 3D models

The floors at which the maximum interstory drift ratios (IDR) were determined for linear 2D and 3D models of 10-, 15- and 20-storey buildings. In this context, primarily the models were represented by 5-story groups and then the frequency of occurrence for the floor where the maximum IDR occurs is calculated in percent as shown in Figure 8. These values were given as the ratio that the number of occurrences of the maximum relative displacement in the mentioned group to the number of the earthquake records used. Figure 8 illustrates that the 2D and 3D models have similar results indicating good representation of 2D models for their 3D models. When the buildings are evaluated separately, it is seen that the maximum IDR is concentrated in the lower floors of the 10-story buildings, in the middle floors of the 15-story buildings, and in the lower and upper floors of the 20-story buildings. The maximum IDR observed at the upper stories for the buildings with no shear walls can be explained with the reduction in column sizes at the upper stories, the decrease in effective section stiffness due to lower column axial loads and forward directivity effect of the ground motion records used in the study [8, 9].

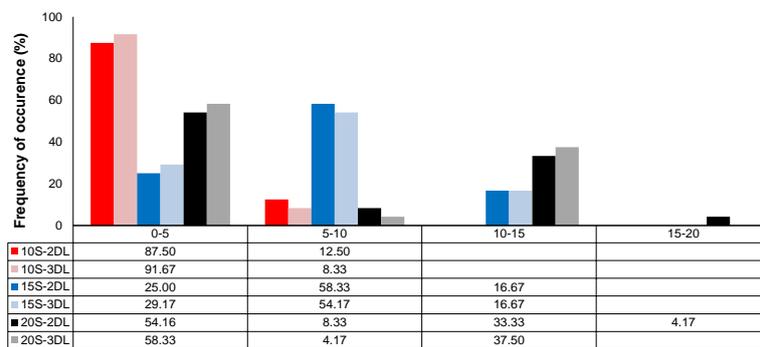


Fig.8. Location of maximum interstory drift ratio for linear 10-, 15- and 20-storey building models

The results of linear and nonlinear time history dynamic analyses are compared for the roof and interstory drift ratios in order to visualize success of linear models in estimating nonlinear demands of RC buildings. Tables 5 and 6 lists nonlinear roof and interstory drift ratio demands for 2D and 3D models. Figure 9a compares the average roof drift ratio of linear and nonlinear models. The average roof drift demands obtained with linear models are normalized by that obtained using corresponding nonlinear models. It is obvious that linear models provide higher demand estimates than their corresponding nonlinear models. The 2D linear 10-storey building model represents reasonably well its nonlinear model while the 3D linear 15- and 20-storey building models provides better demand estimates. It should be kept in mind that the dominant vibration periods of 2D and 3D models of 10-storey building are very close while there are differences in dominant vibration periods of 2D and 3D models of 15- and 20-storey buildings. The better representation of nonlinear model for 10-storey buildings can be attributed to having closer vibration periods. Similar trends are also observed for the interstory drift ratios as seen in Figure 9b.

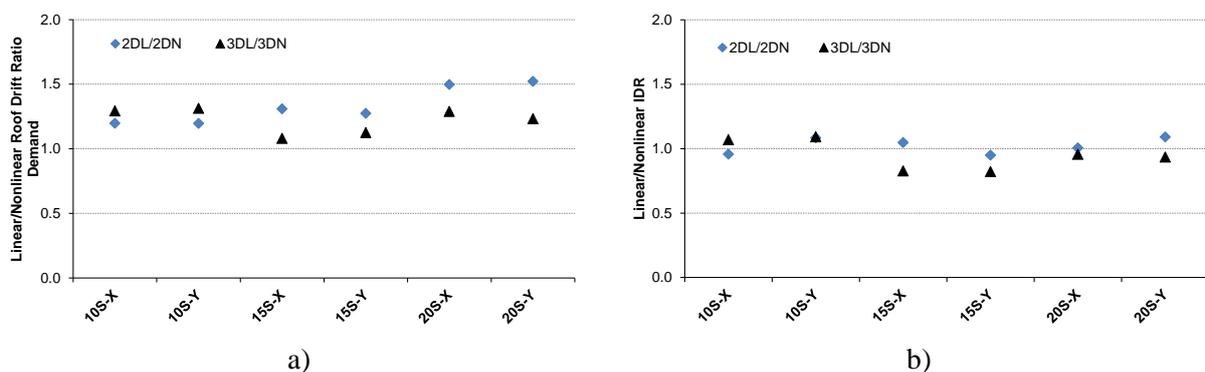


Fig.9. Comparison of average roof and interstory drift ratio demands for linear and nonlinear models

The estimates of 2D and 3D linear and 2D nonlinear models were also compared to that of 3D nonlinear model in order to visualize success of linear and 2D nonlinear models in seismic demand estimates of RC buildings as shown in Figure 11. It is obvious that the 2D linear models gives higher demand estimates having 30 to 50% higher estimates compared to the 3D nonlinear models. In general, 2D nonlinear models are the best representation of 3D nonlinear models.

Table 5. Roof drift ratio demands of 10-, 15- and 20-storey nonlinear building models (%)

Earthquake	10-storey building				15-storey building				20-storey building			
	2D-N		3D-N		2D-N		3D-N		2D-N		3D-N	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
Cap-Pet090	0.16	0.16	0.15	0.16	0.09	0.09	0.09	0.09	0.07	0.08	0.06	0.07
Dzc-Bolu090	0.62	0.68	0.66	0.75	0.64	0.61	0.54	0.50	0.32	0.29	0.45	0.43
Erz-Ew	0.92	1.02	0.88	0.84	0.88	0.85	0.60	0.60	0.51	0.52	0.62	0.60
Impvall-Bra315	0.43	0.35	0.46	0.39	0.34	0.35	0.31	0.30	0.24	0.23	0.26	0.28
Kobe-Tak090	1.41	1.39	1.70	1.95	1.19	1.18	1.09	1.03	0.80	0.78	0.87	0.90
Koc-Dzc270	1.24	1.11	1.18	0.87	0.69	0.71	0.76	0.74	0.41	0.46	0.52	0.62
Koc-Gbz000	0.34	0.27	0.32	0.21	0.29	0.28	0.24	0.24	0.19	0.23	0.20	0.21
Landers-Lcn275	1.11	1.07	1.07	0.95	1.12	0.94	0.60	0.57	1.16	0.77	0.81	0.65
Lomap-Lex090	1.68	1.54	1.19	1.20	1.11	1.11	0.99	0.57	0.67	0.80	0.78	0.84
Morgan-Cyc285	0.93	1.12	0.87	0.88	0.59	0.61	0.57	0.56	0.44	0.46	0.44	0.46
Northr-Nwh360	1.18	1.11	0.85	0.86	1.13	1.08	0.84	0.83	0.82	0.75	0.79	0.76
Northr-Syl090	1.57	1.56	0.89	0.92	0.88	0.81	0.95	0.94	0.58	0.51	0.61	0.63
Maximum	1.68	1.56	1.70	1.95	1.19	1.18	1.09	1.03	1.16	0.80	0.87	0.90
Minimum	0.16	0.16	0.15	0.16	0.09	0.09	0.09	0.09	0.07	0.08	0.06	0.07
Average	0.97	0.95	0.85	0.83	0.75	0.72	0.63	0.58	0.52	0.49	0.53	0.54

Table 6. Interstory drift ratio demands of 10-, 15- and 20-storey nonlinear building models (%)

Earthquake	10-storey building				15-storey building				20-storey building			
	2D-N		3D-N		2D-N		3D-N		2D-N		3D-N	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
Cap-Pet090	0.37	0.35	0.31	0.31	0.33	0.29	2.53	2.93	0.17	0.19	0.16	0.16
Dzc-Bolu090	1.52	1.27	1.22	1.38	1.67	1.56	1.21	1.24	0.85	0.74	1.02	0.94
Erz-Ew	1.70	1.66	1.52	1.34	1.90	1.91	1.45	1.38	1.30	1.39	1.45	1.45
Impvall-Bra315	0.62	0.54	0.63	0.58	0.60	0.57	0.53	0.52	0.48	0.39	0.38	0.39
Kobe-Tak090	2.37	2.08	2.63	3.11	2.34	2.37	2.48	2.33	1.83	1.52	1.45	1.63
Koc-Dzc270	1.99	1.63	1.86	1.45	1.42	1.52	1.43	1.44	0.85	0.85	0.86	1.02
Koc-Gbz000	0.56	0.45	0.51	0.29	0.49	0.43	0.40	0.38	0.48	0.33	0.36	0.36
Landers-Lcn275	1.77	1.71	1.73	1.58	1.35	1.21	0.97	0.98	5.98	2.60	3.55	1.54
Lomap-Lex090	2.55	2.19	2.05	1.93	2.39	2.41	1.91	0.98	1.48	1.57	1.29	1.46
Morgan-Cyc285	1.80	1.81	1.55	1.50	1.30	1.34	1.17	1.21	1.18	0.98	0.88	0.85
Northr-Nwh360	1.98	1.60	1.59	1.58	2.37	2.42	1.67	1.73	2.86	2.00	1.85	1.41
Northr-Syl090	2.25	2.37	1.49	1.39	2.17	1.89	1.65	1.71	2.60	1.75	2.29	1.45
Maximum	2.55	2.37	2.63	3.11	2.39	2.42	2.53	2.93	5.98	2.60	3.55	1.63
Minimum	0.37	0.35	0.31	0.29	0.33	0.29	0.40	0.38	0.17	0.19	0.16	0.16
Average	1.62	1.47	1.42	1.37	1.53	1.49	1.45	1.40	1.67	1.19	1.30	1.06

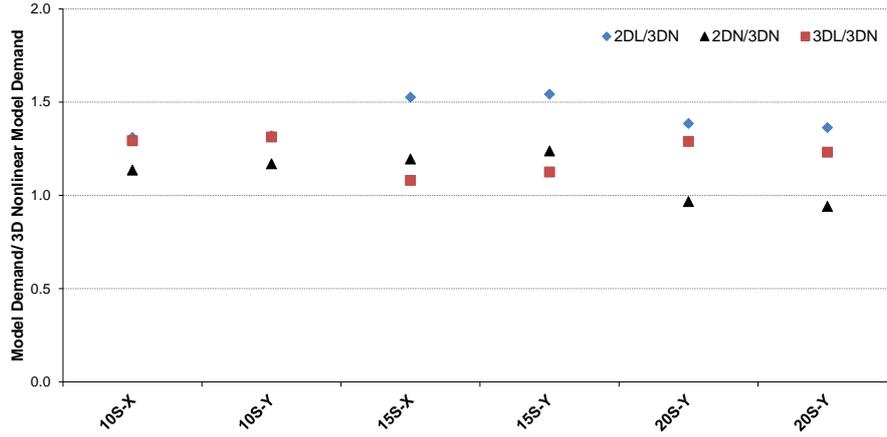


Fig.11. The ratio of displacement demands obtained from models to 3D nonlinear displacement demand

5. Observations and results

This study compared displacement demands obtained from linear and nonlinear time history analyses of 2D and 3D models to investigate how 2D models reflect 3-D models. The estimates of 2D and 3D linear and 2D nonlinear models were also compared to that of 3D nonlinear model in order to visualize success of linear and 2D nonlinear models in seismic displacement estimates of RC buildings. A total of 288 dynamic analyses were performed with 12 different earthquake records taking into account the two principal directions of 10-, 15- and 20-storey buildings. The observations and outcomes are summarized below:

- The roof and interstory drift demands illustrate that the 10-storey building models have the highest demand ratios and scatter. The comparison of 3D and 2D models clearly points out that the 2D models have higher scatters.
- The comparison of average roof and interstory drift ratios for 2D and 3D models obviously indicates that the 2D linear models reflects their 3D models reasonably well for 10- and 20-storey buildings. However, it is difficult to say similar observation for 15-storey buildings. The differences between 2D and 3D models in demands estimates are about 0%, %50 and 12% for 10-, 15- and 20-storey buildings, respectively.
- The maximum interstory drift ratios were concentrated at lower floors of 10-storey buildings, at the middle floors of 15-storey buildings, and at the lower or upper floors of 20-storey buildings. This observation indicates that as the number of storey increases, it is difficult to estimate location of the floor with maximum interstory drift.
- The results of linear and nonlinear time history dynamic analyses are compared for the roof and interstory drift ratios in order to visualize success of linear models in estimating nonlinear demands of RC buildings. The average roof and interstory drift demands obtained with linear models are normalized by that obtained using corresponding nonlinear models. The results show that linear models provide higher demand estimates than their corresponding nonlinear models. The 2D linear 10-storey building model represents reasonably well its nonlinear model while the 3D linear 15- and 20-storey building models provides better demand estimates. It should be kept in mind that the dominant vibration periods of 2D and 3D models of 10-storey building are very close while there are differences in dominant vibration periods of 2D and 3D models of 15- and 20-storey buildings. The better representation of nonlinear model for 10-storey buildings can be attributed to having closer vibration periods.

In general, the outcomes of the current study imply that 2D representation of 3D models needs careful modelling. The buildings are usually designed according to the related earthquake code considering both gravity and seismic loads. Then, an interior frame is used for 2D modelling. The periods of 3D and 2D models need to be closer in order to have proper representation. Another observation is that the 2D linear elastic models do not properly represent the 3D nonlinear models. Thus, it is recommended to use 3D models when linear modelling is preferred. Since the 2D nonlinear models represent reasonably well their 3D nonlinear ones, the 2D modelling can be preferred for the buildings with no irregularity due to extensive labor and time required for 3D nonlinear models.

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