The applicability of Direct Displacement-Based Design in designing concrete buildings located in near-fault regions

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ABSTRACT :

The purpose of this paper is to investigate the applicability of the current DBD methodology developed by Priestley et al, for concrete structures due to near-fault ground motions and current available UBC spectrum. In this regard, after designing a few structures with various heights, series of nonlinear time history analysis, using the available near-fault records, were performed. According to the result of these analyses, the true behavior of these structures is compared with the desired performance, (displacement and drift which are the initial assumption of design). The results suggest that using near-fault factors introduced in current seismic codes may not provide consistent protection against near-fault effects. Moreover, this comparison will prove the need of reliable design spectrum to be used in DBD.

KEYWORDS: Displacement-Based Design, Near-fault, Concrete Buildings, UBC-97 Spectrum

1. INTRODUCTION

Seismic design methods are going to be completed in vanguard countries in earthquake engineering field. Current traditional methods for seismic design are based on limiting forces and stresses in structural members, and also they consider some preventive criteria for story drift to control damages but they do not seem to be adequate to be trusted. Therefore, scientists have become interested to investigate new design methods, say: Performance-based design method.

Performance-based is a general purpose design method in which the criteria are based on reaching a desired performance. The desired performance in structures can be defined through different parameters such as: energy, force, specific strength in structures, displacement of a special point, story drift, and etc. However, the most important principal which is used more by scientists in the last decades is displacement as a key and initial point for designing (displacement-based design (DBD)) [1].

The use of displacement-based design is becoming accepted as the logical direction for seismic design practice. Among all displacement-based design methods only few ones can be used in codes for designing purpose. The particular form known as Direct Displacement based Design (DDBD) has been developed over the past 10 years [Priestley and Kowalsky, 2000], with recent specific studies demonstrating that it provides consistent results for reinforced concrete structural wall design [2].

Although the study which was carried out with Loeding et al in 1998 [3] investigated the application of DDBD to reinforced concrete frames (giving comparison between DDBD and traditional force-based design approaches), their response has not been meticulously tested. Consequently this study investigates the use of the established DDBD method, and the ability of the method to satisfy code specified storey drift limits and displacement in the near-fault regions. In order to investigate the applicability of the method in near-fault regions the spectrum which is proposed in UBC97 code is used for designing new concrete frames since this code has the only near-fault spectrum. To test the dynamic performance of the designed structures, inelastic time history analyses are carried out using ten real near-fault records from SAC Steel project and a series of simple buildings designed according to the DDBD process.

Although the established method is reliable for some near-fault records, we can't use it in all near-fault areas since the displacements and drifts of the designed frames based on UBC97 spectrum don't satisfy the code specified limits appropriately for all records.

2. METHODOLOGY

The general DDBD method is given in detail by Priestley and Kowalsky [2000] and based on representing the multi degree of freedom structures with a single degree of freedom as shown in Fig. 1(a). According to Fig. 1, the structure is represented by equivalent characters such as: effective stiffness at design displacement [Fig 1(b)], effective mass, effective height, equivalent damping which depends on the material and the ductility of a system. Referring to Fig 1(d), the design base shear is determined as

$$V_b = K_e \Delta_d \tag{2.1}$$

where Δ_d represents the design displacement of the substitute structure at maximum response. After determining the base shear, it should be distributed along the height of the building and static analysis should be carried out. The structure will be designed by the forces obtained from static analysis.

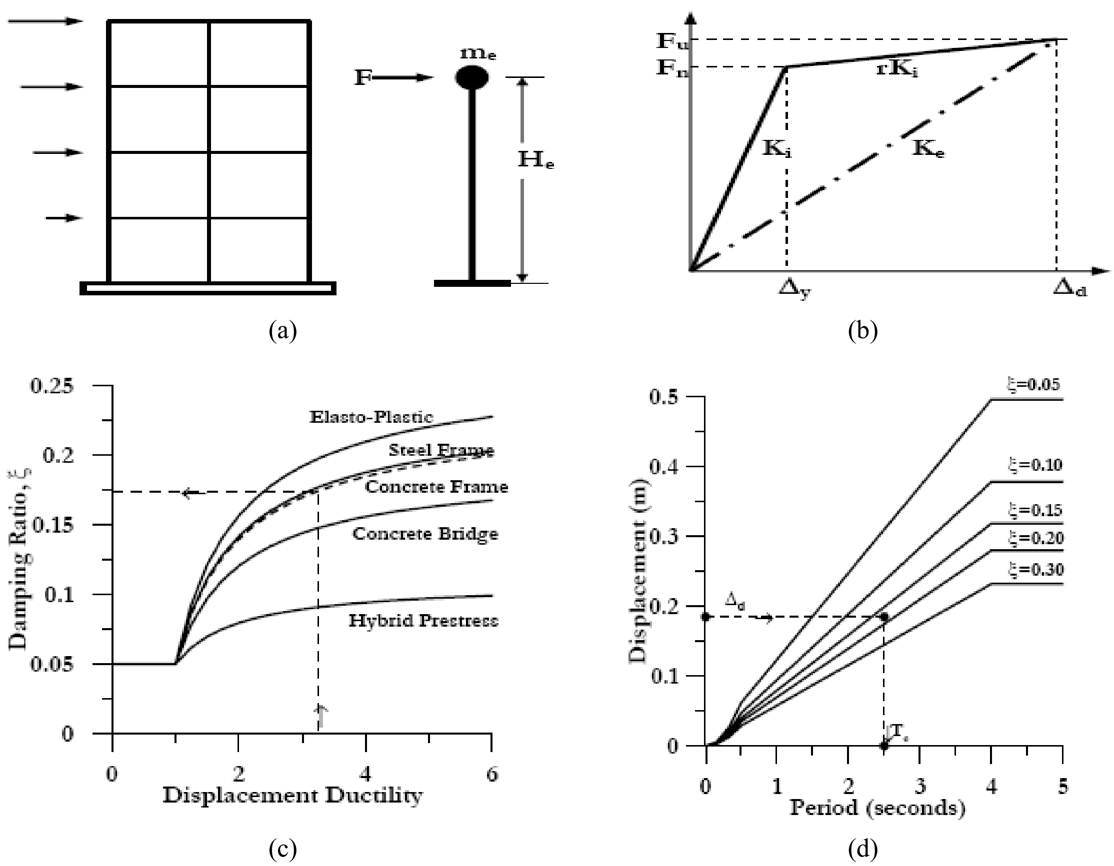

Figure 1 Fundamentals of Direct Displacement-Based Design. (a) Simulation of MDOF structure with SDOF, (b) effective stiffness versus ductility (c) equivalent viscous damping versus ductility, and (d) design displacement spectrum [2].

The general steps of the DDBD method is described as a flowchart in Fig. 2.

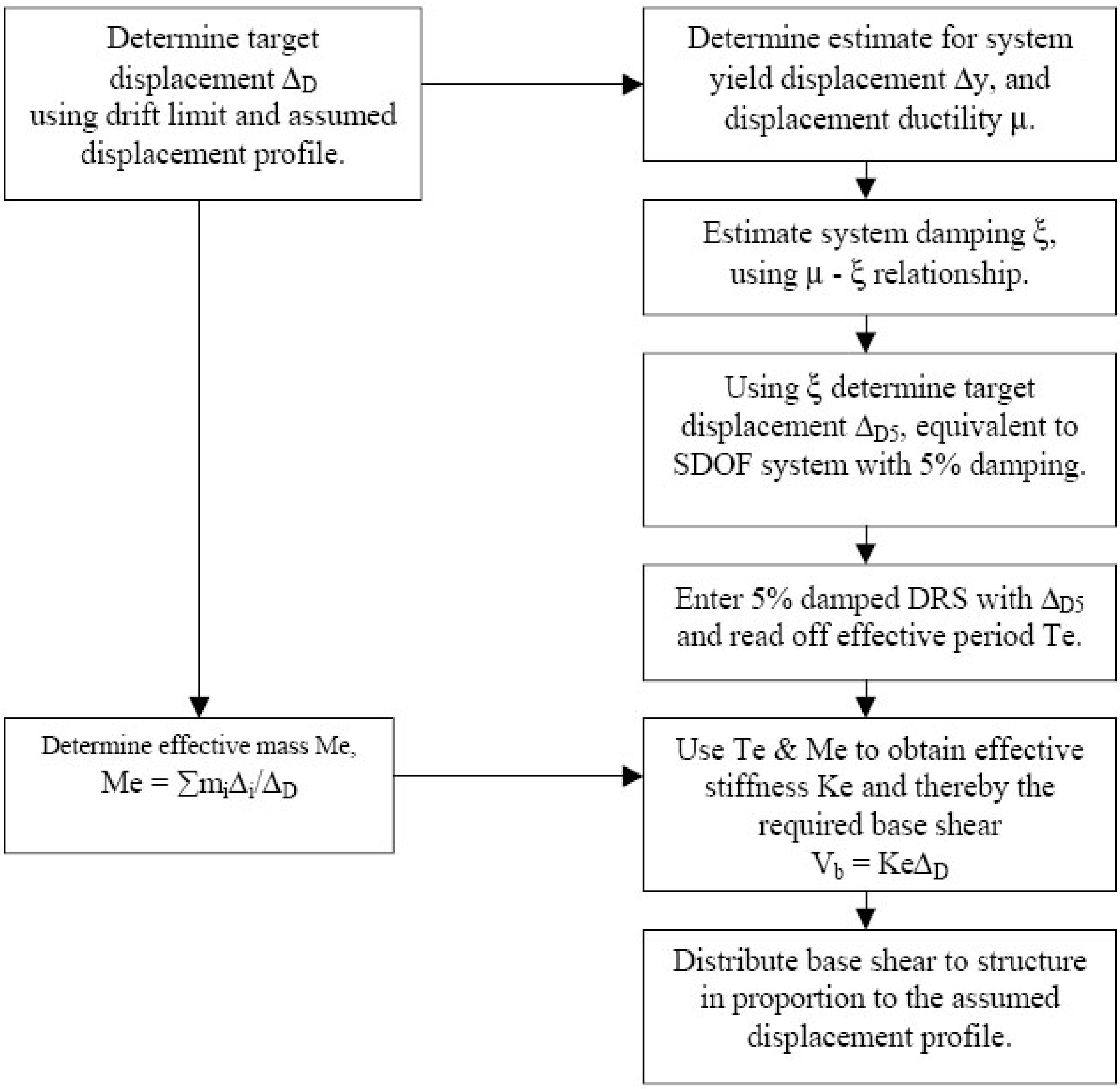

Figure 2 Direct Displacement Based Design [4].

For determining the design base shear in this study the near-fault spectrum which is proposed in the UBC97 code is used. The near-fault spectrum in this code is based on using some increasing coefficients which multiply to the basic UBC97 spectrum that is used for designing purpose in far-field areas. These coefficients depend on the activity of the fault and the distance from the fault location. This acceleration spectrum should convert to displacement spectrum according to the Eqn. 2.2, since we use the displacement spectra in DDBD to obtain the effective period.

$$\Delta_{T,5} = \frac{T^2}{4\pi^2} a_{T,5} \cdot g \tag{2.2}$$

For obtaining the effective period from displacement spectrum, the displacement spectrum should be determined in different levels of damping. Eqn. 2.3 is used based on Eurocode EC8 and Priestley's suggestions.

$$\Delta_{T,\xi} = \Delta_{T,5}\left[\frac{7}{2+\xi}\right]^{0.25} \tag{2.3}$$

3. CASE STUDY

To analyze the applicability of the DDBD methodology four 2D reinforced concrete Frames with various height are used. Some results are compared with the non-linear dynamic procedure results.

3.1Description of theFrames

In this study four frames of 4, 8, 10 and 12 storey with constant storey heights (3.2 meters) and two beam spans (each of them is 5.5 meters) as typically shown in Fig. 3 were considered. The structure was designed according to UBC-97 near-fault spectrum, assuming a subsoil class C, active faults and below 7 km the distance from active fault. Dead and live loads were also considered in the design. The program Opensees is adopted. P-D effect is also considered in the analysis purpose. The weight of each storey of the frames is considered to be 420 kN. The characteristics of the materials are $f'_c = 35MPa$; $\rho = 2.4t/m^3$; $E_c = 27800MPa$; $f_y = 450MPa$.

For nonlinear time history analysis the records from SAC Steel project were used. The set of 10 ground motions used in this study are listed in Table I.

Table I Special carachters of the near-fault records

Record	Earthquake	Station	Magnitude	Fault Distance (km)	PGV ($\frac{cm}{s}$)
LP89lgpc	Loma Prieta, 1989	Los Gatos	7	3.5	173
LP89lex	Loma Prieta, 1989	Lexington	7	6.3	179
EZ92erzi	Erzincan, 1992	Erzincan	6.7	2	119
LN92lucr	Landers, 1992	Lucerne	7.3	1.1	136
NR94rrs	Northridge, 1994	Rinaldi	6.7	7.5	175
NR94sylm	Northridge, 1994	Olive View	6.7	6.4	122
KB95kobj	Kobe, 1995	JMA	6.9	0.6	160
KB95tato	Kobe, 1995	Takatori	6.9	1.5	174
CM92petr	C. Mendocino, 92	Petrolia	7.1	8.5	125.77
Tabas78	Tabas, 1978	Tabas	7.4	1.2	110.04

3.2 Design of the Structure

Based on the selected performance objective, i.e. damage control, a drift range of 1% to 2% is expected to ensure that the strain limits in critical members do not attain their design values, as proposed in ATC-40 (1996). In this study a drift of 2% is considered. For example, we consider the four storey frame. Since the structure consists of only four stories, a linear distribution is considered to evaluate the displacement profile. Thus, the story displacements obtained are as follows:

$\Delta_1 = 0.064m$, $\Delta_2 = 0.128m$, $\Delta_3 = 0.192m$, $\Delta_4 = 0.256m$.

The design displacement is obtained equal to 0.192 *m*. The effective system displacement occurs at a height called as effective height, estimated 9.6 *m*. Equivalent damping ratio according to priestley's suggestion for R/C frames will be 13%. With the use of design displacement and damping ratio the effective period will be determined according to Fig. 3.

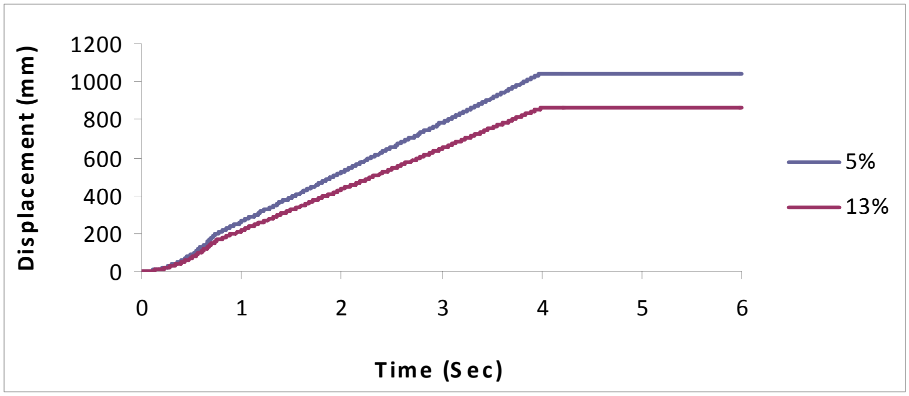

Figure 3 Reduced displacement spectrum for designing of four storey frame

According to effective period of 0.9 second the base shear is given as 1271 kN. This base shear is distributed along the height of the building according to the assumed displacement profile and a static analysis is carried out. At last the frame will be designed according to the forces from this static analysis. Some important factors in designing purpose according to DDBD are shown in table II.

Table II Important factors for frames design

	Building Height			
	4-storey	8-storey	10-storey	12-storey
Effective Mass (tones)	136	265	331	380
Effective Period (sec)	0.9	1.53	1.8	2.04
Design Displacement (mm)	192	323	376	420
Base Shear (kN)	1271	1442	1517	1593

3.3 Performance Evaluation

In order to evaluate the performance of the designed structure series of nonlinear time history analysis are performed. In Fig 4, one sample from time history of a first storey of four storey frame under Kobe earthquake excitation is shown. It is obvious from this figure that in the initial steps of the earthquake the structure suffer a severe pulse and nonlinear behavior is seen from the structure and the permanent displacement because of this nonlinearity can be figured out easily.

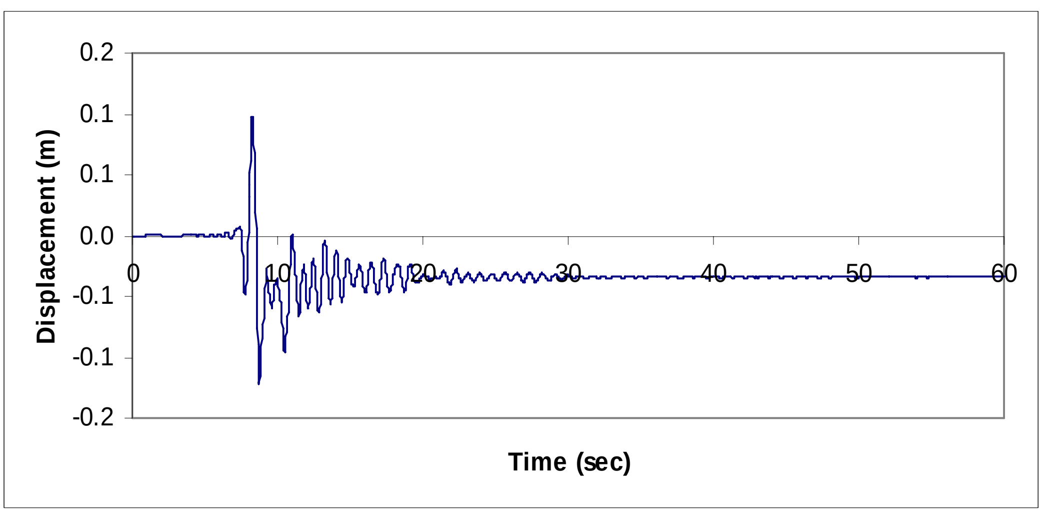

Figure 4 Time history of a first storey in a four storey frame (Kobe earthquake)

For evaluating the performance of the current DDBD method in near-fault regions with the use of UBC-97 spectrum, the displacements and inter-storey drifts which are obtained from nonlinear time history analysis are compared with the design values which are determined in the first step of the design process based on the assumed design limit state.

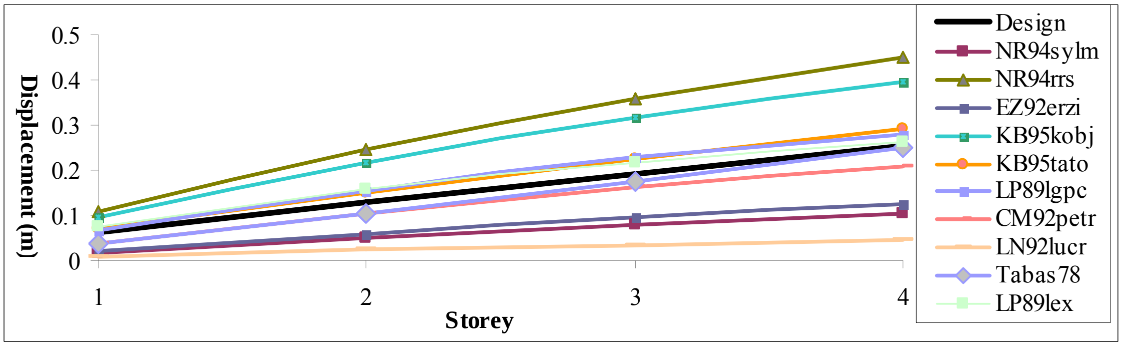

Figure 4 Storey displacement comparison (4-Storey)

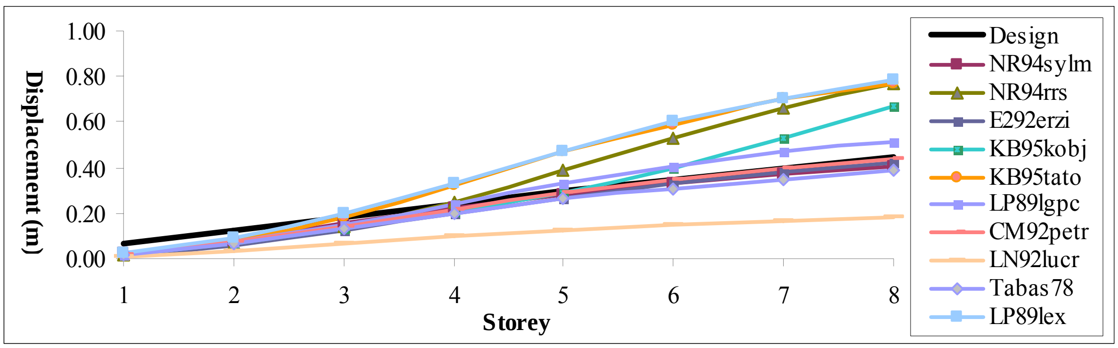

Figure 5 Storey displacement comparison (8-Storey)

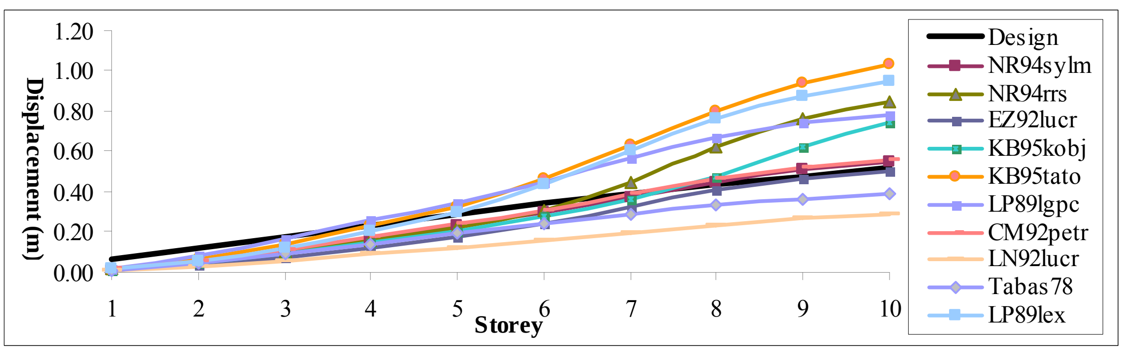

Figure 6 Storey displacement comparison (10-Storey)

In the Fig. 4 to 7 the line which is named as design is the allowable displacement that is determined according to the assumed limit state. According to these figures it is found out that the displacement limitation is satisfied for some of our records. For example for the records such as NR94sylm, EZ92erzi, CM92Petr, LN92lucr and Tabas78 the displacements result from time history analysis are satisfied the design values and their value are below the limitations. These records as it is clearly can be seen from table have the PGV below 130 cm/s. But for other records which have the PGV more than 160 cm/s the design limitation is not properly satisfied. In some records such as KB95tato and Lp89lex displacements result from time history analysis are 50% above the design displacement value.

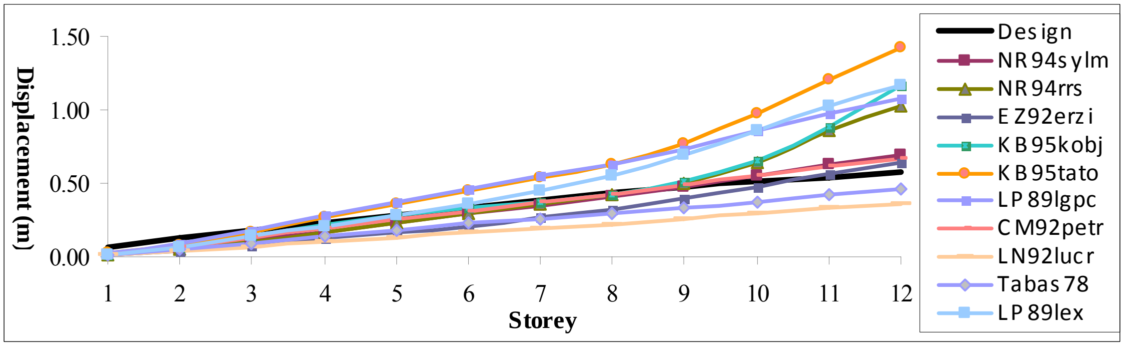

Figure 7 Storey displacement comparison (12-Storey)

For investigating the performance of the design method we also consider the amount of the drift from time history analysis and compare them with the drift design values. In this regard again it is found that for records such as NR94sylm, EZ92erzi, CM92Petr, LN92lucr and Tabas78 the design values are satisfies appropriately. But for the rest of the records the design values are not satisfied by the analysis results. In Fig 8, these results are shown.

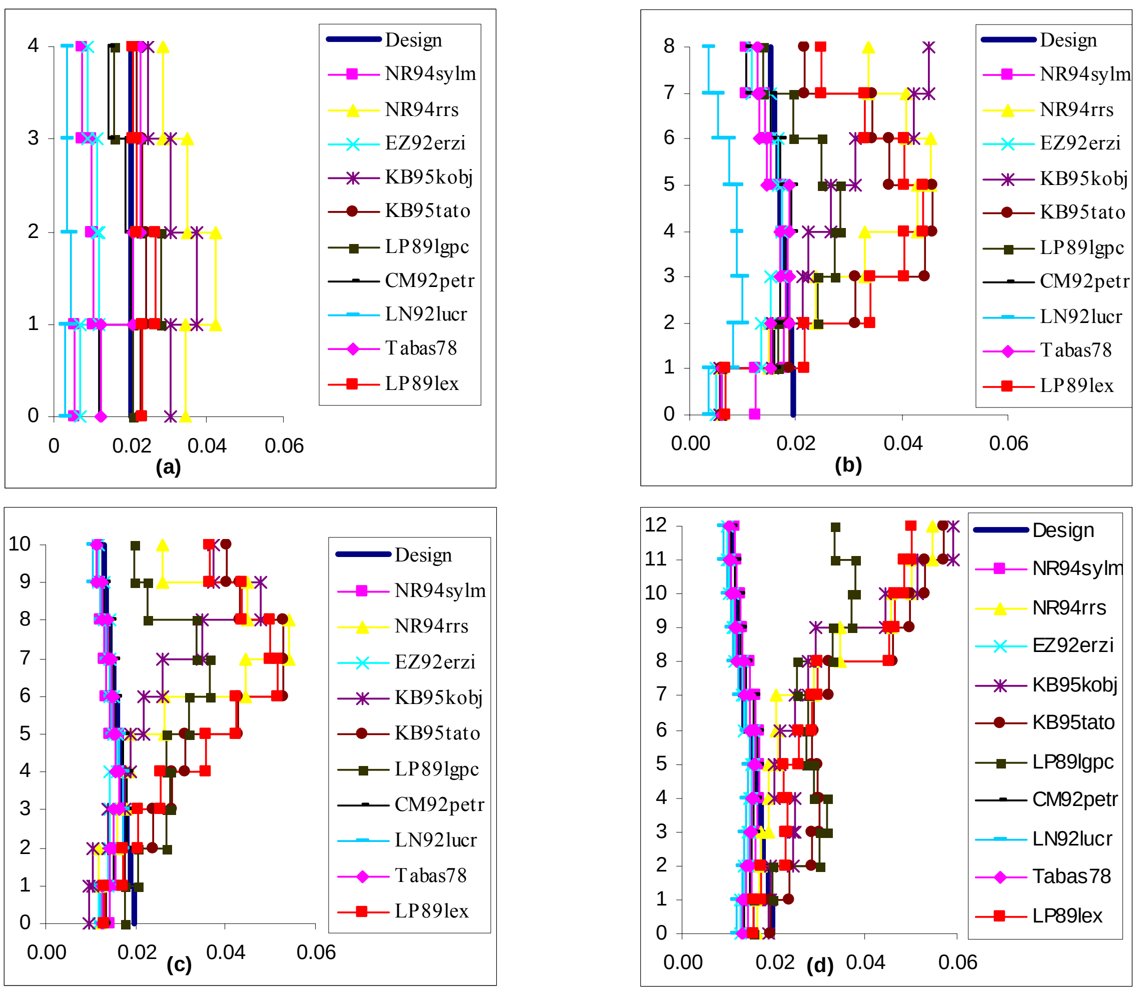

Figure 8 Inter-storey drift comparison; (a) 4-Storey, (b) 8-Storey, (c) 10-Storey, (d) 12-Storey.

All of the above results are related to analysis with the fault-normal component of the records. For investigating the fault-parallel effect only the four-storey frame analysied since in the near-fault earthquakes the fault-normal component imposes a larger displacement and ductility demand to the structures.

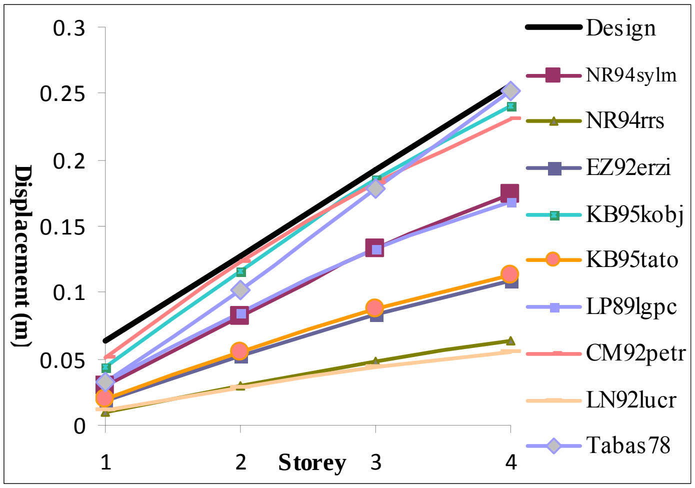

Figure 9(a) Storey displacement comparison

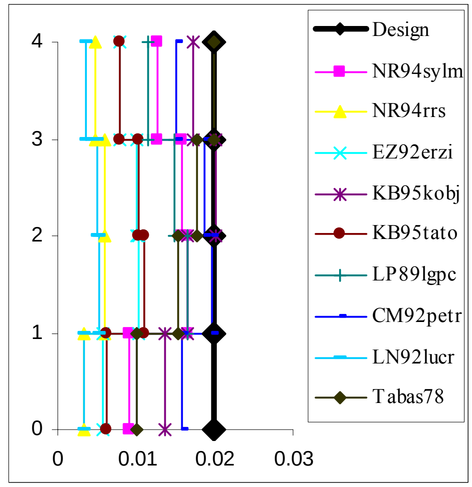

Figure 9(b)Inter-storey drift comparison

As it is shown in the Fig. 9, the displacement and inter-storey drift obtained from the time history analysis due to fault-parallel component are satisfied and below the design limitation. It is entirely confirm that fault-normal component in the near-fault earthquakes is much severe than the fault-parallel component.

3. CONCLUSION

- The fault-normal component of the near-fault ground motions with forward directivity is severe imposes larger displacement and inter-story drift demand to the structures than fault-parallel component.
- The strength and deformation demands of the fault-normal component of many near-fault ground motions are much larger than that of the fault-parallel component primarily because the peak acceleration, velocity and displacement of the former are much larger.
- Although the current DDBD method is reliable for some near-fault records, we can't use it in all near-fault areas since the displacements and drifts of the designed frames based on UBC97 spectrum don't satisfy the code specified limits appropriately for all records.
- It is felt that the response spectrum in the building codes should be defined based on PGA, PGV and PGD values rather than some factors dependent on activity of fault and the distance from fault location.
- Therefore the new design spectrum for near-fault region can be proposed by modification of the UBC97 spectrum based on the special characteristics of the near-fault records.

REFRENCE

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