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# Evaluating the difference in the effect of distance on the seismic demand estimated using nonlinear dynamic analysis and Bayesian statistics in near and far fields

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## Abstract

Seismic demand estimation of structures (which is considered as one of the main components of performance-based designing) is along with various uncertainties, the most important of which is fault-to-site distance. In fact, with the variation in fault-to-site distance of an accelerogram, its effect on seismic demand estimation would differ. However, it seems that this distance impact on the seismic demand will be different in far and near fields concerning the distinct nature of near field. The main aim of this study is to verify this issue and determine the impact of fault-to-site distance on seismic demand of steel moment resisting frames in near and far fields using nonlinear dynamic analysis and Bayesian statistics. Nonlinear dynamic analysis is used to cover the actual nonlinear behavior of the structure in near-collapse performance level and the Bayesian approach to cover all uncertainties. Concerning the research objectives, two generic steel moment resisting frames of 3-storey with rigid behavior and 15-storey with flexible behavior have been selected and nonlinearly modeled in OpenSees. At the next stage, these frames were analyzed through incremental nonlinear dynamic analysis under five groups of 40 accelerograms that were similar in terms of all features except for fault-to-site distance and the results were used for determining their seismic demand. In so far as the only variable in this analysis is fault-to-site distance, the difference in the results could be attributed to this variable. According to the results, from statistical approach, there is some difference between the impact of distance variation on seismic demand in near and far fields which is subject to some variables such as the behavior of the frame and its performance level.

*Keywords:* Nonlinear Dynamic Analysis, Bayesian Statistics, Near and Far Fields Earthquakes, Seismic Demand, Fault-to-Site Distance

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## 1. Introduction

The main challenge for the structure design engineers in determining the performance of the structure and designing is to determine the behavior of structure against earthquake. That is because of various uncertainties in the forces resulting from earthquake and the structure's response to these forces. Certainly, the presence of various uncertainties in a problem makes it inevitable to use probability method rather than a certain method [25, 14]. So far, what has been proposed as the application of probabilities in earthquake engineering has been confined to selection of a ground motion parameter (such as ground acceleration or spectral acceleration) based on the return period as the design parameter and multiplied by a set of coefficients (such as the coefficient of behavior, the significance coefficient and etc.) and calculate the earthquake forces. It is clear that the reliability of the structure designed by such design method will be completely uncertain against the collapse resulting from an earthquake [6].

The occurrence of several destructive and sever earthquakes in recent years and their adverse effects, which were unexpected, proved the inefficiency of the above method more than ever. The Northridge earthquake in 17 January 1994 is the best example to prove this issue. The most significant event is the damage to the steel moment resisting frames that were considered as very reliable systems against earthquake [7]. In this earthquake, 200 steel resisting frames suffered from failure in beam to column connection which was totally in contraction with the expected behavior against earthquake. After this earthquake, the owners of structures realized that bearing extra cost in the construction phase, which increases the reliability of the structure's behavior, will be negligible in comparison with the cost of probable damage to the structure. Therefore, they asked the structure engineers to design structures with better performance [22].

All these lead to reconsideration of all standards, methods and philosophies related to designing of structures with the aim of determining a framework for predicting the seismic behavior of structures. The new philosophy was designing the structures based on their performance; which is called performance-based design. In new performance-based designing method, estimation of seismic demand is considered as one of the main components of describing the performance of structure. The main challenge in this estimation is various uncertainties and randomness in the earthquake phenomenon and the seismic response of structures [5]. Therefore, the use of a probabilistic framework in this estimation seems to be necessary; which is called Probabilistic Seismic Demand Analysis or PSDA [13]. In fact, PSDA is a strategy for calculating the annual probability of exceeding the seismic demand parameter of a structure in a certain site from a certain value. The seismic demand estimation of a structure in a certain site is such that the seismic hazard curve of Intensity Measure (IM) parameter for the intended site is combined with the results obtained from nonlinear dynamic analysis of that structure under a set of accelerometers using the total theory of probabilities to yield the desired results [19].

In mathematical words, if the seismic demand parameter of maximum inter-storey drift ratio (which is a good parameter for describing the nonlinear behavior, especially total collapse of steel moment-resisting frames) is selected and represented by DR, and intensity measure parameter by IM, the problem of probabilistic seismic demand analysis, i.e. the annual probability of DR exceeding the certain value of x, or, in mathematical words, $P[DR > x]$ is expressed as follow [16]:

$$P[DR > x] = \int P[DR > x|IM = y].|dH_{IM}(y)| \quad (1)$$

In this expression, $H_{IM}(y)$ means the annual probability of $IM$ exceeding the certain $y$ value; i.e., the seismic curve of $IM$ parameter, whose differential in point $y$ has been used. This component is usually calculated by probabilistic seismic hazard analysis methods. The other important term in this equation is $P[DR > x|IM = y]$, which is interpreted as the probability of exceeding of seismic demand parameter from certain value of $x$ on the condition of $IM$ parameter equal to y [17].

Now, it is time to refer to the main objective of this paper which is, determining the probability of demand occurrence or P $[DR > x]$ with consideration of a main challenge, i.e. near field issue. One of the main challenges in seismic demand estimation which is now very significant is near field issue. In fact, the certain and distinct type of ground motion resulting from earthquake in near field and the ambiguous response of structure to these motions has made the seismic demand estimation for structures in the near field a real challenge [23, 13]. Moreover, it has made many studies dealing with this issue. The research problem in this paper can be evaluated in this regard. The present study deals with the effects of near-field on the seismic demand in the steel moment resisting frames. It is sought to investigate the difference in the distance effect on the seismic demand estimated in the steel moment resisting frames using Bayesian statistics in near and far fields from a statistical approach. In this paper, Bayesian statistics will be used to evaluate the reliability of these effects [8, 9]. In fact, the reason for choosing Bayesian statistics in this study is its capability in modeling all statistical stochastic and uncertainties and existing modeling in near-field and the response of the structure to increase the reliability of results.

## 2. Using Bayesian Statistics in Demand Analysis

In overall, there are three main strategies for performing statistical calculations: Moments method, maximum likelihood and Bayesian method [3]. In this regard, Bayesian statistics is the best possible option for statistical calculations of the phenomena of high uncertainty, such as earthquake, due to high capability in simultaneous modeling of uncertainty and randomness [4]. In fact, the reason for choosing Bayesian statistics in this study is its capability in modeling all statistical stochastic and uncertainties and existing modeling in near-field and the response of the structure to increase the reliability of results. Here, the Bayesian method is briefly presented: The details could be found in different references [21, 11, 12]. Assume that:

$$D(x, \theta, \sigma) = d(x, \theta) + \sigma.\epsilon \quad (2)$$

is a mathematical model for predicting variable $D$ based on a set of observed variables, i.e. $X$; where $d(x_2\theta)$ is the certain part $pf$ model, $\theta$ is the vector of unknown parameters of the model and $\epsilon$ is a normal stochastic variable with a zero mean and standard deviation of 1 which is indicative of the existing uncertainties in the prediction model. Moreover, $\sigma$ is the standard deviation of the model which is taken as an unknown parameter. Therefore, the vector of unknown parameters that should be determined using the existing data and through statistical calculations include$\Phi(\theta, \sigma)$ Now, the following equation is used in Bayesian statistics to determine these parameters:

$$f(\Phi) = c.L(\Phi).p(\Phi) \quad (3)$$

Where, $p(\Phi)$ is defined as the prior distribution of unknowns, which is indicative of their current data before data collection. Using the new data, which includes the observed variables, i.e. $X$, the new level of data about the unknown parameters is defined in form of its likelihood function, i.e. $L(\Phi)$. Combining the prior distribution and the existing data, the posterior distribution of unknown parameters, i.e. $f(\Phi)$, which is reflection of the level of new data about unknowns, will be calculated that are the desired results. In this regard, $s$ plays the role of a scaling parameter to guarantee the posterior distribution function integral equaling unit. Through such strategy, it is possible to calculate the unknown parameters of the model. In this paper, Bayesian regression based on Markov Chain Monte Carlo stimulation technique, which leads to fully Bayesian estimation of prior and posterior mean, is used to estimate the form of functions and its unknown parameter. All regressions in this study and the estimation of the parameters of probabilistic seismic demand model have been done through this method.

## 3. Defining the target steel moment resisting frames with nonlinear behavior

This study is basically statistical and the results will be interpreted through statistical and probabilistic approach; therefore, it's so important that the structural models also have such capability. In other words, in order to access the reliable and acceptable statistical results, the selection of appropriate structural models for steel moment resisting frames and precise modeling is very significant.

The results of previous studies show that a reliable option for generating statistically generalizable results is to use the concept of similar steel moment resisting frames. The results of different studies have proved that these one-bay frames are capable of stimulating the behavior of frames with multiple bays. As previously stated, the main aim of this study is to evaluate the difference in the effect of distance on the estimated seismic demand in the steel moment resisting frames using Bayesian statistics in near and far fields [1]; therefore, it seems that the use of two-dimensional model is a good option for this purpose. On the other hand, the structured used in making a statistical analysis shall not represent a certain structure with unique features, since it prevents generalization of statistical results. Concerning these points, it can be said that the use of similar one-bay steel moment resisting frames in different stories is the appropriate option to achieve the objectives as stated in this study [20].

In this paper, in order to show the effects of the rigidity and ductility of the frame on the results, two 3-storeyrigid frames (with first mode period of 0.3, which is representative of rigid frame in the similar resisting frames) and two 15-storeyductile frames (with first mode period of 1.5 which is representative of rigid frame in the similar resisting frames) have been used. The lumped mass model of these two frames is seen in the following figure.

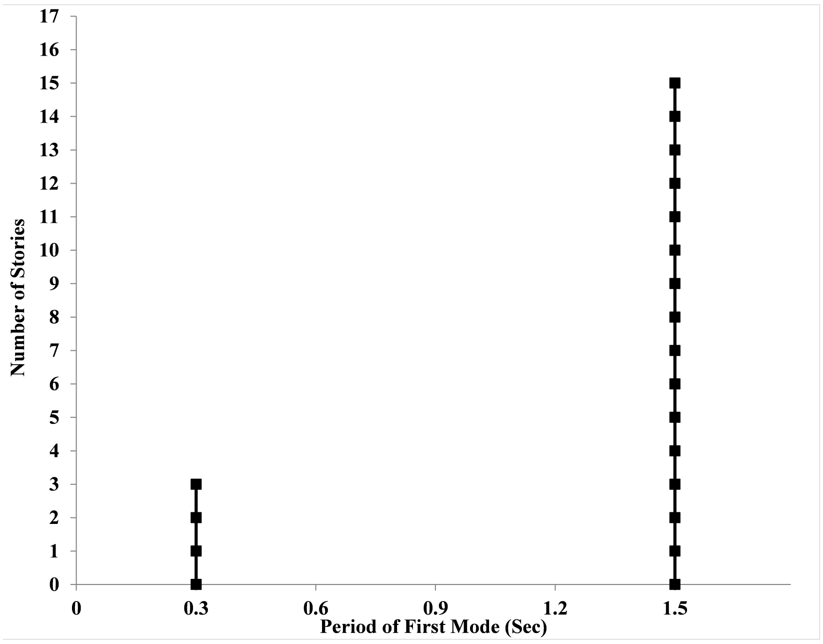

Figure 1: First mode period of two moment resisting frames of 3 and 15 stories in this study

Moreover, in this study, the nonlinear behavior at the members' level has been modeled using rotational springs (with the rigidity and strength deterioration) at the end of beams and columns' base). Moreover, the peak-oriented model has been used to show the cyclic behavior (Figure 2). In this behavior, the cyclic behavior proposed by Ibara and Krawinkler is utilized to consider the cyclic deterioration. In this model, using the concepts of energy, four states of cyclic deterioration in strength, post-capping strength, unloading stiffness and reloading stiffness are taken into account using a cyclic deterioration parameter. The parameters of which are defined in figure 2.

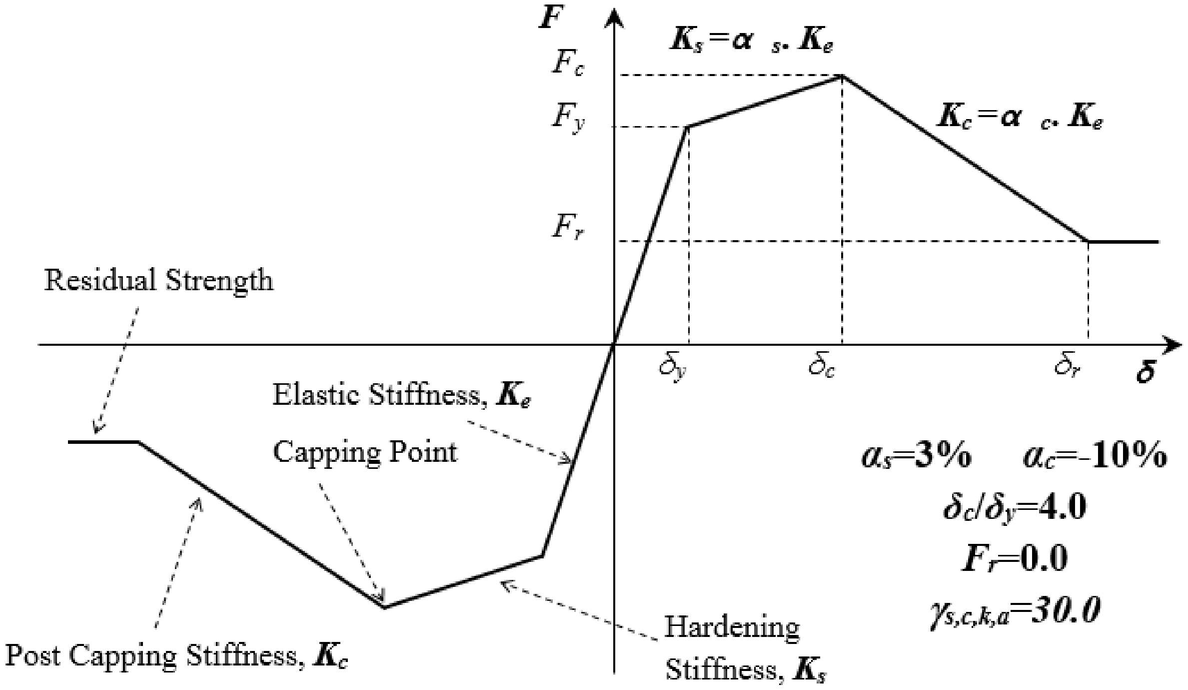

Figure 2: The nonlinear strength curve defined for modeling the nonlinear behavior of target frames

## 4. Selection of accelerograms

The aim of this paper is to evaluate the effect of distance on the estimated seismic demand of steel moment resisting frames using Bayesian statistics in near and far fields. Therefore, first a statistical relation between fault-to-site distance and seismic demand should be evaluated and then it should be studied that when the accelerograms belong to near field, the results of seismic demand estimation will be meaningfully different from other accelerograms [10].

This objective could be a good guideline for appropriate selection of accelerograms. In fact, in this paper, a set of accelerograms should be selected in such a way that all their features except distance are the same. These specifications include magnitude, site condition, fault mechanism and etc [2]. In this part, this philosophy will be sued for selection of accelerograms that are appropriate for nonlinear dynamic analysis. In this paper, site condition C has been selected as the target site condition based on NEHRP bylaw classification [15].

After determining the site conditions, it is required to define appropriate intervals for the accelerograms' distance. As far as the aim of evaluating the difference between the effect of distance on the seismic demand estimated in the steel moment resisting frames using Bayesian statistic in near and far fields, it is obvious that one of the accelerogram groups in terms of distance shall belong to this interval which is defined as $0-13km$. In terms of statistical consistency, other groups of almost similar intervals will be defined, i.e. $13-30km$, $30-45km$, $45-60km$ and finally 60 to $100km$. The paired accelerograms belonging to these groups with the site condition $C$ can be seen in the following table.

Table 1: The number of existing accelerograms with site condition $C$

| The number of paired accelerograms with site condition $C$ | Distance interval | Group number |
|---|---|---|
| 60 | $0-13Km$ | $G1$ |
| 99 | $13-30Km$ | $G2$ |
| 61 | $30-45Km$ | $G3$ |
| 57 | $45-60Km$ | $G4$ |
| 57 | $60-99Km$ | $G5$ |

Now, it is possible to select any number of accelerograms with the same magnitude from the paired accelerograms in the above table. To this end, after investigation of the existing accelerograms in each interval, 20 paired accelerograms were selected for each group with their magnitudes almost of the same statistical distribution. This sameness of statistical distribution means the exact sameness of the maximum value (7.6), minimum value (6.0) and mean value (8.6) and uniform distribution of magnitudes in the interval. In figure 3, this distribution of magnitudes is presented which indicates that the aim of this paper in selection of accelerograms, i.e. omitting the effect of different magnitudes in the quintuple distance groups, is satisfied.

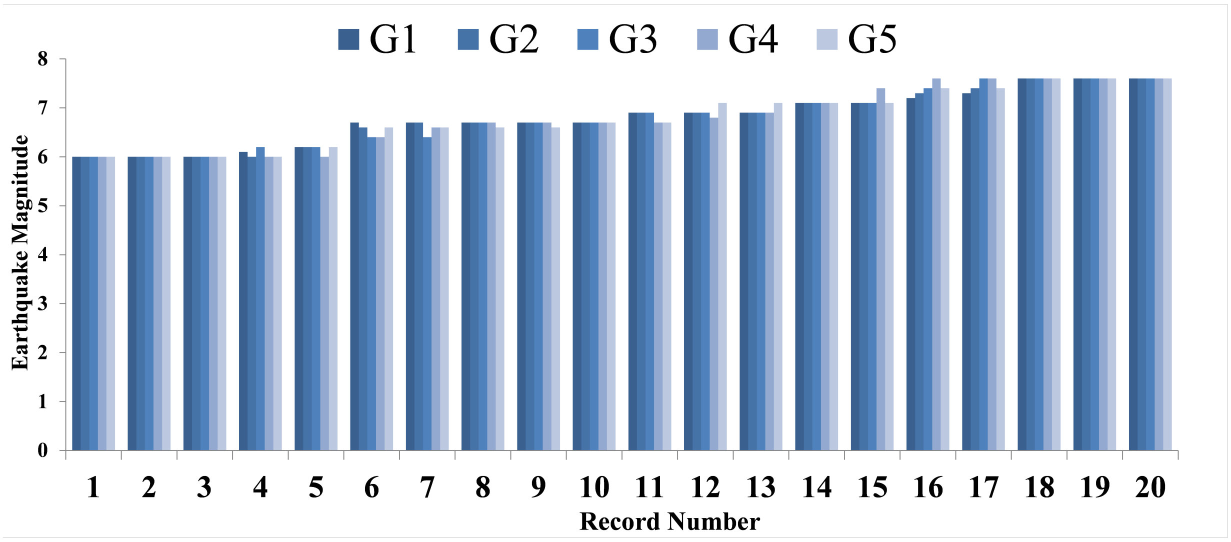

Figure 3: The magnitude distribution in five selected groups for accelerograms

In fact, the constitution of these quintuple groups, five groups of accelerograms are formed that are completely distinct in terms of distance- one group in near field- and similar in terms of other features, especially magnitude and site condition [24].

## 5. Nonlinear incremental dynamic analysis of frames and determination of probabilistic seismic demand model

In this paper, for seismic demand estimation, the Incremental Dynamic Analysis (IDA) will be used which is a reliable method. The next step after modeling the similar steel moment resisting frames and selection of five groups of accelerograms is to produce the results for determination of probabilistic seismic demand analysis using IDA [26].

For incremental dynamic analysis, first appropriate parameters should be selected for defining intensity measure and seismic demand of structure. In determining the probabilistic seismic demand model, the appropriate selection of these two parameters is significant and has been always the focus of various studies. In this study, the first mode spectral acceleration has been selected as the IM parameter and maximum relative displacement between stories as the selected seismic demand parameter.

As previously stated, in this study, five groups of 40 accelerograms will be used that are classified based on distance to fault. Therefore, it is possible to start incremental dynamic analysis after selecting two IM parameters, the seismic demand parameter and defining five groups of accelerograms. In this paper, in order to prepare a complete data bank for determining the probabilistic seismic demand analysis, a computationally complicated but conceptually simple process will be used.

In this algorithm, first all 200 accelerograms will be scaled using a scalability coefficient which is different for each accelerogram, such that their first mode spectral acceleration will be $0.05g$. Then, similar steel moment resisting frames modeled under these scaled accelerograms will be analyzed through nonlinear dynamic method and maximum relative drift between the stories recorded in this analysis due to each accelerogram will be stored as data point with their IM (which is in fact$0.05g$). In other words, the first step in this algorithm is to store the set of maximum relative inter-storey drift, which all have been obtained in respect to the first mode spectral acceleration as equal to $0.05g$, for each frame.

At the next step, the first mode spectral acceleration of all accelerograms will increase one step, i.e. $0.05g$, and reaches $0.01g$.

In this step, nonlinear dynamic analysis will be done and the set of numbers related to maximum inter-storey drift, that all equal to $0.01g$ in respect to first mode spectral acceleration, will be added to the data bank of each frame. This increasing trend of first mode spectral acceleration of each accelerogram increases with step of $0.05g$ until the mentioned accelerogram causes total collapse of the structure, which could be different for each frame. These data banks (5 banks for each frame and in sum 10 data banks) will be important data to determine the probabilistic seismic demand model.

The results of $IDA$ will be used to determine the probabilistic seismic demand model of the frames. The probabilistic seismic demand model is considered as the main component in seismic demand estimation and means the probability of seismic demand parameter (maximum relative inter-storey ratio) exceeding certain value of $x$ on the condition of $IM$ occurrence up to $y$. In other words, the model intends to calculate the average value of seismic demand parameter in respect to certain $IM$ value.

The most logical suggestion for determining the probabilistic seismic demand model is to perform time history analysis for different levels of ground motion intensity and determine demand in each level. It is obvious that the at a certain level of ground motion intensity measure, the demand calculated using different accelerograms is a random value and will differ from an accelerogram to other. This set of required data for determining probabilistic seismic demand model is in fact the data bank obtained from $IDA$ in the previous section.

The relation determined in this way is called probabilistic seismic demand model. Nowadays, the following relation is recommended as an appropriate probabilistic model for steel moment resisting frames [18]:

$$ln(DR) = a.ln(SA1) + w + \sigma.\epsilon \quad (4)$$

Where, $\sigma$ is standard deviation of the model and $\epsilon$ is a normal random variable with zero mean and unit standard deviation and used for modeling the uncertainty and randomness at a certain demand level. Moreover, $a$ and $w$ are the model parameters to determine the relation between the IM (first mode spectral acceleration $SA1$) and seismic demand parameter (maximum inter-storey relative drift, $DR$). In this paper, this model will be used for determining seismic demand.

## 6. The results of nonlinear *IDA* of frames

The mentioned frames in section 3 will be nonlinearly analyzed under the effect of 200 accelerograms presented in section 4 through IDA which is presented in section 5. This analysis will yield massive data that are presented in this section. In figure 4, the results of nonlinear IDA of 3-storey frame has been shown for five groups of accelerograms. The rigid behavior of 3-storey frame, which leads to bilinear behavior of this frame and its sudden fracture under the effect of target accelerograms, could be easily seen in this figure. The significant depression for the accelerograms that are selected uniformly indicates the uncertainty of earthquake.

These graphs are shown for 15-storey frame in figure 5. As seen in these figures, the ductile behavior of this frame is completely different from the rigid behavior of 3-storey frame and the ductile behavior of 15-storey frame leads to gradual displacement of this frame until the collapse point. Moreover, the dispersion in the results could be easily seen.

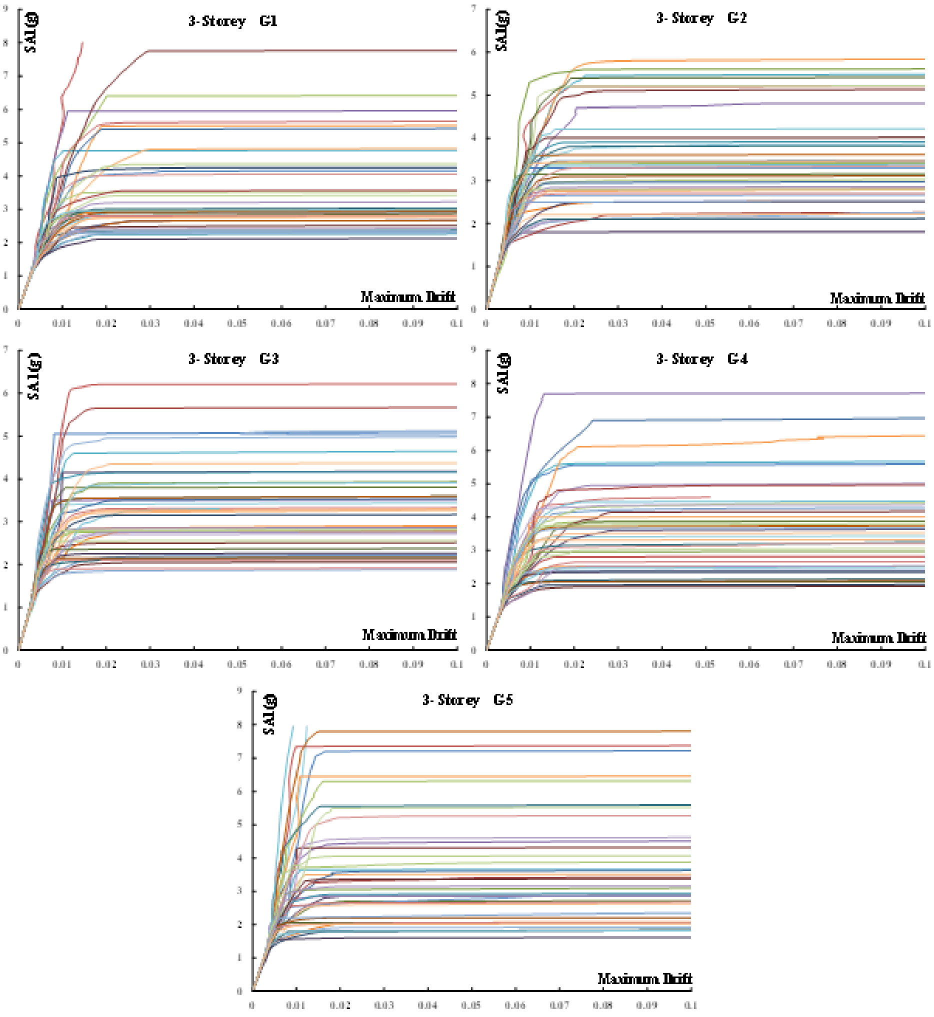

Figure 4: The results of nonlinear IAD of 3-storey frame under 5 groups of accelerograms

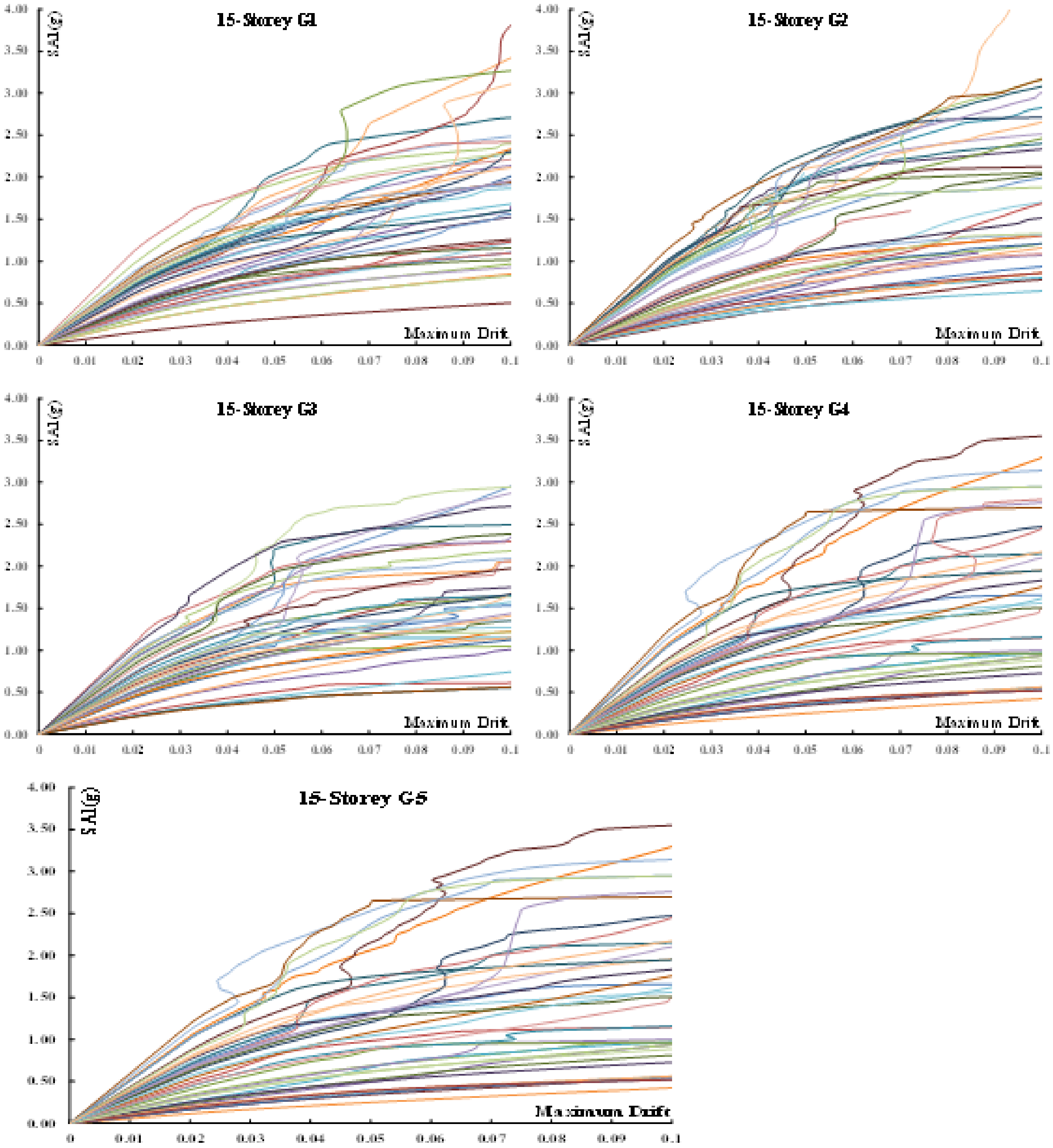

Figure 5: The results of nonlinear IAD of 15-storey frame under 5 groups of accelerograms

## 7. Determination of probabilistic seismic demand model for target structures

In the previous section, two frames of 3 and 15 stories were analyzed through nonlinear $IDA$ under the effect of 200 accelerograms with different distance to fault. As it is observed, the obtained results in form of behavioral frames were subject to various variables such as the properties of the accelerograms (specifically distance to fault), performance level, ductile or rigid behavior and the number of stories, therefore, one or a few IDA curve cannot be an appropriate tool for determining the effect of fault-to-site distance on the seismic demand of the steel moment resisting frames in near and far fields, because of the considerable dispersion in the results.

In order to overcome this challenge, instead of direct use of curves and their interpretation, the results will be used for determining the probabilistic seismic demand for 3 and 15-storey frames. In fact, the main application of the results of several $IDA$ is to determine the probabilistic seismic demand model which will be done in this part.

In other words, in this section, using the results of $IDA$ under the effect of five different accelerogram groups, the probabilistic seismic demand model will be determined for each frame. Moreover, as previously said, the IM parameter used in this study is first mode spectral acceleration, i.e. SA1, and the demand index is maximum inter-story drift ratio ($DR$), and the equation will turn into figure 4 using a linear regression analysis between $IM$ and obtained demand logarithm. As an example, in figure6, this model has been calculated for two frames under the effect of 1st and 5th groups. Table 2 presents all 10 determined models.

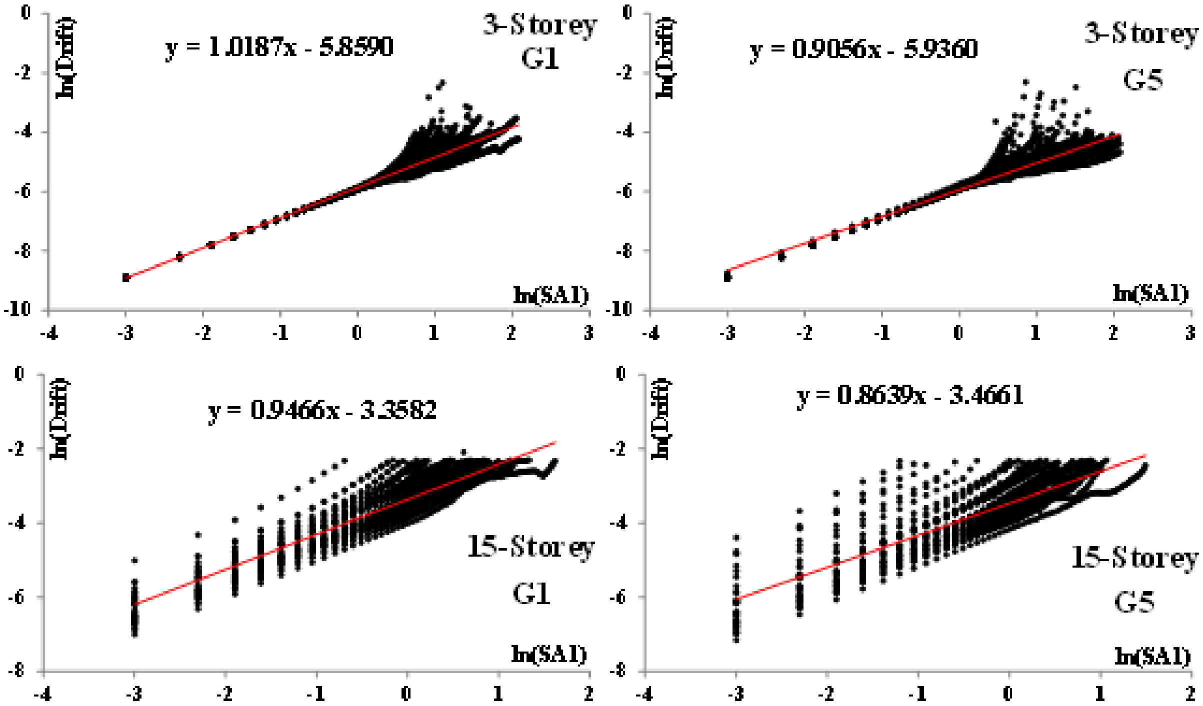

Figure 6: Samples of probabilistic seismic demand model in 3 and 15-storey frame

Table 2: Determination of probabilistic seismic demand model for two frames under 5 groups of accelerograms

| Group | 3-Storey frame | 15-Storey frame |
|---|---|---|
| $G1$ | $ln(DR) = 1.0187ln(SA1) - 5.8590 + 0.2615\epsilon$ | $ln(DR) = 0.9466ln(SA1) - 3.3582 + 0.3852\epsilon$ |
| $G2$ | $ln(DR) = 1.0336ln(SA1) - 5.8678 + 0.2210\epsilon$ | $ln(DR) = 0.9003ln(SA1) - 3.4296 + 0.4329\epsilon$ |
| $G3$ | $ln(DR) = 0.9975ln(SA1) - 5.8909 + 0.2383\epsilon$ | $ln(DR) = 0.9232ln(SA1) - 3.4566 + 0.4256\epsilon$ |
| $G4$ | $ln(DR) = 1.0161ln(SA1) - 5.8811 + 0.2755\epsilon$ | $ln(DR) = 0.8244ln(SA1) - 3.4132 + 0.5034\epsilon$ |
| $G5$ | $ln(DR) = 0.9056ln(SA1) - 5.9360 + 0.2888\epsilon$ | $ln(DR) = 0.8639ln(SA1) - 3.4661 + 0.5063\epsilon$ |

## 8. The effect of distance to fault on standard deviation of probabilistic seismic demand model

As far as the standard deviations of the probabilistic seismic demand model obtained in the previous section indicates the randomness and uncertainty in the dispersion of results and directly shows precision in demand estimation, The precise comparative analysis of this parameter could be effective on evaluating the difference in the effect of distance on the seismic demand estimated using nonlinear dynamic analysis and Bayesian statistics in near and far fields which is done in figure 7.

It can be seen that the SD variation trend of probabilistic seismic demand analysis in far field in 3-storey frame is incremental in respect to average distance variation of accelerograms used in calibration by distancing from the fault. However, it is not true in the near field, where very high SD is recorded in this point. Therefore, an important result is that in the rigid 3-storey frame, the effect of fault-to-site distance on $SD$ of the probabilistic seismic demand analysis of steel moment resisting frames is different in near and far fields. In the far field, distancing from the fault will increase the $SD$; however, in the near-field, it leads to decrease in $SD$.

Moreover, according to this figure, in the ductile 15-storey frame, there is no difference in the effect of fault-to-site distance on the $SD$ of seismic demand model of steel moment resisting frames in near and far fields despite the rigid 3-storey frame. Based on this figure, increase in the fault-to-site distance both in near and far fields will lead to increase in $SD$ so that in the near field, the minimum $SD$ and in case of using far accelerograms, maximum $SD$ will be observed.

This result shows that the effect of fault-to-site distance on the SD of probabilistic seismic demand model of steel moment resisting frames in the near and far fields is a function of the frame behavior and in the rigid and ductile frames will yield different results.

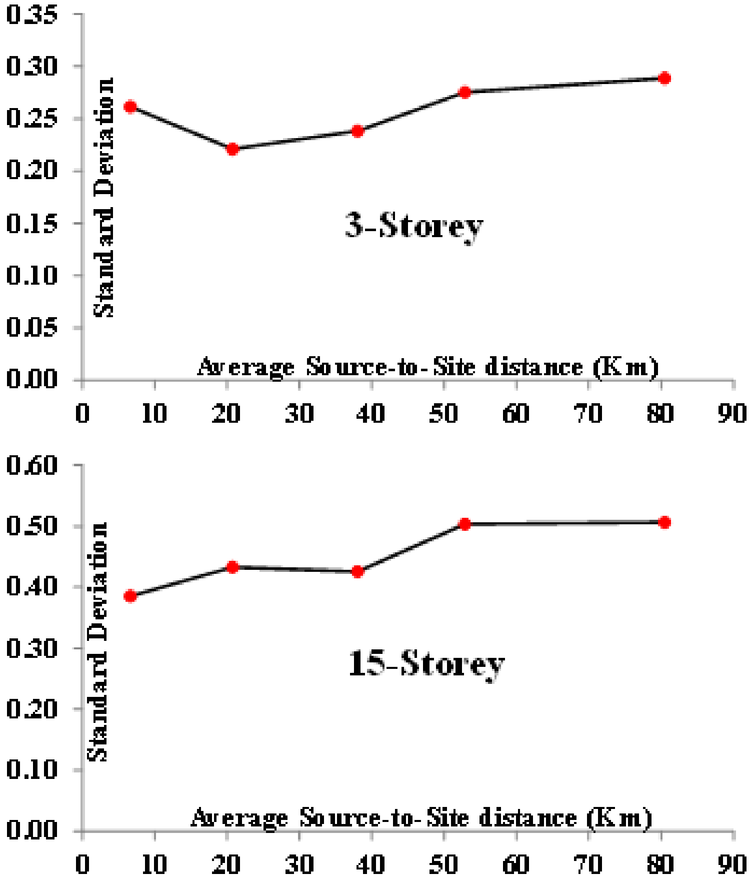

Figure 7: The effect of distance to fault on standard deviation of probabilistic seismic demand model

## 9. The effect of fault-to-site distance on seismic demand

More important than SD of a model is the seismic demand estimated with it; therefore, the main comparison in this study is on the seismic demand estimated for two frames in different performance levels using 5 different accelerogram models; so that it is possible to evaluate the difference in the effect of distance on the seismic demand estimated using nonlinear dynamic analysis and Bayesian statistics in near and far fields; which is one in figure 8. In this study concerning the concepts and performance of similar frames, three different performance levels (regardless of the standard performance levels) have been selected for the analysis:

A) The performance level in which the behavior of the structure is completely elastic and the drift will be 0.0012 for 3-Storey frame and 0.006 for 15-storey frame.

B) The performance level in which the behavior of structure is elastic in some accelerograms and plastic in others and generally it is changing from elastic to plastic state. Moreover, the drift will be 0.006 for 3-Storey frame and 0.03 for 15-storey frame.

C) The performance level in which all accelerograms have led to plastic behavior in the frame and the structure is at collapse threshold, where the drift is 0.012 for 3-Storey frame and 0.06 for 15-storey frame.

The spectral acceleration variation trend corresponding to different performance levels of two frames based on average variations of the distance of accelerograms used in its calculation is determined in figure 8. In the 3-storey frame and elastic performance level, the point in the fault near field is completely different from other points and in the far field, the spectral acceleration corresponding to elastic performance level has decreased; however, in the point in the neat field, the condition is completely different and with increase of the distance, the corresponding acceleration has also increased. Furthermore, according to these figures, by distancing in the far field, the value of spectral acceleration corresponding to the elastic-plastic performance level has increased; however, in the near field, with increase in distance, no increase has been observed in the acceleration which indicates different condition in near field as compared to far field. Furthermore, increase of distance in the far field has led to increase in the value of spectral acceleration corresponding to the plastic performance level; however, in the near field, with increase in distance, no increase has been observed in the acceleration or even a negligible reduction has occurred which indicates different condition in near field as compared to far field.

Moreover, based on this figure, at elastic performance of 15-storey frame, no significant difference is seen in near and far fields and the increase in distance leads to increase in the acceleration corresponding to the drift at elastic performance level. This is completely in contradiction with the result obtained about the 3-storey rigid frame and shows that the difference in the fault-to-site distance on the seismic demand of steel moment resisting frames in near and far fields is a function of the behavior of the frame (rigid or ductile) in addition to performance level. At elastic-plastic performance level, the variation trend is similar to the previous state and shows that in terms of fault-to-site distance on the seismic demand of steel moment resisting frames, there is no difference in near and far fields in terms of being increasing or decreasing. However, despite the elastic state, there is a significant mutation in distance variation from near to far field. In fact, while in far field, the slope is decreasing and the increase in distance gradually leads to decrease of earthquake hazard level; the distance variation from near to far field will suddenly reduce the risk at elastic-plastic performance level. This result is in fact the ideal result of this paper which proves that from statistical approach, there is no difference between far and near field with the distance variation. These results are valid for plastic performance level.

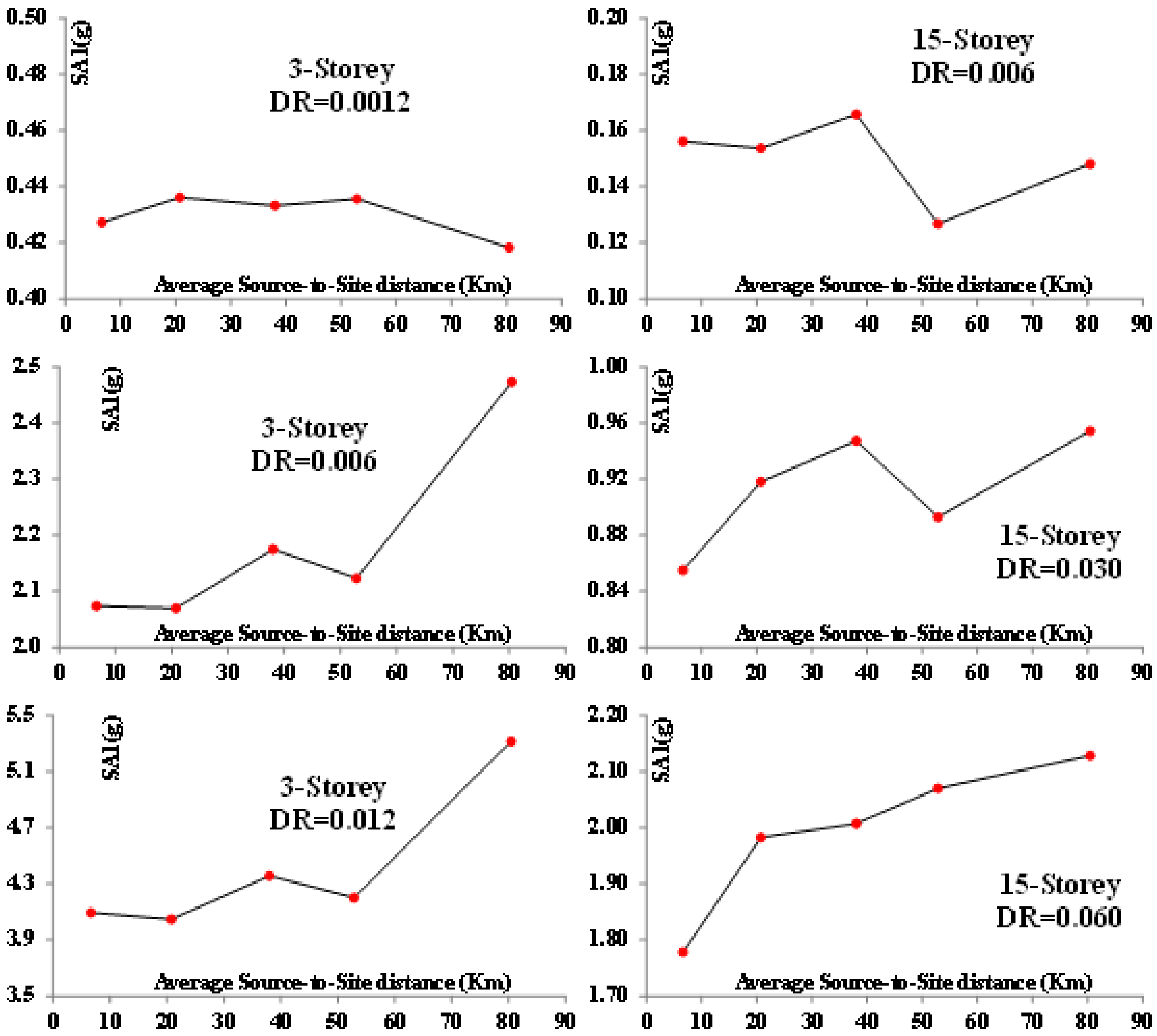

Figure 8: The spectral acceleration variation trend corresponding to different performance levels of two frames based on average variations of distance of accelerograms used in its calculation

## 10. Conclusion

- The comparison of SD of probabilistic seismic demand model from 5 accelerogram groups with different distances from fault in rigid 3-storey frame indicates the different effect of this distance on the standard deviation in near and far field. This study showed that the SD variation trend of probabilistic seismic demand analysis in far field in 3-storey frame is incremental in respect to average distance variation of accelerograms used in calibration by distancing from the fault. However, it is not true in the near field, where very high SD is recorded in this point. Therefore, it can be said that in far field, increased distance from the fault leads to increase in SD; however, in the near field, it leads to decrease in SD.

- The results of this study show that in ductile 15-storey frame, there is no difference in the effect of fault-to-site distance on the SD of seismic demand model of steel moment resisting frames in near and far fields despite rigid 3-storey frame. Based on the results, increase in the fault-to-site distance both in near and far fields will lead to increase in SD so that in the near field, the minimum SD and in case of using far accelerograms, maximum SD will be observed.

- The results show that the effect of fault-to-site distance on the SD of probabilistic seismic demand model of steel moment resisting frames in the near and far fields is a function of the frame behavior and in the rigid and ductile frames will yield different results.

- The results indicate that in 3-storey rigid frame and at all performance levels, the trend of the effect of distance on the seismic demand will be different in near and far fields. Based on the results of far field, increased distance leads to decrease in the spectral acceleration corresponding to elastic performance level; however, in the point in the neat field, the condition is completely different and increased distance leads to increase in the corresponding acceleration. Furthermore, at elastic-plastic and plastic performance levels, it is different such that in far field, the increase in distance has led to increase in the spectral acceleration corresponding to elastic-plastic and plastic performance levels; however, in the near field, with increase in distance, no increase has been observed in the acceleration which indicates different condition in near field as compared to far field.

- In sum, the results of this study show that in rigid 3-storey frame, the effect of fault-to-site distance on seismic demand of steel moment resisting frames is different in near and far fields; however, how they differ is a function of performance level. It is such that in the far field and at elastic performance level, the increase in distance leads to decrease in spectral acceleration corresponding to this performance level; however, in the near field, increased distance leads to increase in this corresponding acceleration. This is completely different at elastic-plastic and plastic performance levels such that in the far field, increase in distance leads to increase in the spectral acceleration corresponding to these two performance levels; however, in near field, this increase is not observed.

- The results of this study showed that in 15-storey ductile frame, no significant difference is seen in near and far fields and the increase in distance leads to increase in the acceleration corresponding to the drift at all performance levels. This is completely in contradiction with the result obtained about the 3-storey rigid frame and shows that the difference in the fault-to-site distance on the seismic demand of steel moment resisting frames in near and far fields is a function of the behavior of the frame (rigid or ductile) in addition to performance level.

- This study showed that in 15-storey ductile frame and at elastic-plastic and plastic performance levels, on contrary to elastic state, there is a significant mutation in distance variation from near to far field. In fact, while in far field, increase in distance gradually leads to decrease of earthquake hazard level; the distance variation from near to far field will suddenly reduce the risk at elastic-plastic and plastic performance levels. This result is in fact the ideal result of this paper which proves that from statistical approach, there is no difference between far and near field with the distance variation.

- According to the results, from statistical approach, there is some difference between the impact of distance variation on seismic demand in near and far fields which is subject to some variables such as the behavior of the frame and its performance level.

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