*International Journal of Civil and Structural Engineering– IJCSE*
*Volume 2 : Issue 1* *[ISSN : 2372-3971]*
*Publication Date: 30 April, 2015*

# Evaluation of story drift ratios of steel special moment frames under ground motions scaled to approximate a uniform hazard spectrum

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***Abstract*—Current structural design codes like ASCE/SEI 07-10 permit the engineer to use three number of ground motion records approximating to a uniform hazard spectrum on condition that the maximum of the obtained displacements should be used during seismic performance assessment. However, if at least seven number of ground motion records are selected and scaled to this aim, mean of the obtained displacements shall be used. It is rather arguable if the former compensates the latter considering the fact that dispersion of structural response parameters are generally too high under the effect or earthquake loading. In this work, initially a suite of seven ground motions all of which scaled to approximate the design response spectrum of ASCE/SEI 07-10 is prepared, afterwards all possible trio combinations of these seven records are determined and each subset re-scaled to fit the response spectrum. A total of 35 subsets are prepared in this sense. The amount of approximation to the target spectrum is also determined for each set, and eventually 5 subsets with maximum, minimum and medium approximation levels are chosen. In order to study the story drift distributions of steel special moment frames under the effect of these prepared sets, a ten story model frame is designed per US design codes. The results indicate that the use of record subset with the highest approximation to the target spectrum does not result in the maximum story drift ratios of the sub set to be close to the mean story drift ratios of the main set with 7 records. Moreover, the difference between the mean story drift ratios of the main set and the maximum story drift ratios of the subset can be considerably high especially for the floor level with the peak maximum story drift ratio among the other floor levels.**

***Keywords*—selecting and scaling of earthquake records, steel special moment frame, story drift ratio**

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## I. Introduction

The main challenge to overcome during the seismic performance evaluation of structures with nonlinear dynamic procedures is to establish earthquake suites matching to a uniform hazard spectrum. However, there is currently no consensus in the earthquake engineering community on how to appropriately select and scale earthquake ground motions to this aim [1]. One of the basic questions next to many others is how many number of records shall be used? Current practice compatible with the design codes like ASCE/SEI 07-10 is to utilize 7 records and taking the mean of the obtained displacements after the analyses or selecting and scaling 3 records and taking the maximum of the displacements [2]. It is quite arguable if these methods compensate each other owing to the fact that dispersion of structural displacements are generally high under earthquake loads. Namely, since the dispersion is high the difference between the maximum and mean values will most probably be high.

This work is an attempt to compare the mean and maximum inelastic peak structural displacements, obtained with the use of 7-recorded and 3-recorded earthquake suites matching to a uniform hazard spectrum, respectively.

## II. Design and Modeling of the Frame

An office building containing two perimeter special steel moment frames (SMF) in one direction and two perimeter special concentrically braced steel frames (SCBF) in the opposite direction is considered (Fig. 1). SMF and SCBF are the components of the lateral load resisting part of the building whereas the remaining beam-to-column connections are simple, thus the remaining components can resist only the gravity loads. Actually, one of the perimeter steel special moment frames is investigated during parametric studies. Load and Resistance Factor Design of the ANSI/AISC 360-10 is taken into consideration while assigning the cross sectional properties of the structural elements [3]. To provide adequate amount of global ductility, capacity based design principles are used per ANSI/AISC 341-10[4]. The loads, load combinations and design response spectrum are based on ASCE/SEI 7-10. In the model ASTM A992 steel is used for both columns and girders. Dead load for the normal stories is 3.83 kN/m$^2$ (80 psf) , including the weight of the steel structural elements self-weights. Live load is 3.11 kN/m$^2$ (65 psf) for the normal stories. Dead load and live load are considered as 3.11 kN/m$^2$ (65 psf) and 2.87kN/m$^2$ (60 psf) for the roof floor. The site class is considered as C per ASCE/SEI 07-10. The mapped maximum considered earthquake spectral response acceleration values at short and 1 second periods are 1.5g and 0.6g.

Equivalent lateral load procedure of ASCE/SEI 7-10 is used to consider the earthquake load effects the fundamental period of the model frame is found as 2.36 s.

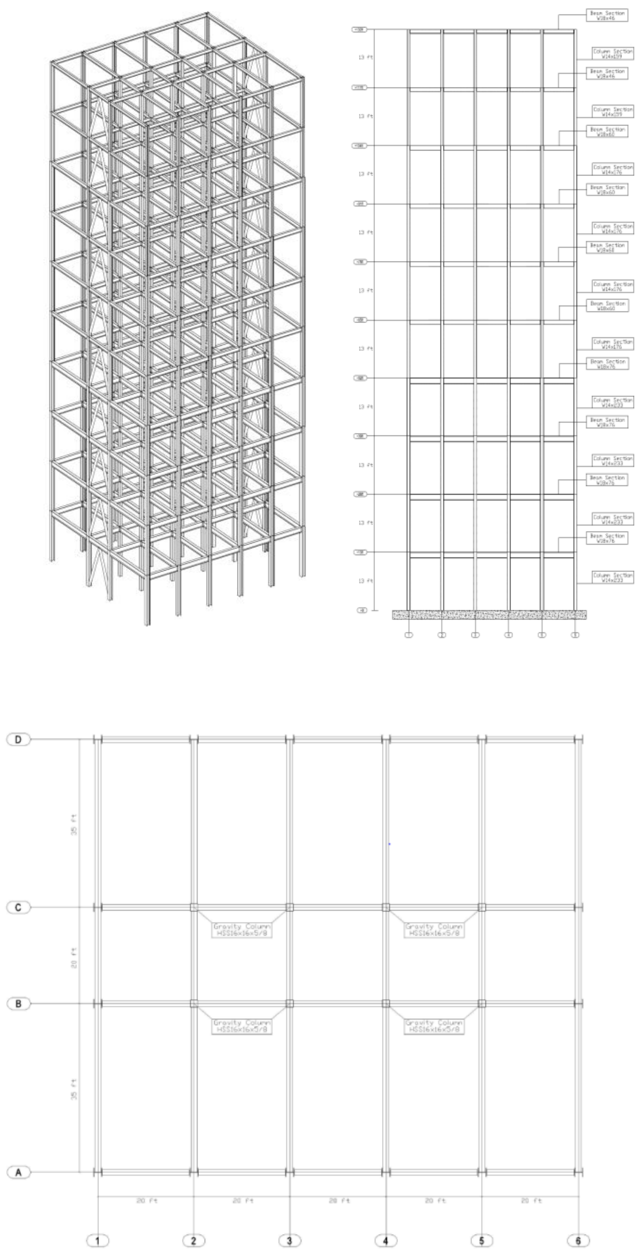

Figure 1. Basic properties of the office building

In two dimensional model P-Delta effects are taken into consideration by the use of leaning column approach. To this aim the basic properties of the gravity columns are utilized. All the inelastic actions of the structural elements are deformation controlled. There is an $R_y$ factor of 1.1 for structural elements' strength calculations. Rigid end offsets are taken into consideration and the composite slab is assumed to behave as a rigid diaphragm.

TABLE I. ASIGNED PROFILES

| STORY | Column | Beam | Gravity Column |
|---|---|---|---|
| 10 | W14x159 | W18x46 | HSS16x16x5/8 |
| 9 | W14x159 | W18x46 | HSS16x16x5/8 |
| 8 | W14x176 | W18x60 | HSS16x16x5/8 |
| 7 | W14x176 | W18x60 | HSS16x16x5/8 |
| 6 | W14x176 | W18x60 | HSS16x16x5/8 |
| 5 | W14x176 | W18x60 | HSS16x16x5/8 |
| 4 | W14x233 | W18x76 | HSS16x16x5/8 |
| 3 | W14x233 | W18x76 | HSS16x16x5/8 |
| 2 | W14x233 | W18x76 | HSS16x16x5/8 |
| 1 | W14x233 | W18x76 | HSS16x16x5/8 |

Beam flanges are restrained against lateral torsional buckling adequately so they are assumed to be capable of fully plastifying. All the component plates of the cross sections are seismically compact. Since the expected displacement level is not capable of damaging the beam-to-column connections, strength degradation is not considered. A strain- hardening slope of 3% of the elastic slope is used for the structural elements. Yield rotations of beams and columns are determined according to ASCE/SEI:41-06[5].

Initially, static analyses are carried out under the effect of combination of 1.1(D+0.25L) where D and L are dead and live loads and consequently nonlinear dynamic analyses are carried out on the deformed frame.

## III. Ground Motion Record Sets

In this work, a computer program coded by Dr. Nuri Özhendekci is used during the selection and scaling of ground motion records to approximate a uniform hazard spectrum is a similar version of the one reported by PEER Strong Motion Database Center [6]. On the other hand, "single record" s are used instead of "record pairs" in this work because it is stated in ASCE/SEI 7-10 that where two-dimensional analyses are performed, each ground motion shall consist of one horizontal acceleration history, selected from an actual recorded.

There are six different ground motion sets prepared with the same hazard level of 10% possibility of exceedance in 50 years in order to study the behavior of the model frame under dynamic loads. The reference set (Set 0) has 7 scaled ground motion records compatible with the minimum number of records per ASCE/SEI 7-10. Actually, it is stated that the appropriate records of events should have magnitudes, fault distances and mechanisms that are consistent with the maximum considered earthquake along with ASCE/SEI 7-10, too. However, according to a study conducted by Lervolino and Cornell, there is no need for a careful site specific process of record selection by magnitude and distance [7]. Thus, a specific scenario is not adopted during the establishment of the reference set in order to approximate the design spectrum best. Beside, the horizontal components of the whole database of the PEER Strong Motion Database Center for site class C is used during the iterations in search to this aim[8]. The basic properties of the ground motion records of the reference set is given in Table I.

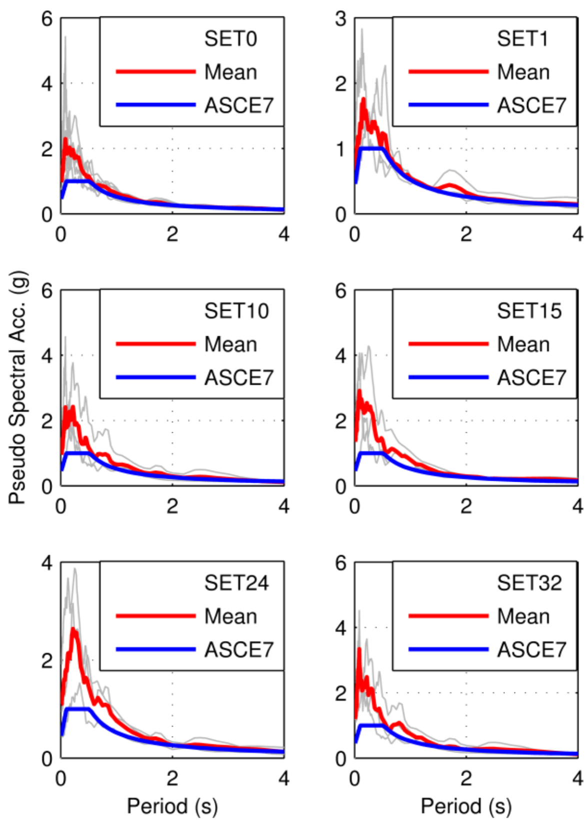


Figure 2. ASCE 7 design response spectrum and the mean of the records of different sets

Initially, all possible trio combinations of the seven ground motion records of the reference set are determined. And records of all of the subsets are re-scaled in order each subset shall approach the uniform hazard spectrum. The level of approximation for the whole subsets are also determined. The quantitative measure used to evaluate how well a time series conforms to the design response spectrum is the mean squared error (MSE) of the difference between the spectral accelerations of the record and the design response spectrum. Finally, subsets with maximum, minimum and three subsets with MSE values nearly equally distributed among the sorted MSE values are chosen. These sets are Set 1, Set 10, Set 15, Set 24, and Set 32. The initial set numbers derived based on all possible trio combinations of existing 7 records are retained. That's why the numbers which the names of the subsets contain are not sequential. The directivity is not considered as a classifying characteristics, thus both fault normal and fault parallel components are selected randomly in order to obtain the best fitting average spectrum. The records of the reference set and subsets and the scale factors for each record per set are provided in Table II and Table III. The response spectra and average spectrum of each record set and design response spectrum are provided in Fig 2.

TABLE II. BASIC PROPERTIES OF THE GROUND MOTIONS OF SET 0

| ***YEAR*** | ***EVENT*** | ***NGA#*** | ***Comp.*** | ***Mag.*** | ***$R_{rup}$ (km)*** |
|---|---|---|---|---|---|
| 1989 | Loma Prieta | 802 | FP | 6.93 | 8.5 |
| 1999 | Chi Chi Taiwan | 1521 | FN | 7.62 | 9 |
| 1976 | Gazli | 126 | FP | 6.80 | 5.46 |
| 1992 | Landers | 879 | FP | 7.28 | 2.19 |
| 1994 | Northridge | 1004 | FN | 6.69 | 8.44 |
| 1985 | Nahanni Canada | 495 | FN | 6.76 | 9.6 |
| 1992 | Cape Mendocino | 825 | FP | 7.01 | 6.96 |

TABLE III. THE SCALE FACTORS OF THE RECORDS OF THE SETS

| NGA # | 802 | 1521 | 126 | 879 | 1004 | 495 | 825 |
|---|---|---|---|---|---|---|---|
| SET 0 | 1.75 | 1.75 | 1.01 | 1.75 | 0.89 | 1.48 | 1.01 |
| SET 1 | 1.395 | 1.4 | 1.4 | -- | -- | -- | -- |
| SET 10 | 1.55 | -- | -- | 1.472 | 1.55 | -- | -- |
| SET 15 | 1.55 | -- | -- | -- | -- | 1.55 | 1.436 |
| SET 24 | -- | 1.272 | -- | -- | 1.3 | -- | 1.3 |
| SET 32 | -- | -- | -- | 1.457 | 1.5 | 1.5 | -- |

## IV. Results of the Analysis

The distribution of the story drift ratios for reference set and subsets are provided in Fig.3-8. Furthermore, the mean values of the reference set, and the maximum values of the subsets are also provided in the same figures.

For the reference set, maximum of the mean story drift ratio is observed at $7^{th}$ floor level with a value of 0.0181, whereas except for first story and top two stories remaining drift ratios are nearly 0.015.

For Set 1, peak of the maximum values is observed at $6^{th}$ floor level with a value of 0.0351, whereas except for first story and top two stories remaining drift ratios are nearly 0.02.

For Set 10, peak of the maximum values is observed at $7^{th}$ floor level with a value of 0.028, whereas except for first story and top two stories remaining drift ratios are nearly 0.02.

For Set 15, peak of the maximum values is observed at $5^{th}$ floor level with a value of 0.0251, whereas except for first story and top two stories remaining drift ratios are nearly 0.02.

For Set 24, peak of the maximum values is observed at 7th floor level with a value of 0.0243, whereas except for first story and top two stories remaining drift ratios are nearly 0.02.

For Set 32, peak of the maximum values is observed at 5th floor level with a value of 0.0285, whereas except for first story and top two stories remaining drift ratios are nearly 0.02.

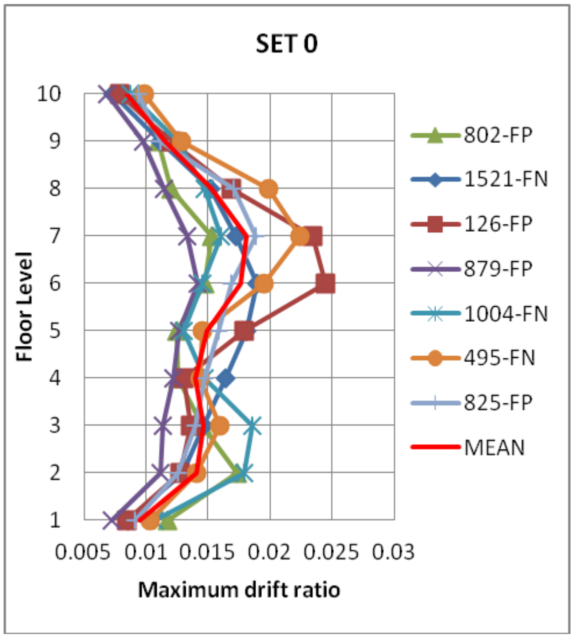


Figure 3. Maximum story drift ratio

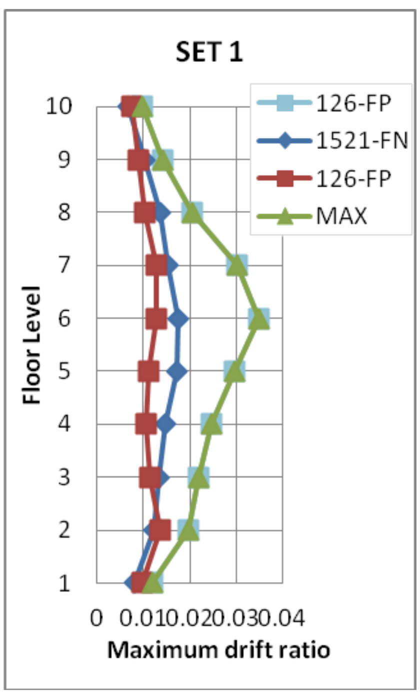


Figure 4. Maximum story drift ratio

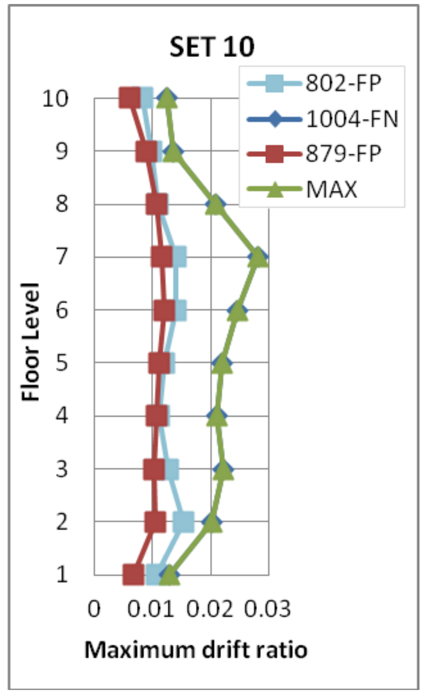


Figure 5. Maximum story drift ratio

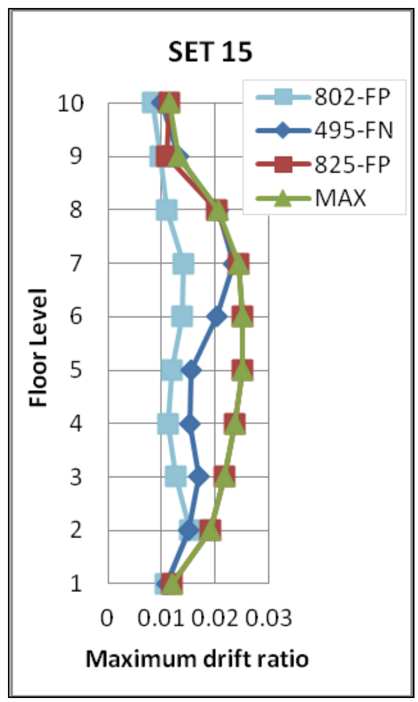


Figure 6. Maximum story drift ratio

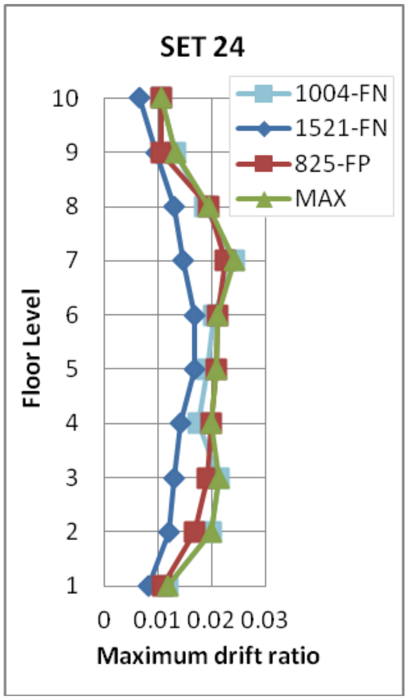


Figure 7. Maximum story drift ratio

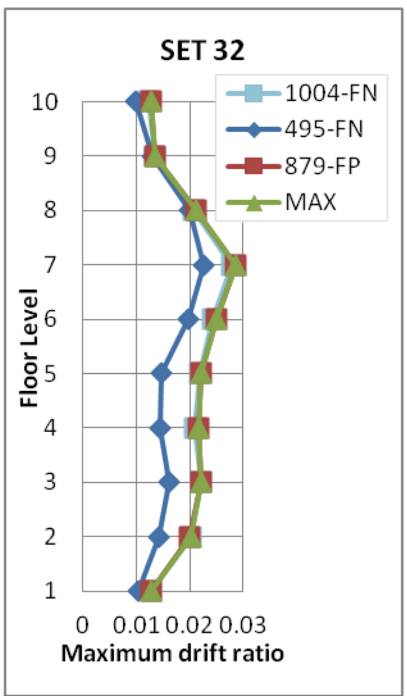


Figure 8. Maximum story drift ratio

# V. Conclusions

The basic purpose of this research is to compare the effects of ground motion suites comprising of 7 and 3 number of records on the inelastic structural displacements. The reference set contains 7 records, average spectrum of which best fits to the target uniform hazard spectrum for the considered database. The whole records of C local site class of the PEER strong ground motion database is utilized for selection. The subsets are deliberately established via the seed records of the reference set, the comparison would be peremptory in this sense. As above mentioned 5 subsets are utilized with various values MSE values.

The mean of the maximum story drift ratios of the reference set are compared to the maximum values of the maximum story drift ratios of the subsets. It is found out that the difference of displacements does not have a systematic relation with MSE values. Furthermore, except for the very similar top two and first story levels subset displacements are generally 25% higher than reference displacements. For only the peak displacements the difference is extremely high as much as 100-200%. This is disquieting such an amount may result in different satisfied performance levels for the reference set and the subsets. Actually, such a result conflicts with the assumption of 3-recorded earthquake sets may compensate 7-recorded sets as long as maximum are used instead of mean displacements.

## *Acknowledgement*

The authors express their gratitude to Dr. Nuri ÖZHENDEKCİ for using the program he coded for selecting and scaling earthquakes to approximate a uniform hazard spectrum.

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