An Investigation on DDBD Approach of Near-Fault RC Frame, RC Wall-Frame and Steel Braced RC Frame Systems

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SUMMARY:
Direct Displacement Based Design (DDBD) is one of the novel approaches for structural design of reinforced concrete frame systems. In this study, DDBD approach is investigated for single moment-resisting reinforced concrete frame, dual reinforced concrete wall-frame and dual steel braced reinforced concrete frame systems. In this methodology, first the displacement profile is calculated, following which the equivalent single degree of freedom system is modeled considering the damping characteristics of each member. Then, having calculated the effective period and secant stiffness of the structure, the base shear is obtained based on which the design process can be carried out. For each system three frames are designed using Direct Displacement Based Design approach. The frames are then analyzed using nonlinear time-history analysis with 7 near-field earthquake accelerograms. In order to reach an understanding of response of the three systems designed using Direct Displacement Based Design, damage index is investigated through lateral drift profile of the models. Compatibility of the above mentioned systems with Direct Displacement Based Design approach is also studied via comparison of the nonlinear time-history analysis results. The results of the analyses indicate efficiency of the DDBD approach for different reinforced concrete structural systems located in near-field regions.

Keywords: Direct Displacement Based Design, RC frame systems, Time-history analysis, Near-field accelerograms

1. INTRODUCTION

In recent years, there has been a great tendency toward performance-based seismic design of structures. Therefore, various methods have been developed namely Capacity Spectrum Method [1], the N-2 Method [2], and Direct Displacement-Based Design method. A new performance-based seismic design procedure called the Direct Displacement-Based Design (DDBD) proposed by Priestley [3] has recently received notable acceptance among researchers. It seems that the methods could be a rational alternative to traditional erroneous force-based seismic design of structures. The method defines the design performance level of the structure in terms of displacement limits. Therefore, displacement is the key parameter of the design method.

Near-Fault ground motions, on the other hand, impose severe seismic demands on structures in terms of displacement and ductility due to the effects of both directivity and fling step pulses. Indeed long-period pulses, and high frequency content of motions in the near-fault zone can excite both short and long period structures quite well. Previous studies [4] have proved the importance of the above mentioned demands on the response of near-fault structures. Many studies [5] have also showed that current force-based seismic design procedures are not appropriate for the design of near-fault structures and more efficient methods are needed.

Due to the importance of severe pulse-type displacement demands on near-fault structures, on one hand, and the key role of displacement in DDBD procedure, on the other, it is argued that the method would be appropriate for seismic design of near-fault type structures.

In this study, DDBD approach is investigated for single moment-resisting reinforced concrete frame, dual reinforced concrete wall-frame and dual steel braced reinforced concrete frame systems.

2. DDBD APPROACH

In this section the DDBD methodology employed for the above mentioned systems is clarified via following flow charts. For each system three 4-, 8- and 12-story models are designed based on the corresponding chart.

2.1. RC Frame systems

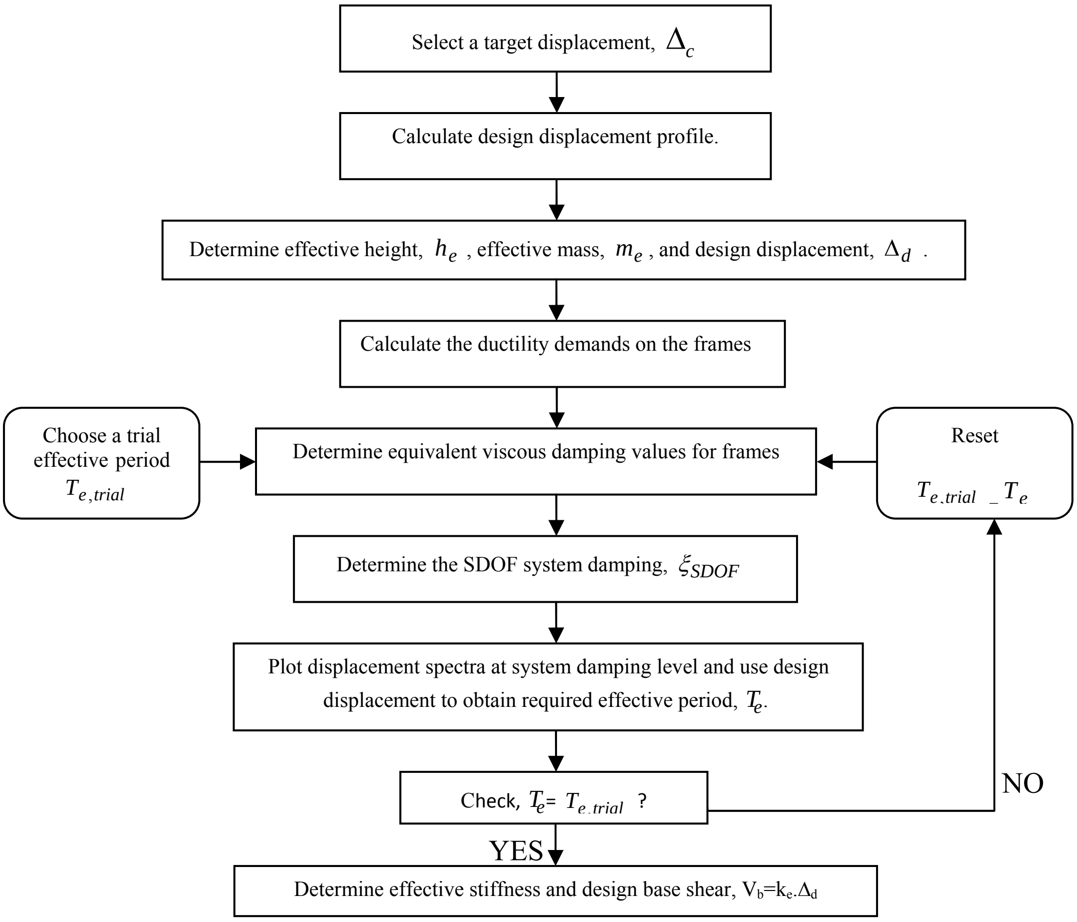

Figure 2.1. DDBD flowchart for RC frames

The final design results of the direct displacement based design approach for the RC frame models are given in Table2.1.

Table 2.1. Initial results of RC frame models

	4 storey	8 storey	12 storey
Drift limit θ_d	0.025	0.025	0.025
Effectivemass m_e (kg)	192660	375680	567920
Effective height H_e (mm)	9105	17650	26320
Designdisplacement Δ_d (mm)	240	404	525
Equivalent damping ξ_{eq}	12.58	12.64	12.2
Effective Period T (s)	1.4	2.1	3
Base shear (kN)	914	1332	1282

2.2. RC Wall-Frame systems

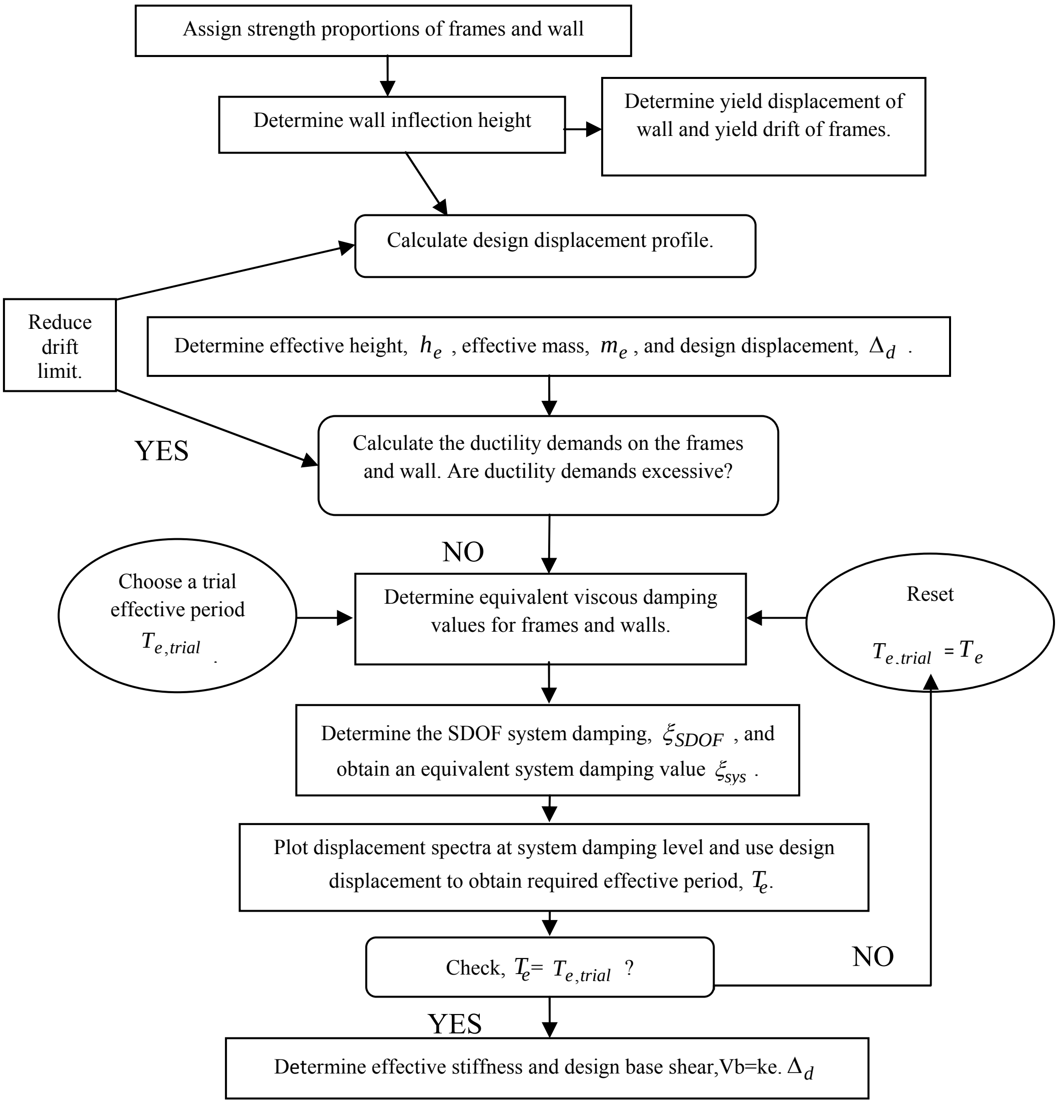

Figure 2.2. DDBD flowchart for RC wall-frames

The final design results of the direct displacement based design approach for the RC wall-frame models are given in Table 2.2.

Table 2.2. Initial results of RC wall-frame models

	4 storey	8 storey	12 storey
Drift limit θ_d	0.025	0.025	0.025
Effectivemass m_e (kg)	795167	1575298	2298357
Effective heightH_e (mm)	10876	20602	30450
Designdisplacement Δ_d (mm)	256	475	663
Equivalent damping ξ_{eq}	12	11.25	10.14
Effective Period T (s)	1.79	2.76	3.50
Base shear (kN)	2504	3875	4907

2.3. Steel braced RC frame systems

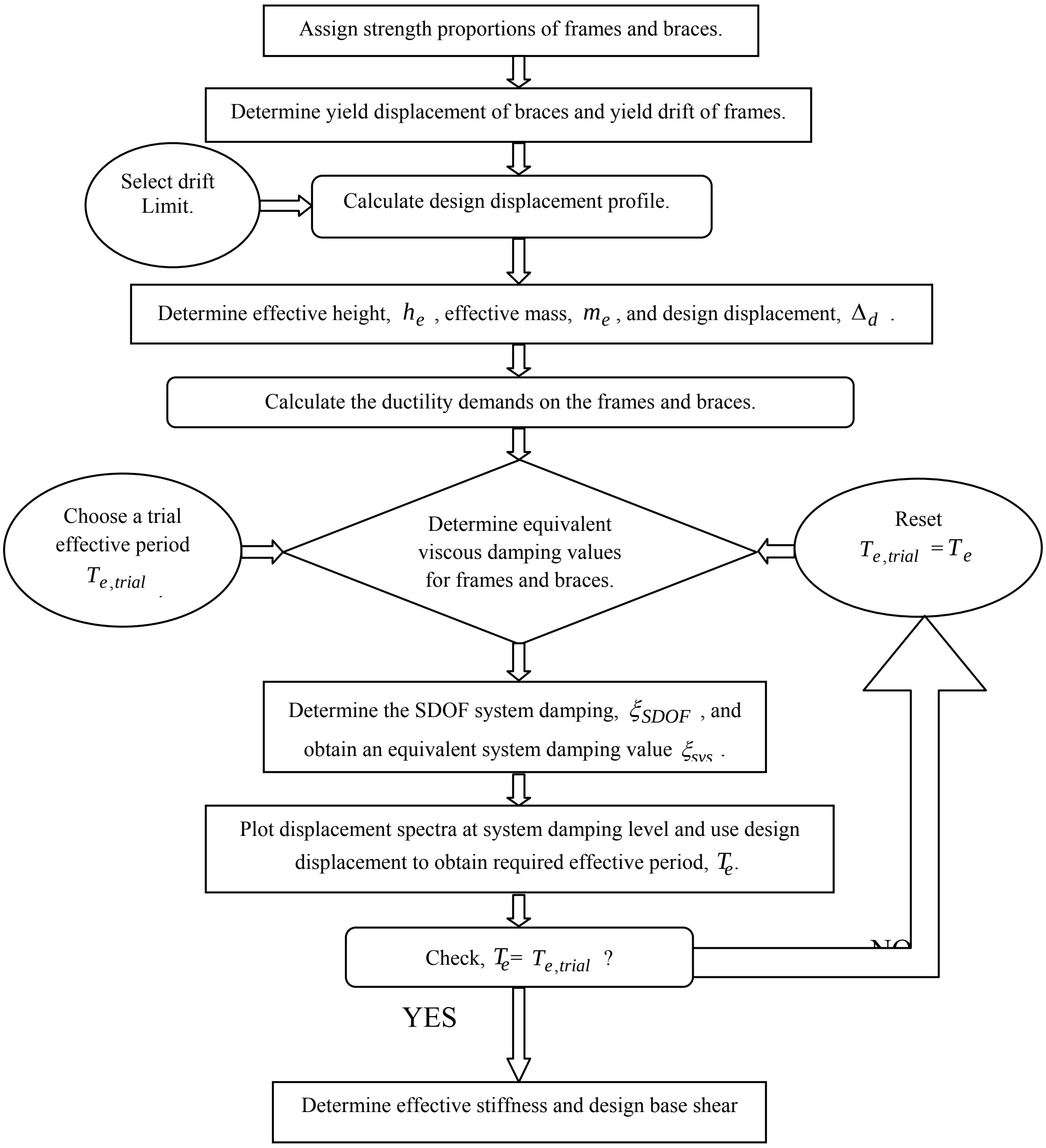

Figure 2.3. DDBD flowchart for steel braced RC frames

The final design results of the direct displacement based design approach for the steel braced RC frame models are given in Table 2.3.

Table 2.3. Initial results of steel braced RC frame models

	4 storey	8 storey	12 storey
Drift limit θ_d	0.025	0.025	0.025
Effectivemass m_e (kg)	229836	462550	694873
Effective heightH_e (mm)	9670	18390	27140
Designdisplacement Δ_d (mm)	230	414	587
Equivalent damping ξ_{eq}	13.62	13.64	13.49
Effective Period T (s)	1.70	2.65	3.30
Base shear (kN)	650.468	991.563	1299.194

3. PROPERTIES OF THE MODELS

Three 4-story, 8-story and 12-story buildings with three different structural configurations (RC Frame, RC Wall-Frame and Steel Braced RC Frame Systems) are designed based on the DDBD approaches mentioned in each section and according to the following considerations.

The structures are assumed to be residential, placed in a very high seismicity region with Soil Type II and according to the Iranian Code of Practise for Seismic Design of Buildings (Standard No.2800, third edition). The material properties are as the following:

$f'_c = 30MPa$, $E_C = 25740MPa$, $f_y = 400\,MPa$, $Es = 200000 \quad MPa$

An internal 2D frame is selected from each of the 4-story, 8-story and 12-story buildings. The frames are 3.5m in height and have 3 spans with 5m in width. Figs. 3.1., 3.2. and 3.3. display the schematic views of the above mentioned systems.

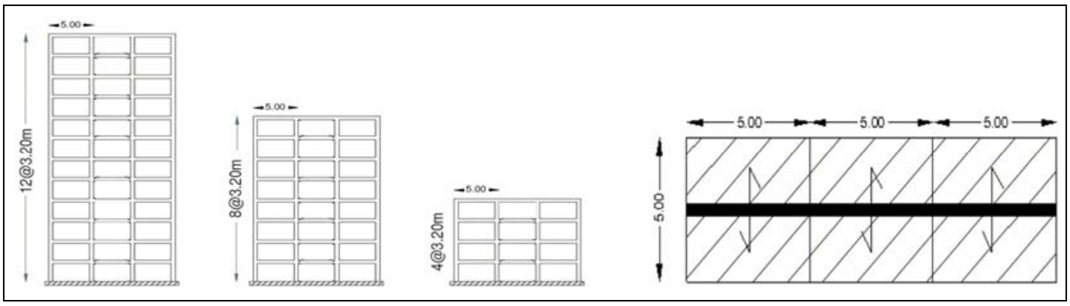

Figure 3.1. Plan and elevation of the RC frame models

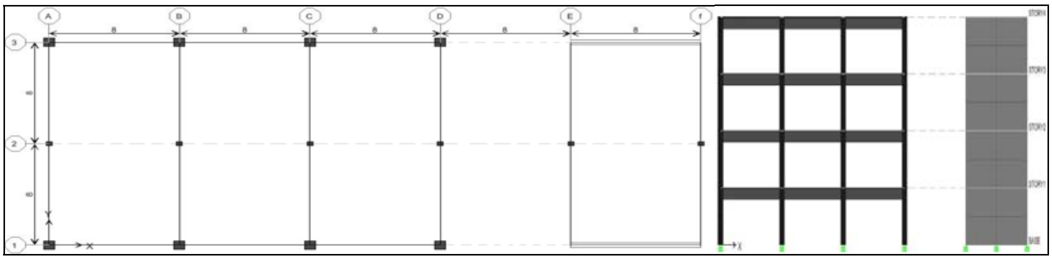

Figure 3.2. Plan and elevation of the RC wall-frame models

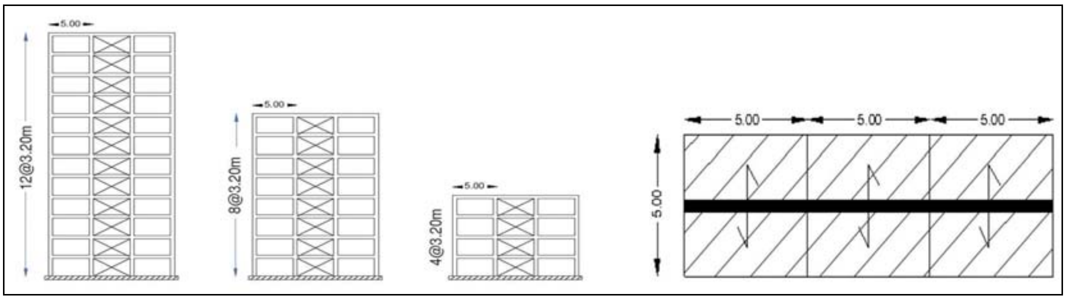

Figure 3.3. Plan and elevation of the steel braced RC frame models

4. PERFORMANCE VERIFICATION

In order to evaluate seismic performance of the structures designed using this method, the nonlinear time-history analysis is carried out using PERFORM 3D. The models simulated using this software have been subjected to 7 near-field accelerograms which were scaled to the utilized design spectrum. Table 4.1. shows some of the most important specifications of the records.

Table 4.1. Characteristics of the selected records

Peak Acceleration (g)	Minimum Distance from Faulting (Km)	Soil Type (USGS)	Magnitude (Ms)	Year	Title
0.267	2.6	C	7.8	1999	Kocali
0.09	2	B	7.3	1999	Duzge
0.4966	4.38	C	6.69	1992	Erzincan
0.519	4	C	7.62	1979	Imperial valley
0.6357	8.34	C	6.9	1995	Kobe
1.22	2.2	B	6.6	1971	Sanfernando
0.852	-	C		1970	Tabas

In this section, a very important verification parameter, namely "inter-story drift" is discussed. Many studies [e.g. Priestley and Alavi and Krawinkler] have shown that inter-story drift have a key role in damage potential of structures. Generally, building codes limit inter-story drift to values within the range of 2% to 2.5% of the story height. As mentioned earlier, a value of 2.5% was selected for this study.The inter-story drift response of the models are displayed in Figs 4.1., 4.2. and 4.3.

Fig. 4.1. represents the inter-story drift profiles of the RC frame models under the selected pulse-type records. In these figures, the design inter-story drift profile is also displayed. Referring to these diagrams, the method performs quite satisfactorily. Maximum inter-story drifts in all RC frame models fall under the specified design profile. The overall profile shapes are similar to those expected for rigid frames. The shape of the profiles for the tall RC frame model (12 story frame) are very similar to natural higher mode shapes of these structures derived from Eigen-value analysis of frames, implying that higher mode effects are important for tall frames.

Fig. 4.2. indicates inter-story drift profile of the RC wall-frame models. Displacement responses of the models are in close agreement with each other, and inter-story drifts of the all the models subjected to the records are below 2.5%. All the lateral displacement responses exhibited some decrease in increasing displacement profile in upper stories which can be attributed to the fact that frames have dominant response in upper stories in comparison with structural walls.

Fig. 4.3. indicates inter-story drift profile of the steel braced RC frame models. The inter-story drifts of the 4 and 8-story models subjected to the records are below 2.5%, but inter-story drift of the12-story model subjected to the records exceeded the design inter-story drift in Stories 1-4, which can be attributed to the bracing buckling in lower stories. The inter-story drifts of the 4 and 8-story models subjected to the records are below 2.5%, except for Imperial Valley Record in both models and Erzincan and Sanfernando Record in the 8-story model. However, inter-story drift of the12-story model subjected to the records exceeded the design inter-story drift in Stories 1-4 demonstrating the fact that this design method was not successful for the 12-story model.

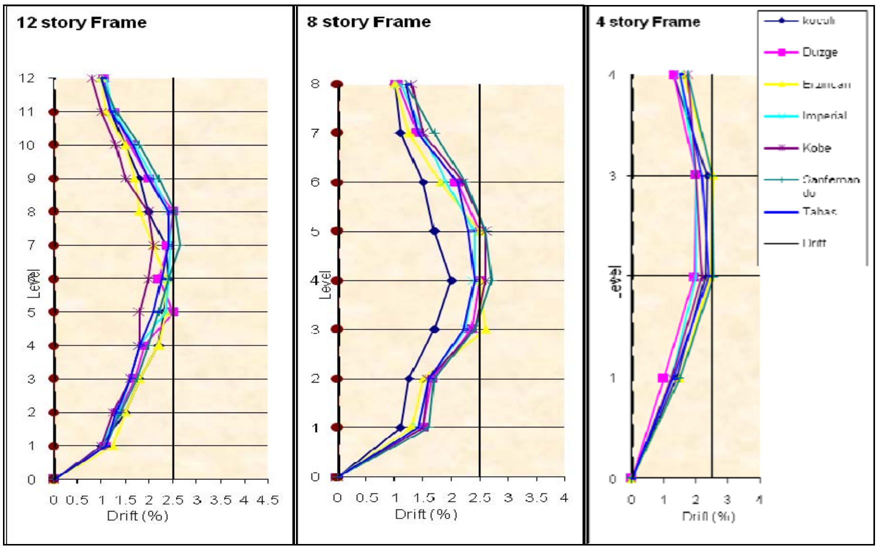

Figure 4.1. Inter-story drift profile of RC frame models

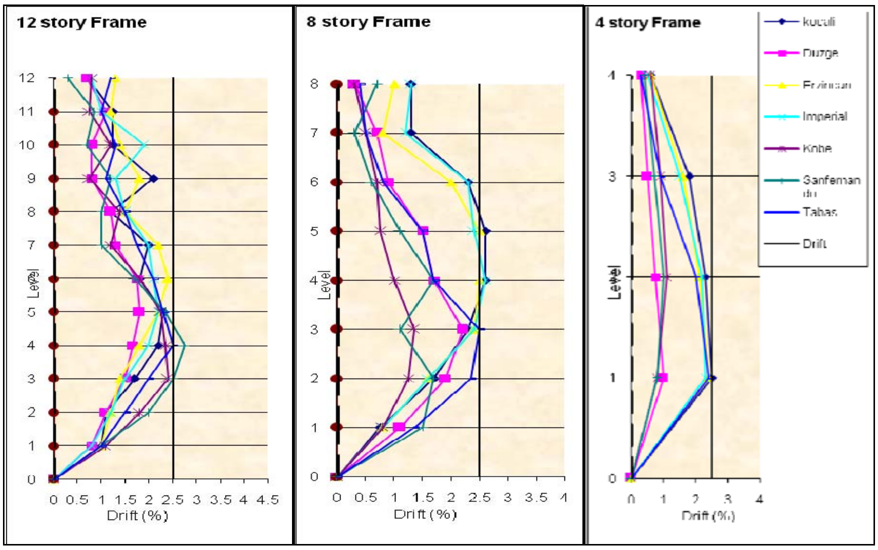

Figure 4.2. Inter-story drift profile of RC wall-frame model

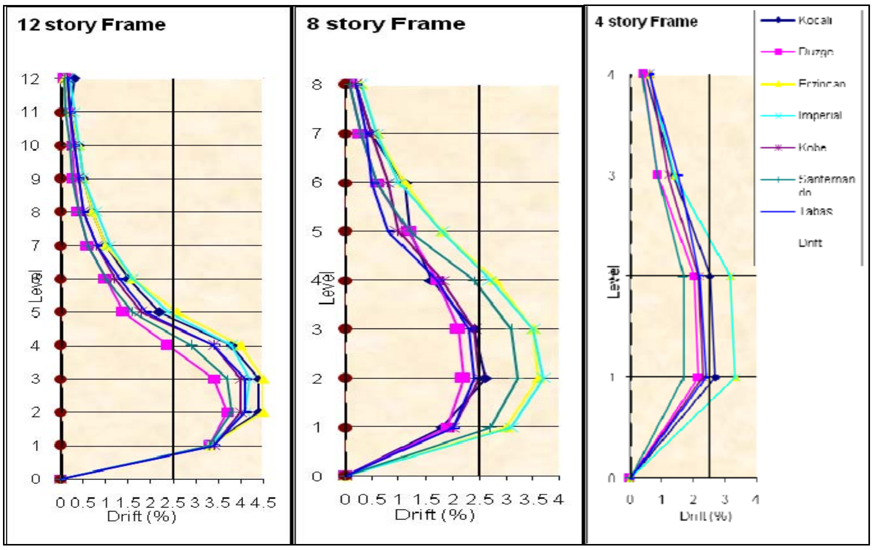

Figure 4.3. Inter-story drift profile of steel braced RC frame models

4. CONCLUDING REMARKS

The present study focuses on seismic behavior of near-fault RC structures design with a new performance-based design tool called the direct displacement-based design.

For this purpose, seismic response of RC frame systems in addition to dual RC wall-frame and steel braced RC frame systems designed using DDBD are investigated.

Performance verification studies show that the method can be regarded as an appropriate alternative to current force-based seismic design of structures. The method, performed quite satisfactorily in term of maximum inter-story drift, even for tall models. Some deviations, especially in tall models, from design values are mainly due to the complex and highly varying nature of frequency content of near-fault records. Another important finding of the study is that, the DDBD methodology is able to design structures with quite controlled residual behavior, an interesting subject which needs further studies.

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