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Assessment of Performance Based Parameters in Near Fault Tall Buildings

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Abstract: Available codes are not well-suited for tall buildings and are very restrictive. In this study, we try to assess parameters such as drift limits, rotation of plastic hinge, capacity-demand ratio, etc. which have a significant role in defining performance levels for near-fault regions. We have selected two-dimensional steel moment resisting frames having 30, 40 and 50 stories. These buildings have been designed according to IBC and AISC practice codes as Special Moment Resisting Frames (SMRF) and have been analyzed by Design Spectrum Analysis (DSA). We have conducted nonlinear dynamic time history analyses by using a suite of near-fault accelerograms to assess the performances of selected buildings. Finally performance levels of structures have been evaluated and estimated and near fault effects on different parameters which are not completely considered in spectral analysis are assessed. Using nonlinear analysis and evaluating performance levels and assessing parameters such as drifts and formation of plastic hinges and their rotations quantities, ratios of capacity-demand, etc. some weak points of customary design method are detected.

Key words: Performance levels, tall buildings, steel moment resisting frames, near fault, nonlinear dynamic analysis

INTRODUCTION

Construction of tall buildings in the world including high seismicity regions is increasing. This is while using existing codes because of some limitations like limited materials, buildings systems, buildings heights, performance limits, etc is still a challenge. Available codes are not well-suited for tall buildings in seismic areas and are very restrictive (Moehle, 2006). Performance Based Design (PBD) is a suitable replaced method. Moehle (2007) has discussed some major points in PBD method and existing challenges especially in tall buildings. Some research in replacing PBD with current strength-based approach in the design of high-rise coupled wall systems have been accomplished (Harries and McNeice, 2006). Also, application of this method in the design of core wall systems has been studied (Klemencic *et al*., 2006). In addition, other aspects of applying PBD procedure for tall buildings like ground motion records in nonlinear model (Bozorgnia *et al*., 2007) should be studied.

In this study, we try to assess parameters such as drift limits, rotation of plastic hinge, etc., which have a significant role in defining performance levels and other quantities like capacity-demand ratio after a preliminary design of tall buildings for near-fault regions. Considering uncertainties of analysis procedures in calculating these responses and the role of modeling method and ground motion records in nonlinear dynamic analysis and interpretation of its results and different behavior of tall buildings like their long vibration periods, assessing the adequacy of performance levels quantitative limit states regarding tall buildings and near fault records looks useful.

NONLINEAR DYNAMIC ANALYSIS

For this study, we have selected two-dimensional steel moment resisting frames with three bays and different heights having 30, 40 and 50 stories. These buildings have been designed using well-established force-based method according to IBC (2003) and AISC practice codes as Special Moment Resisting Frames (SMRF) and have been analyzed by Design Spectrum Analysis (DSA), in order to obtain a proper design for structural elements. In the design procedure, provisions such as minimum base shear, story drifts limitations, weak beam-strong column criterion and other high seismicity related provisions have been considered. For the analysis and design of the structures in this phase the ETABS software has been utilized. In order to assess the performances of selected buildings we have conducted nonlinear dynamic time history analysis by using a suite of near-fault accelerograms which have been scaled to

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definite design spectrum. The designed structures have been used by importing into PERFORM-3D software in order to create a nonlinear model (Computers and Structures Inc., 2006). Also, the selected near fault ground motion records for dynamic loading of nonlinear model have been scaled to design spectrum using RASCAL software. Finally performance levels of structures have been evaluated and estimated and near fault effects on different parameters which are not completely considered in spectral analysis are assessed (Powell, 2006).

Model properties: After a preliminary design in order to assess the behavior of the structures under near fault earthquakes, the nonlinear model using following elements and force-deformation relationships and deformation capacities in PERFORM-3D has been created. There are a number of different ways to model inelastic beams and columns in PERFORM. At one extreme are finite element models using fiber sections. At the other extreme are chord rotation models that consider the member as a whole and essentially requires that one to specify only the relationship between end moment and end rotation. In between these extremes are a number of other models. In this study the chord rotation model for beams and columns has been selected. The basic model is shown in Fig. 1. This is a symmetrical beam with equal and opposite end moments and no loads along the beam length. To use this model one has to specify the nonlinear relationship between the end moment and end rotation. An advantage of this model is that FEMA-356 (2000) gives specific properties, including end rotation capacities.

Figure 2 shows a PERFORM frame compound component for the chord rotation model. The key parts of this model are the FEMA beam components. These are finite length components with nonlinear properties. The model has two of these components, to allow for the case where the strengths are different at the two ends of the element. PERFORM allows for specifying different strengths for the two components and also different lengths to account for cases where the inflection point is not at midspan.

Fig. 1: Chord rotation model

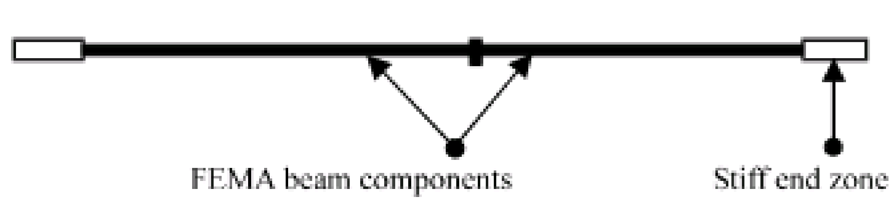

Fig. 2: Basic components for chord rotation model

The PERFORM converts this model to the model shown in Fig. 3. Each FEMA beam component is actually two components, namely a plastic hinge and an elastic segment.

Force-deformation relationship: The F-D relationship shown in Fig. 4 is utilized. For beam components F is end moment and D is end rotation. According to FEMA-356 strength loss is applied so that DL = 9DY and DR = 11DY and FR = 0.001 FU that FR is almost zero. To avoid specifying sudden strength loss that is not realistic the FEMA-356 relationship is replaced with a gradual strength loss shown in Fig. 5. For column elements F is force and D is axial displacement and end rotation.

Deformation and strength capacities: To use the performance based design capabilities, one must specify deformation capacities for inelastic components and/or strength capacities for elastic components. One can then

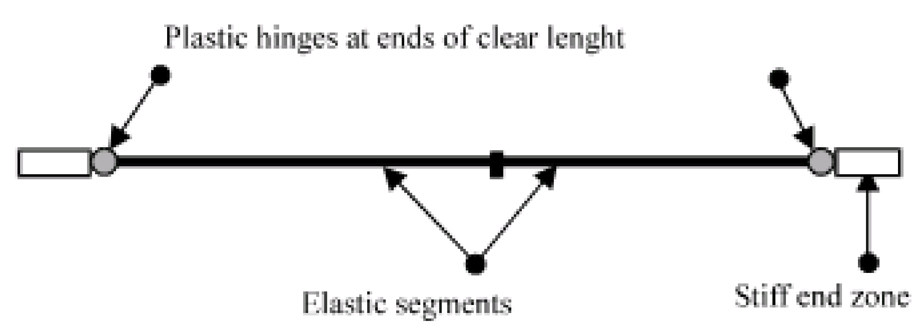

Fig. 3: Beam component with plastic hinges

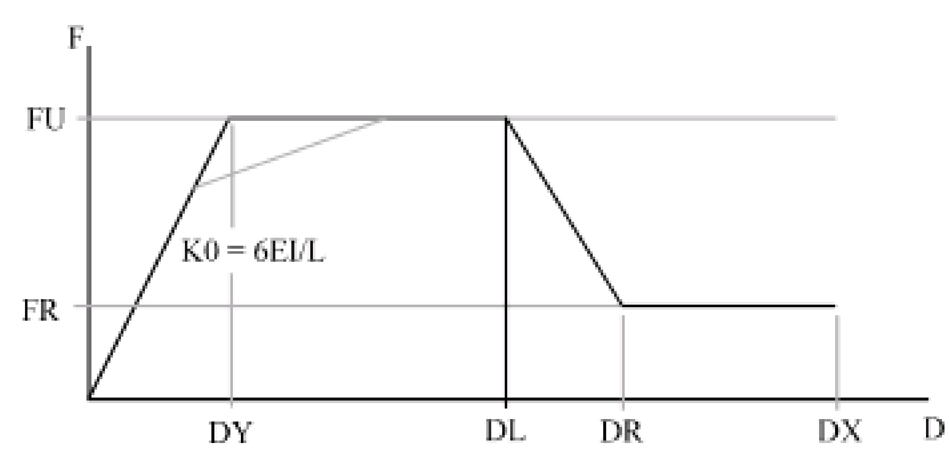

Fig. 4: Force-deformation relationship

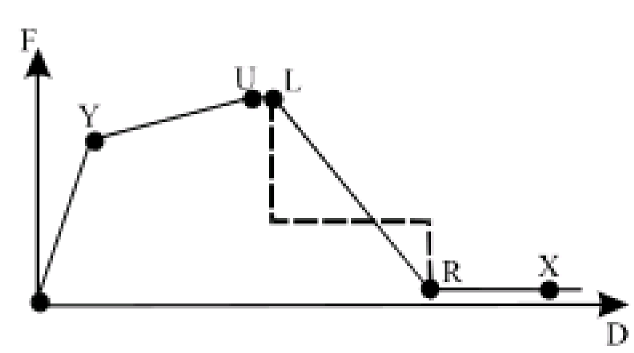

Fig. 5: Replacing gradual strength loss with sudden strength loss

Table 1: Ground motion records used in time history analysis

Earthquake	Year	Magnitude (Ms)	Soil type (USGS)	Distance* (km)	PGA (g)
Erzincan	1992	6.69	C	4.38	0.4996
Sanfernando	1971	6.60	B	2.20	1.2200
Duzge	1999	7.30	B	2.00	0.0900
Imperial valley	1979	7.62	C	4.00	0.5190
Kobe	1995	6.90	C	8.34	0.6357
Kocali	1999	7.80	C	2.60	0.2670
Tabas	1970		C		0.8520

*Closest distance to the fault ruptures

define limit states to make use of these capacities and process the analysis results to give demand-capacity ratios (or limit state usage ratios). For all inelastic components, deformation capacities in three levels have been specified corresponding to immediate occupancy, life safety and collapse prevention, respectively. In this study the deformation capacities according to FEMA 273 (1997) have been utilized namely plastic rotation limits of 2, 7 and 9, respectively for IO, LS and CP performance levels in beams and columns. As well 0.004, 0.025, 0.043 in panel zones for these levels have been applied.

Drift capacities: Both drifts and component deformations as demand-capacity measures will be used. Drift capacities corresponding to the FEMA 273 (1997) have been used.

Limit states and usage ratios: In a large structure there are a large number of component capacities and hence a large number of demand capacity ratios. The demand capacity ratios are organized using limit states into manageable packages. Limit states for story drifts, rotation of plastic hinges in beams and columns and shear strain of panel zones in the three mentioned performance levels have been set up. Finally by grouping the limit states depending on each performance level and earthquake loading of the structure, the calculated usage ratios for limit states during the earthquake loading have been assessed.

Damping: In this model combined modal and Rayleigh damping is used to make sure that higher mode displacements are damped. Therefore in addition to 4% of modal damping, 0.2% of αk damping has been applied.

Selected earthquake records: Seven near fault ground motion records according to the Table 1 have been selected. The selected accelerograms have been scaled to design spectrum using RASCAL software.

NONLINEAR ANALYSIS RESULTS

The fundamental vibration periods for the 50, 40 and 30 story models with 160, 128 and 96 m heights are obtained 4.73, 4.34 and 3.78 sec, respectively from the analysis. And all three cases are more than the code estimated values. That indicates the code relations are conservative.

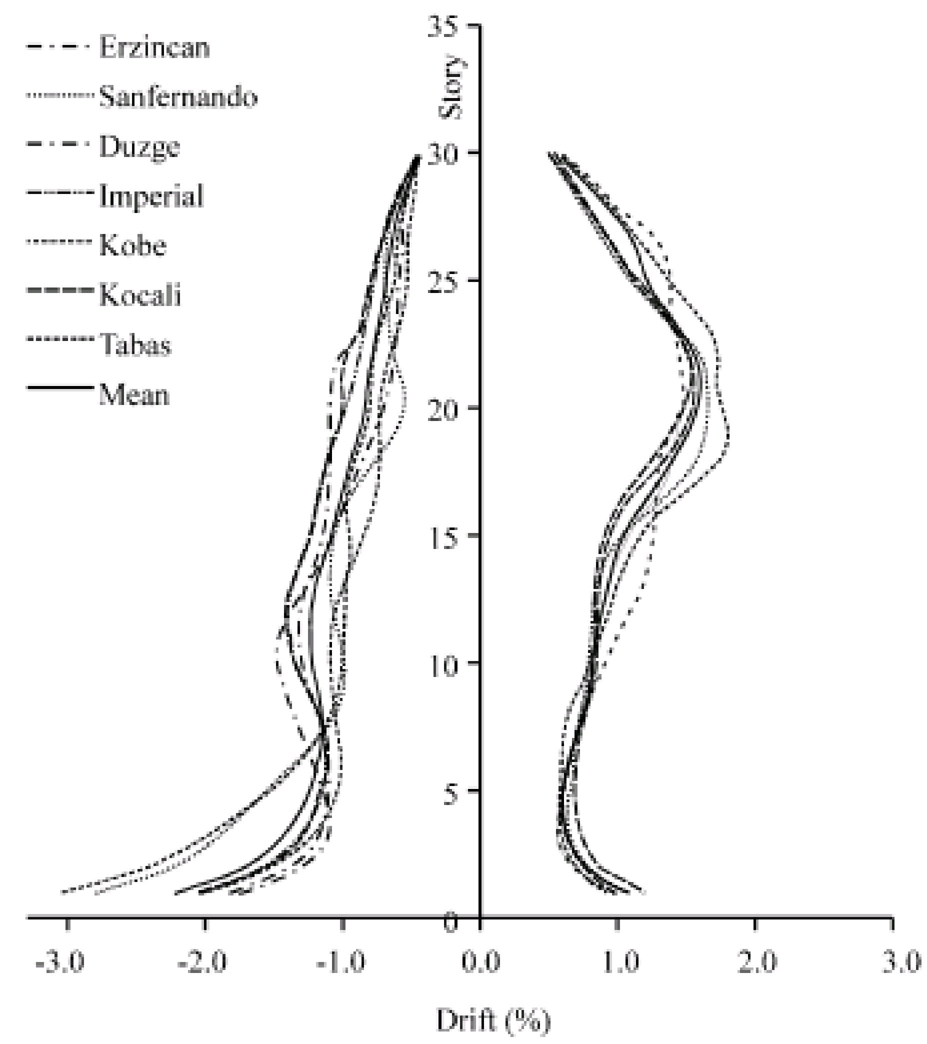

Fig. 6: Maximum story drifts under all seven records (30 story model)

Story drifts are one of the effective quantities on the performance of the structures. To assess this case, all story drifts are calculated during earthquake loading. Then the maximum values in each story at both sides are obtained and these drift profiles are shown in Fig. 6-8.

The maximum drifts are often related to the time when a sudden change has occurred in the energy content or Arias intensity of the record just before. Considering the accelerograms indicates that this sudden change is arising from a pulse in the ground motion record that is common in the near fault records. The difference in the lower stories' drifts of the 50 story model with other ones is because of selecting fixed supports for this model opposing to the others' hinged supports.

Residual drifts quantities are also limited relating to each performance level. Almost in all records the residual drifts have maximum values in lower stories. The noticeable values are shown in the Table 2.

According to the codes when applying 7 or more records the mean values of responses could be used. The mean value of residual drift calculated for all seven records are almost equal or less than 1% that is satisfying for life safety performance level.

To assess performance levels parameters, the quantities of rotation of plastic hinges in beams and

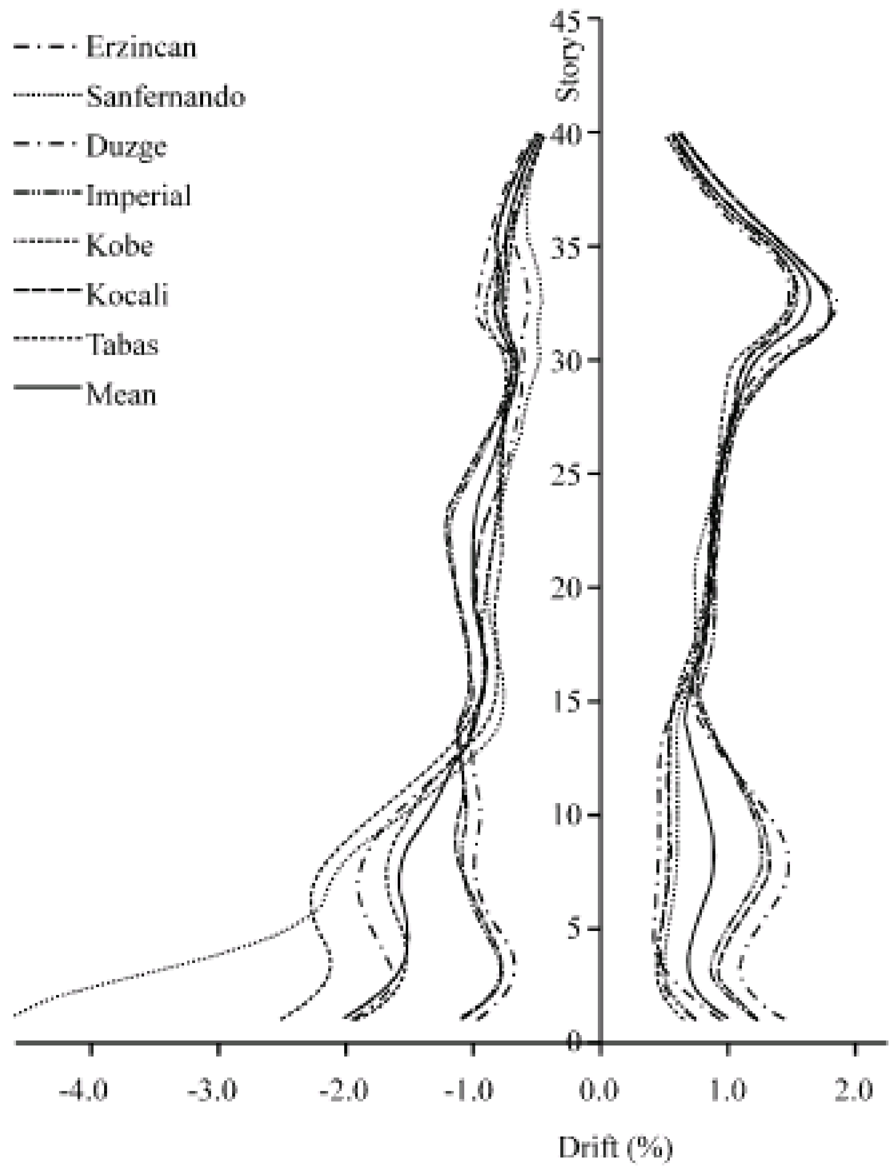

Fig. 7: Maximum story drifts under all seven records (40 story model)

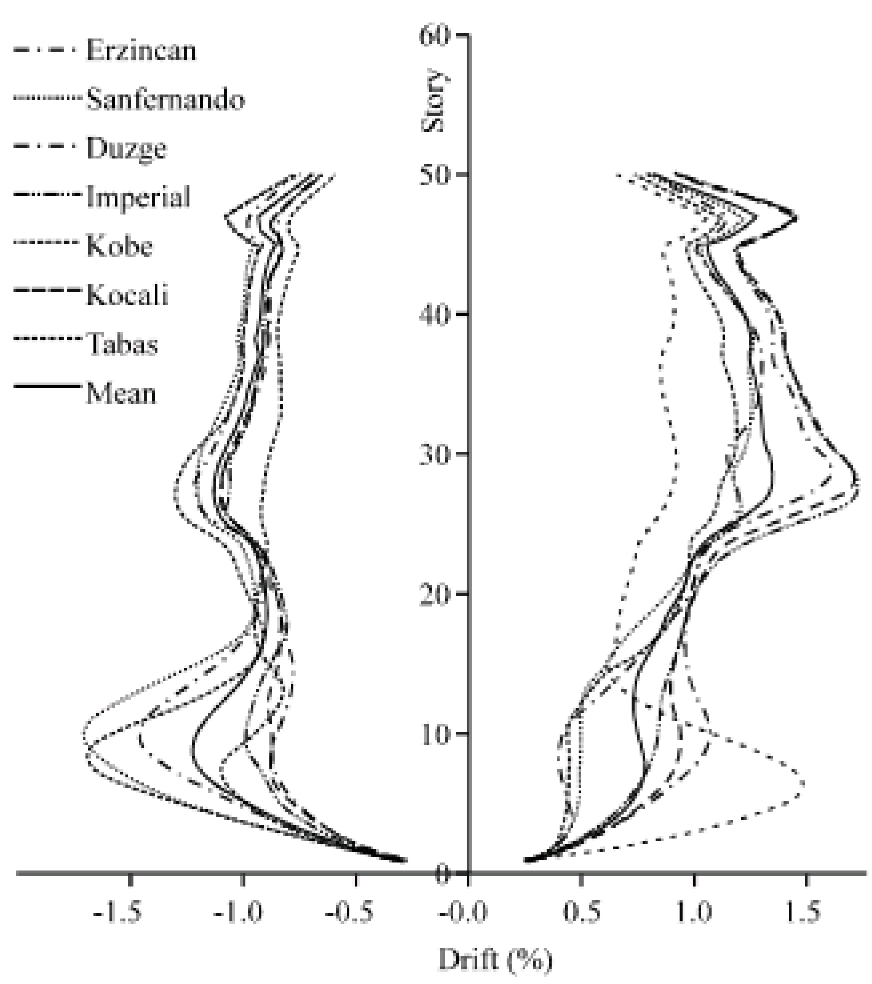

Fig. 8: Maximum story drifts under all seven records (50 story model)

columns and shear strains in panel zones and also story drifts have been calculated in every moment of the earthquake loading. Then by dividing these values to the introduced limit states, demand-capacity values are

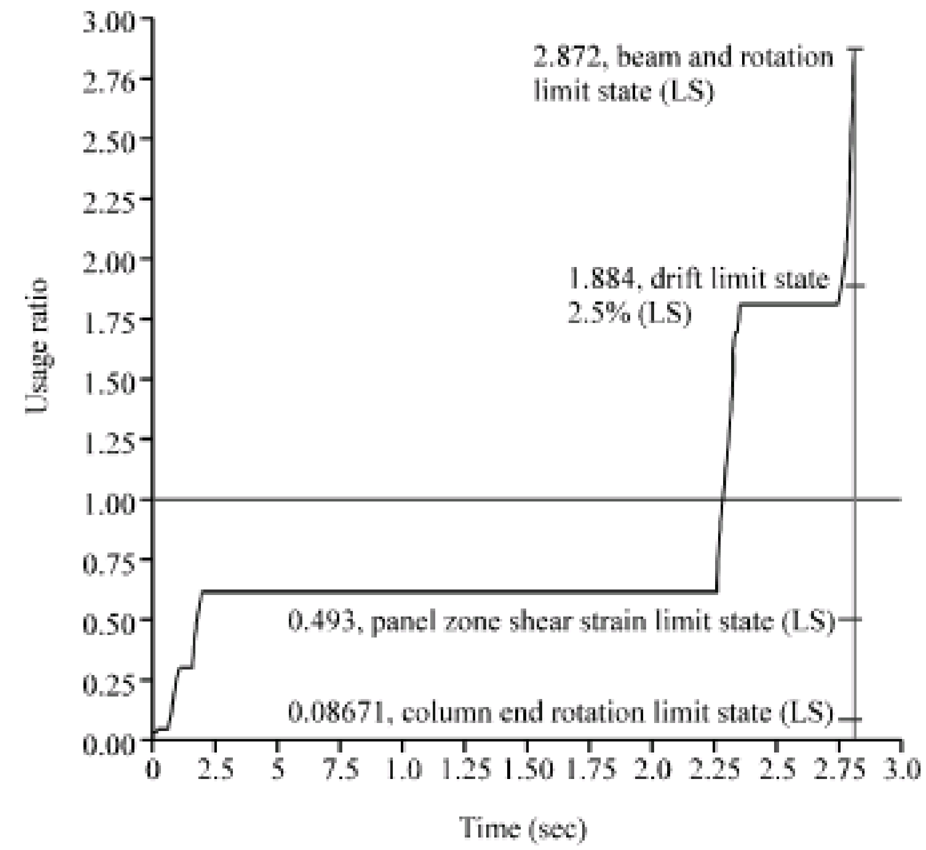

Fig. 9: Envelope of usage ratios of performance parameters for life safety level during Sanfernando earthquake (40 story model)

Table 2: Residual story drifts

	50 Story		40 Story		30 Story	
Earthquake	Story 10	Story 5	Story 5	Story 1	Story 5	Story 1
Erzincan	0.0010	0.0010	0.0050	0.0050	0.0030	0.005
Sanfernando	0.0100	0.0055	0.0175	0.0250	0.0070	0.015
Duzge	0.0050	0.0025	0.0120	0.0125	0.0024	0.002
Imperial valley	0.0010	0.0010	0.0020	0.0030	0.0040	0.008
Kobe	0.0060	0.0040	0.0160	0.0170	0.0070	0.017
Kocali	0.0010	0.0010	0.0030	0.0030	0.0040	0.007
Tabas	0.0020	0.0017	0.0100	0.0125	0.0030	0.005
Mean	0.0037	0.0024	0.0094	0.0111	0.0043	0.008

obtained that is called usage ratios. It is clear that if these values are less than 1 the considered limit is not exceeded. Consequently if the all ratios related to the four mentioned parameters during earthquake are less than 1 the performance level corresponding to the introduced limit states has been satisfied. For example a usage ratios envelope diagram for 40 story model during Sanfernando earthquake is shown in Fig. 9. In order to have a general review the mean value of maximum usage ratios for 7 earthquakes in all three models for the life safety performance level are shown in Fig. 10-12.

The mean value of the maximum usage ratios for LS level, that is expected to be satisfied considering the design objective, indicates that mean demand in the 50, 40 and 30 story models are, respectively 0.54, 1.04, 0.88 times of the capacity. Therefore the performance level of the structures is life safety. While these capacity-demand ratios for immediate occupancy level are 1.93, 3.6, 4.57, respectively.

It's worth mentioning that the drift limits, especially in tall buildings with moment resisting frames,

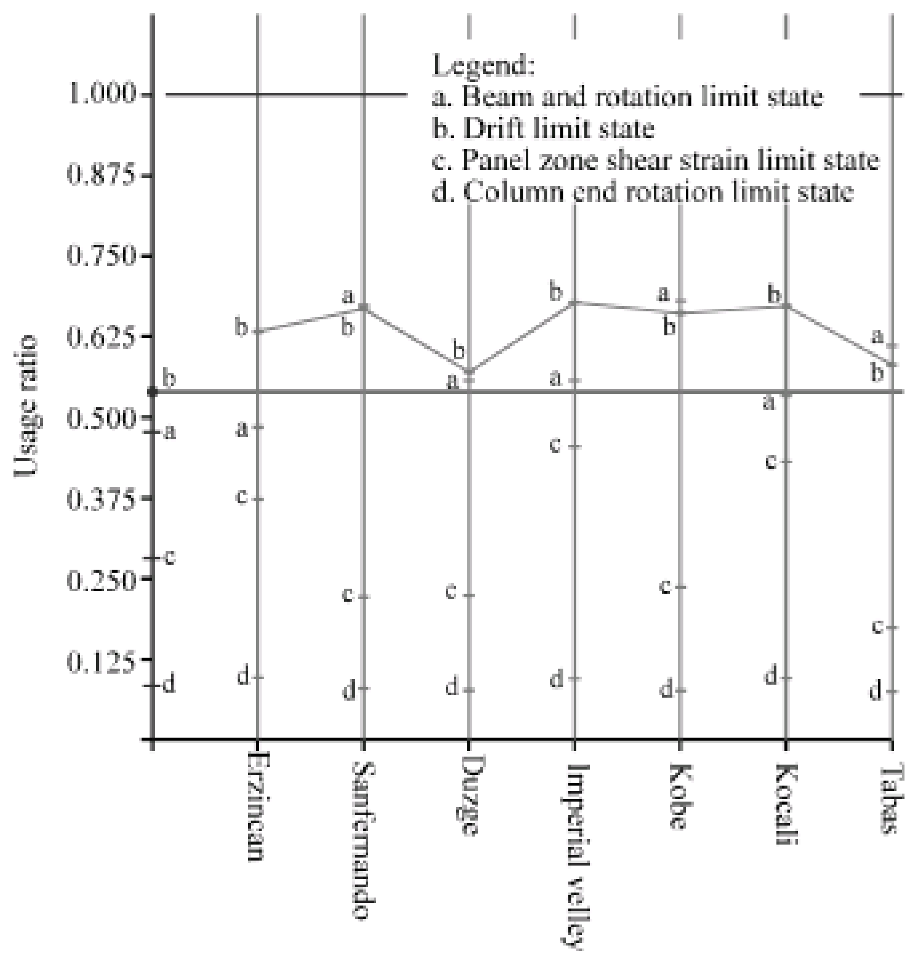

Fig. 10: Mean value of maximum usage ratios for 7 earthquakes for the life safety performance level (50 story model)

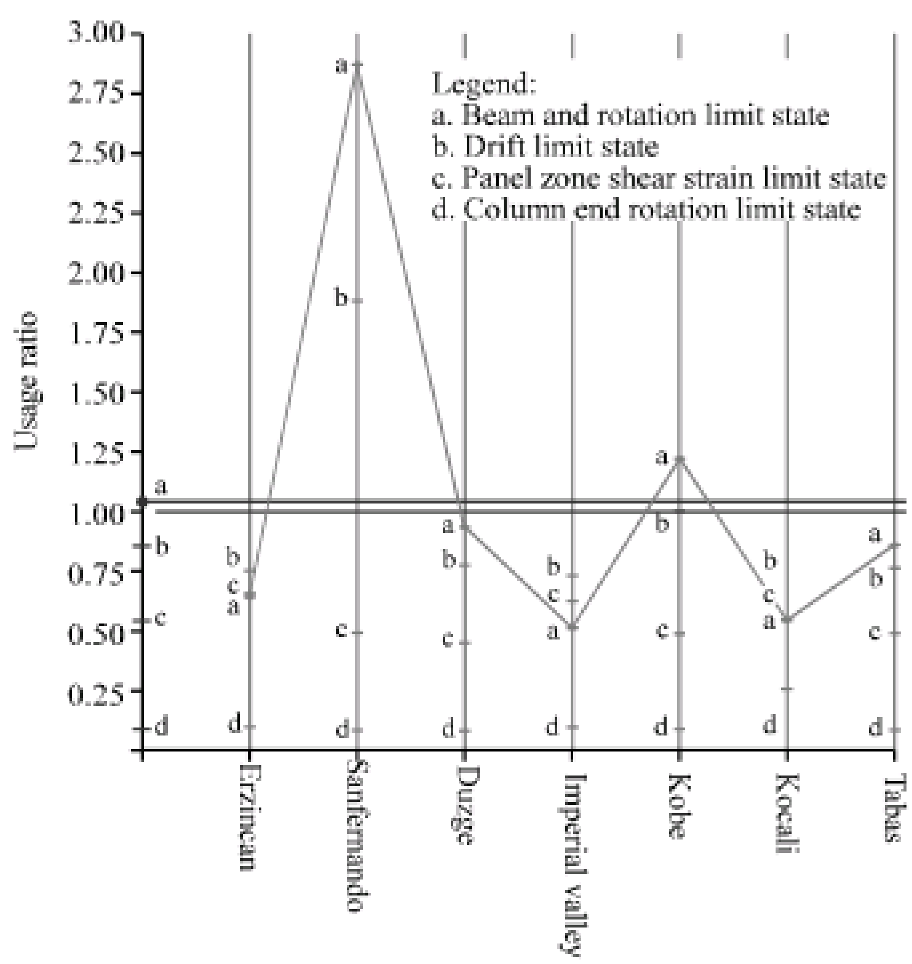

Fig. 11: Mean value of maximum usage ratios for 7 earthquakes for the life safety performance level (40 story model)

are determinant in the design procedure and if not been satisfied the smaller cross sections are sufficient from the strength point of view but with decreased performance level. This trend in the new design codes that are based on performance or displacement is more emphasized.

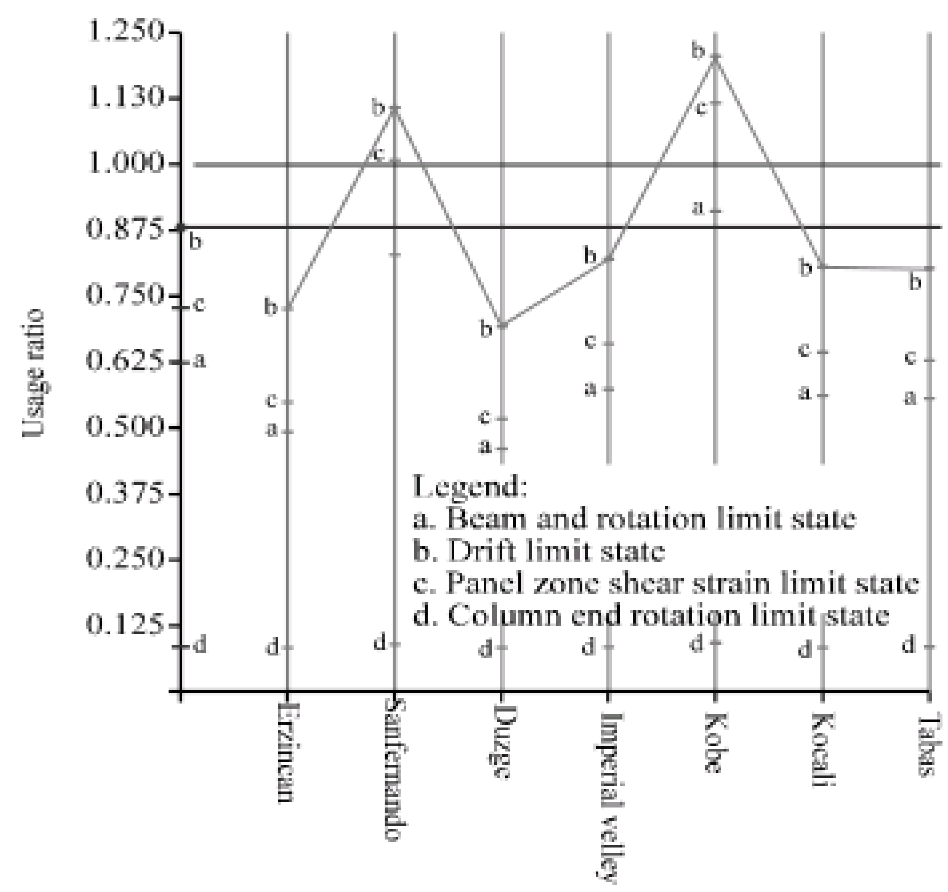

Fig. 12: Mean value of maximum usage ratios for 7 earthquakes for the life safety performance level (30 story model)

Considering the results these points could be mentioned: Conservative code relations in estimating the fundamental vibration periods and minimum base shear provision have determinant role in the force based design, especially in tall buildings.

Observing weak beam-strong column criterion in the initial design led to better behavior of structure under earthquake loading and preventing premature failure.

Noticing dispersion of responses and also capacity-demand ratios in different ground motion records, it looks helpful to apply more records if possible or to consider deviation over mean for more exact and reliable results.

Assessment of performance based parameters with nonlinear time history analysis and applying near fault records especially for important structures in high seismicity regions and studying moment by moment reaction of the structure under those records lead to accurate comprehension of structural behavior in comparison with design spectrum analysis. And weak points of structures from performance point of view are examinable clearly provided that nonlinear modeling and selected records and their scaling procedure are accurate.

CONCLUSION

Comparing the performance levels parameters and their variation during the applied earthquakes and considering the variation of Arias intensity and energy content of the records it is known that most changes of capacity-demand ratios is just after the sudden increase of the energy content due to the pulses of the records. In the Sanfernando and Kobe earthquakes that have got larger usage ratios, review of ground motion parameters indicates that the cumulative absolute velocity and approximately Arias intensity are larger. Moreover irregular and rough accelerograms of these records indicates a wide Fourier spectrum including different frequencies. Considering the exceeding of limit states of performance levels parameters and residual drifts in some records even in the LS level, it is recommended not to trust just mean response values especially in important structures and consider deviation over mean. The inelastic dynamic response to near fault records demonstrates that structures with a fundamental period greater than the pulse period respond differently than shorter period structures. For the former, early yielding occurs in higher stories but the high ductility demands migrate to the bottom stories as the ground motion becomes stronger. For the latter, the maximum demand always occurs in bottom stories (Alavi and Krawinkler, 2001). In these structures because of fundamental period greater than pulse period, similar behavior was observed as well in story drifts.

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