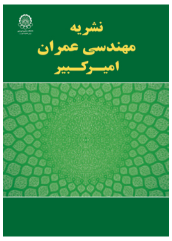

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Seismic Performance Factors of Special Moment Resisting Steel Frames Subjected to Far- and Near-Field Ground Motions

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ABSTRACT: Different and to some extent poor seismic performance of structural systems under various types of near-field earthquake excitation, made re-assess and re-evaluation of "seismic performance factors" used in building codes, an inevitable important task. In this paper, seismic performance of special moment resisting steel frame system (SMRSF) under near-Field (with and without pulse) and far-field record excitation is investigated through FEMA P695 methodology. In order to cover the "design space" of the selected structural system, archetypes consisted of 1, 2, 3, 5, 8 and 15 story buildings with 4 and 8 meters bay are selected and designed based on Iran's national building codes for a "very high seismic" region. Corresponding non-linear models are built based on most recent advances in structural components modeling using OpenSees software. At first by performing non-linear static analysis, overstrength factor and period-based ductility are evaluated and quality of non-linear models is controlled. Afterwards, incremental dynamic analyses (IDA) are performed using far-field, near-field pulse like and non pulse like records. Finally, by using IDA results, "adjusted collapse margin ratio (ACMR)" of the models are calculated and compared to "allowable collapse margin ratio ($ACMR_{allowable}$)". Therefore, seismic performance of the models are evaluated and "response modification coefficient" (R) for the system is investigated and compared with this factor under different types of ground motion records. Results indicated that except for 15 story buildings, proposed "response modification coefficient" and "over-strength factor "for SMRSF system are adequate under far-field records. However under pulse like near field ground motions, it was observed that short period structures are to some extent vulnerable. For long period structures, in contrast with far-field records, seismic performance of structures designed by prescriptive provisions has adequate performance under near-field pulse like motions.

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1- Introduction

Since occurrence of some devastating near-field earthquakes like Northridge 1994, a great deal of researches has been conducted to understand nature and special effects of these earthquakes and therefore phenomena like directivity and fling step were detected and defined. In this regard, forward directivity has proved to be one the main reasons behind most damages to buildings experiencing near field earthquakes [1]. Despite all the studies performed during these two decades, yet steel special moment frames have not been the subject of a thorough investigation under near field records by a reliable performance-based methodology; therefore in this paper, seismic performance of steel special moment frame structures with other-than RBS connections designed based on current codes is evaluated using FEMA P695 methodology. At first FEMA P695 methodology is briefly introduced and afterwards steps of this methodology is applied on steel SMF system using far-field and near-field records. Finally, results and evaluation of seismic performance of each model and therefore the system is presented and acceptability of proposed seismic factors (including "response modification coefficient" (R factor) and "overstrength factor" (Ω_0)) is investigated.

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2- Methodology

FEMA P695 methodology gives us a general and reliable approach in order to estimate and quantify seismic performance of structural systems and also seismic response parameters (including R and Ω_0) of structures designed by linear methods. Performance evaluation of structural systems is based on estimation of safety against collapse in which allowable margin of safety for each system is dependent on response modification coefficient (R) and overall amount of uncertainty in the performance evaluation process. Furthermore, overstrength factor (Ω_0) and period-based ductility factor (μ_T) can be evaluated through this methodology [2].

Based on Fema P695 methodology, determining "Index archetype" is the first step of covering design space of the structural system; in this regard a 3 story building with 3 bays, regular in plane, residential occupancy located in a very high seismic region is selected as index archetype. To develop the archetypes and performance groups, key parameters would be number of stories, span lengths and period of the buildings. Therefore archetypes consisted of 1, 2, 3, 5, 8 and 15 story buildings with 4 and 8 meters spans are selected to form the performance groups and cover the design space.

Design provisions of Steel SMF structures are those of Iranian national building codes. In this regard design of beams and columns are based on strength, lateral displacement, P-Delta and strong column-weak beam criteria. In this study, models are designed based on following considerations: seismic design of all the models is done using Equivalent Lateral Force (ELF) procedure (R=10 and Ω_0=2.8); box section and IPE sections are selected for columns and beams respectively; column bases are fixed and beam-column connections are all other-than RBS ones.

Non-linear models are developed using OpenSees software. In the analytical model, beams and columns are consisted of 3 elastic elements and 2 plastic hinges at both ends which are fully responsible to represent non-linear and hysteretic behavior of these elements. P-delta effects are incorporated using leaning column approach [3]. Panel zone is a rectangular comprised of 8 rigid elements, 3 hinges and one rotational spring with trilinear behavior based on Gupta-Krawinkler model [4]. Column and beams plastic hinges moment-rotation behavior is based on modified Ibarra-Krawinkler deterioration model [5].

3- Results and Discussion

By performing pushover analysis, quality of nonlinear models is investigated and overstrength and period-based ductility factors are calculated (Ω_0 and μ_T). It is observed that the proposed overstrength factor (Ω_0=2.8) for Steel SMF system is appropriate since the calculated overstrength factor of different performance groups are within the range of 2.8 to 4.4. Moreover, overstrength of models with 8 meters spans are more than those of 4 meters ones and overstrength is reduced by increase in height of the structures. The amount of period-based ductility for the system is calculated to be 7 (μ_T =7).

To evaluate seismic performance of the structures in accordance with Fema P695 methodology, incremental dynamic analyses (IDA) are implemented to calculate median collapse level and safety margins of the models. In this regard, IDA curves with EDP of “maximum inner-story drift ratio (MIDR)” correspondent to IM of “spectral acceleration with 5% damping in 1st mode (Sa(T1,5%))” of structures are derived for each archetype under different sets of earthquake records; in this study three sets of records comprised of far-field, near-field without pulse and near-field with pulse records are used. Records with pulse are those identified by wavelet analyses and contain a strong velocity pulse at the beginning of the record due to the effects of forward directivity phenomenon [6].

By processing IDA results, collapse margin ratios (CMR) are derived for each model; afterwards adjusted collapse margin ratios (ACMR) are calculated by taking into account the frequency content (spectral shape) of the ground motion record set; in this regard spectral shape factors (SSFs) are determined based on first mode of vibration period (T1), Period-based Ductility (μ_T) of the model and seismicity of the region. Finally by comparison of “adjusted collapse margin ratio (ACMR)” of the models with “allowable collapse margin ratio”, seismic performance of the models is evaluated, correctness of proposed “response modification coefficient” (R) is investigated and comparison of the collapse performance of the system under different types of earthquake records excitation is made. Determining allowable collapse margin ratio for each model is dependent on the amounts of period-based ductility and the overall uncertainties in the performance evaluation process comprised of record-to-record, design requirements, test data and modeling uncertainties.

By analyzing results of far-field record set, it is seen that all short-period models and performance groups passed the performance target with high margins of safety and most of long-period models except for 15-story ones have also managed to fulfill the target; therefore it is concluded that seismic performance of the system is acceptable and the proposed response modification coefficient (R=10) is appropriate however requirements of the system for tall buildings needs some modifications. In this regard, utilizing period-based response modification coefficient or increasing base shear or allowable inner-story drifts are proposed as solutions to the problem.

Analysis of safety margins of archetypes against collapse reveals that under far-field and near-field without pulse records, all short-period structures have appropriate safety margins against collapse however for long-period structures this safety is greatly reduced as the period increases; therefore 15-story structures and their performance groups failed to meet the acceptance criteria. Furthermore, it is observed that models with 8 meter span have higher safety margins comparing to those with 4-meter span.

Although pattern of variation of collapse safety margin in relation to the period of the structures are similar under both near field with and without pulse records, but status of structures in passing seismic performance targets differ greatly under these two record sets; performance of short-period models is weaker when subjected to near-field with pulse records; in contrast, performance of long-period structures is weaker when subjected to near-field without pulse records.

4- Conclusions

According to the results of pushover analyses, it is confirmed that the proposed overstrength factor for steel SMF system is appropriate; based on incremental dynamic analyses and Pass/Fail status of archetypes and performance groups, it is concluded that proposed response modification coefficient is appropriate and the system satisfies FEMA P695 performance targets.

Under far-field records excitations, all models pass the acceptance criteria with great safety margins except for 15-story buildings which lead to the failure of long period performance groups. Under near-field without pulse records, seismic performance status of the system is very similar to those of far-field ones; but under near-field with pulse records, performance status are totally different. Short-period models show poor performance under near-field with pulse records as 1-story model with 4-meter span and 2-story model with 8-meter span failed to meet the performance targets. In contrast, long-period structures show better performance when subjected to near-field with pulse records as all the models and performance groups satisfy the performance targets. It is concluded that short-period structures are the ones more susceptible to near-field with pulse records and therefore effects of such records must be taken into account in their design process.

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