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An Investigation into the Effect of Soil Type and Strong Ground Motion (SGM) Records on Fragility Curves of Concrete Buildings

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ABSTRACT

The aim of the study is to investigate the effect of soil type and strong ground motion (SGM) on fragility curves of 4 and 7-storey moment-resisting concrete frame buildings. The present study is considered as an applied study which is based on several analytical models. In order to prepare the fragility curves for this type of moment-resisting concrete frame buildings, the modeling method and their behavior under near-field and far-field accelerograms are studied. In this study, spectral displacement (sd) parameter is used to measure seismic intensity. Finally, the effects of soil type and the type of selected SGM record of near- and far-field on fragility curves are analyzed using comparative study. In order to perform nonlinear time history analysis, 3 records in far-field and 3 records in near field are selected according to the terms of the Iranian Seismic Code Standard No. 2800 and are scaled with a spectrum corresponding to a high level of hazard and specified soil type. SGM records are increased using IDA method and are applied on 4 and 7-storey buildings located on different types of soil. The applied earthquakes recorded in this study caused the least displacement in short structures with a low period of vibration, while in rather long structures, displacement and the probability of building collapse were increased.

Keywords: Near- and Far Field SGM records, Fragility Curves, Moment Resisting Reinforced Concrete Frames

I. INTRODUCTION

Iran is one of the earthquake-prone countries in the world. In recent earthquakes, poor quality of buildings has caused major injury and financial losses. For many years, the aim of the seismic codes has been to design structures with high reliability to resist against earthquake. Despite the fact that the code for designing earthquake-resistant structures are mainly aimed to reduce the life losses of earthquake and recent experiences of earthquakes have also shown their effectiveness to reduce earthquake losses, but great earthquakes show that in some cases, the amount of structural and non-structural damages to buildings was very high and led to enormous financial losses (Ghaderi and Asadi, 2014). Various seismic codes provide criteria for considering soil-structure interaction in the analysis of structure in order to take into account the actual seismic performance of the structure. There are various methods to model the soil-structure interaction including direct and substructure methods. In the direct method, the structure and significant volume of the substructure soil are analyzed in a general model. In the substructure method, using the springs and dampers, the substructure soil behavior is modeled (Baanizadeh, 2014). The limitation of assessing the seismic demands on lightweight nonstructural components caused by successive earthquakes is investigated. In this study, dynamic nonlinear analysis is carried out on reference structures to assess the accuracy of the equations for predicting seismic forces on nonstructural sensitive components and systems in Eurocode. Borounsi et al. (2016) conducted a study to assess 2011 Virginia earthquake damages and developed seismic fragility for the Washington Monument. The study anticipates the probability of occurrence of damage to the Washington Monument during the future earthquakes. A finite element model of this monument is developed and updated based on the dynamic properties of the structure identified through the measurement of ambient vibration. The calibrated model was used to study the behavior of this monument in 2011 Virginia earthquake. In this study, a nonlinear analysis was carried out for two groups of site-compatible ground motions to provide different levels of seismic hazard for the Washington Monument and examined the probability of occurrence of structural and non-structural damages. Since the structure and its foundation are constructed on soil, so soil as a main bed of stimulation has an impact on its response and its behavior. Various codes apply the effects of soil type on the design and control of the structure in various forms. The Iranian seismic codes no. 2800considers the impact of the type of earth (soil) on the structure by defining the reflection coefficient and American Uniform Building Code (UBC) by defining spectral acceleration. The important matter in defining and typifying soil types is to classify and determine the related coefficients to achieve safety and economic related issues of the structure. High levels of earthquake hazards, along with the high physical vulnerability of structures, lead to a major earthquake hazard in Iran, which must be managed in a variety of ways. The assessment of earthquake damage on existing structures is an essential process for assessing production performance against future earthquakes that are necessary for insurance industry, decision-making processes to do loss reduction measures and post-disaster recovery or rehabilitation. The reduction of irreparable damage has always been the ultimate goal of earthquake engineering researchers and scientists.

Many parameters have been used to obtain a more reasonable function for structures under earthquake vibration in seismic regulations (Shahsavar, 2002). Given the lack of a classified vulnerability curve for Iran's buildings, Sadeqi et al. (2015) did a study in this field. He used an empirical approach involving statistical processing on existing data from previous studies to create a vulnerability curve for Iranian buildings and criticized the fragility/vulnerability curves available in Iran and other countries. In this study, soil type and selected mapping are considered as variables. By examining the moment resisting frame buildings with an average height, we can obtain their fragility curves for future research and decision making.

II. Methodology

In order to study the effect of the soil type on the fragility curve, it is necessary to design structures of the same type on different soils and with different SGM records and their behavior under the influence of the recorded SGM in each soil should be measured, its fragility curve is plotted and the results are compared with each other. Before designing, first the past studies should be carefully examined and then the SGM records of the near and far field should be selected. After that, the technical specifications of the soil types in the Iranian codes are reviewed. In this research, using 4 and 7-storey concrete moment-resisting frame buildings are modeled, in which the SAP 2000 software version 14 near field and far field accelerogram records are used during the analysis process. It should be noted that the parameter *sd* is used to measure the seismic intensity. Finally, the effects of soil type and the type of selected SGM records of near- and far-field on fragility curves are analyzed and compared to each other.

2.1 Definition and estimation of fragility curve

Fragility curve isthe probability of exceeding a given damage state in different levels of seismic motions. Mathematically,building fragility is defined as the probability of damageoccurrance in the building due to earthquake within j intensity based on the idamageis definedbasedon the equation 1

$$F_{ij} = prob[D \geq d_t / IM] \qquad (1)$$

Where in equation (1), F is fragility function and *IM* is the parameter of intensity measure. This scale can be even different,peak ground acceleration

(PGA), peak ground direction (PGD), spectral acceleration (S_a) and spectral direction (S_d) for instance, D is the damage rateaffected by this circumstances occurrence in the structure (e.g,story drift) d_i is the rate of specified damage of the structure which is called i damage style. This damage is evaluated qualitatively and quantitatively by the various capabilities like simple plasticity and proportional movement.

Seismic fragility curves are due to various intensity of seismic records.The probability of discussed engineered demands in the structural and non-structural parts of the selected amounts is known as the criterion fracture. Based on this theory, when it is said about fracture or damage manes that required engineered parameters arecrossed the predetermined amounts defined for reflexator function level's red line. Seismic curves are considered as the two-variable probable distribution function and according to thecumulative probability assumption, engineered demand parameter eitherbigger or equal to the intended damage level as shown in equation 2:

$$f(x) = \emptyset\left[\frac{1}{\beta}\left(\ln\frac{x}{\epsilon}\right)\right] \quad (2)$$

In the equationabove, $f(x)$, β and $\in$ are called probabilityof distributed function, deflection criterion and average or scale parameter respectively. After analyzing and determining distribution parameter ofnorthemal logarithm, seismic curves for each of those three buildings are drawn based on non-stop usage function. Life safety curves will be drawn and evaluated as defined in the global safety standard in 2008 (which also in this study is considered as the base of the performance level of life safety).

2.2Incremental dynamic analysis (IDA)

Inthe international dynamic analysis,somerecordedaccelerogramsin the ground aregradually scaled by a coefficient so as a result of this scale, structure analysis respond contains all district's demeanor from the second it appears to the second of instability by creating thea mechanism of falling. Meanwhile, the actual structure response can be anticipated by using IDA curve. With this curve, the actual structure's response and thedesign parameterswill be clearer and figure out about the authenticity of the previous methods e.g. types of lateral load, push over method or spectral methods.

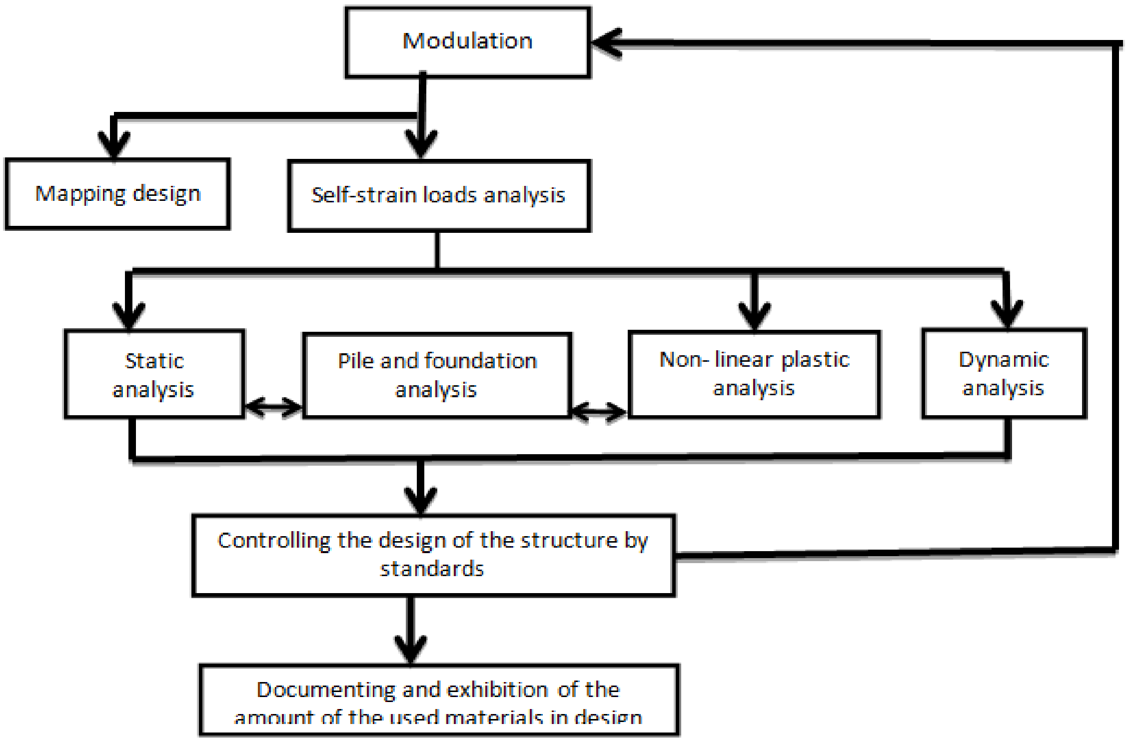

Fig 1: Dynamic analysis levels in both linear and nonlinear condition

2.3 The characteristics of the studied model

The considered buildings in this study are 4 and 7-storey concrete moment-resisting frame buildings with a lateral load-resisting system that far field and near field accelerograms are used to analyze them. Length of building entrances is 3 and 2 meters. Storey height in the buildingis considered 3.20meter.

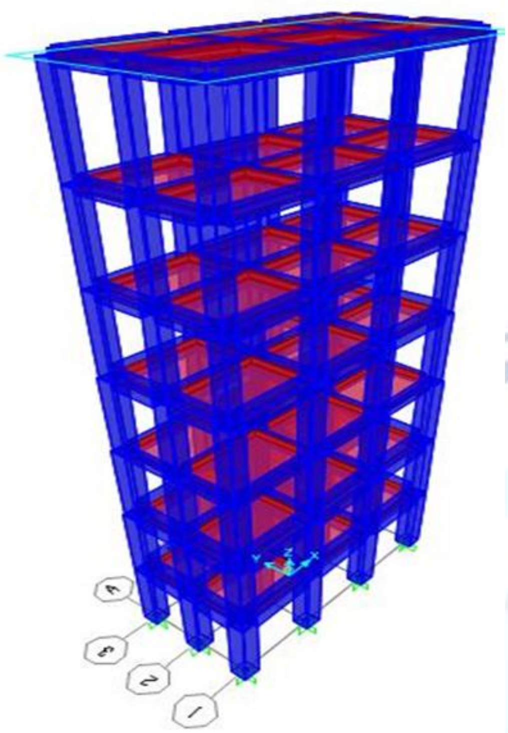

Figure 3 (a) the model of the studied 7-strorey building

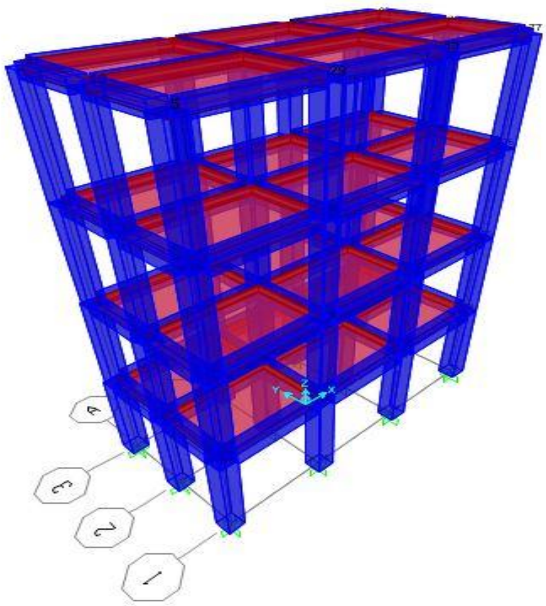

Figure 3 (b) the model of the studied 4-strorey building

Studied structures specification s are shown in tables 1 and 2.

Table 1The minimum and maximum considered cross-sections in a 7-storey building

	Minimum cross secttion of beam	Maxumiom grid dimention	Minimum dimensions of column	Maximum dimension of column
Dimentions	30 x40	30x 40	45x 45	60 x60
Bars	6Φ 10	8Φ 20	8Φ1 0	12 Φ22

Table 2The minimum and maximum considered sections in a 4-storey building

	Minimum cross secttion of beam	Maxumiom dimention of beam	Minimum dimensions of column	Maximum dimension of column
Dimensions	30 x40	30X 40	45x 45	60 x60
Bars	6Φ 10	8Φ 20	8Φ1 0	12 Φ22

Period of vibration of two frames is calculated according to the art 3-3-3 of the 2800 regulation. The detailsrelated to the attended period of vibration is shown in table 3

Table 3 Period of vibration of studied frame

	4-floor building	7-floor building
Period of vabration according to the equation	0.46	0.77
Period of vibration observing the article 3-3-3	0.58	0.96

2.4 The characteristics of the selected accelerograms

Up to now, different suggestions in the selection and scaling process of accelerograms are presented that one of them is Iranian Code Standard No.2800. According to this code, accelerograms (3 to 7 of them) should be scaled in the way that the resulting spectrum from these accelerograms should be equal or be more than the range of spectrum of the design in the desired frequency range. But this suggestion does not create any confidence that how many accelerograms is needed to nonlinear analysis of a particular structure. This number may be different for different structures. On the other hand, the definition of the desired frequency range is not seemed clear and the sensitivity of the structure's response to the range of frequencies should be studied. High scatter of the dynamic responses under accelerograms, which are selected and scaled according to Iranian Code Standard No.2800, is not ignorable. In the selected mapping of the distance from the fault, the type of the soil and the time of the strong movement of the earth have been noticed. The considered soils in this study are all 4 types of soils and the record is related to far and near station from the fault and the time of the strong movement of the earth is more than 10 seconds. The basic acceleration of the considered design in the present study is equal to 0.35.

In this study, the selected accelerograms are scaled according to Iranian Code Standard No. 2800 and first, the accelerogram is scaled to the maximum value. It means that the maximum acceleration in the component, that has larger maximum, is equal to the acceleration of gravity g. in the first step, all of accelerograms get coordinate according to its spectral distance then the response spectrum of each pair of accelerogram for 5% damping is plotted. Accelerogram is scaled in the way that the amount of the spectrum related to the accelerogram does not be less than the amount of spectrum of the standard design for every period in the range of 0.2T to 1.5T. Then the assigned scaled coefficient is multiplied in the scaled accelerogram and has been used in the analysis of the time history. Figure 4 and figure 5 show the spectrums of design of early accelerograms of type 3 soil for near distance and for 4-storey building and for 7-storey building, respectively. Table 4 shows the characteristics of the selected mapping to nonlinear analysis of time history.

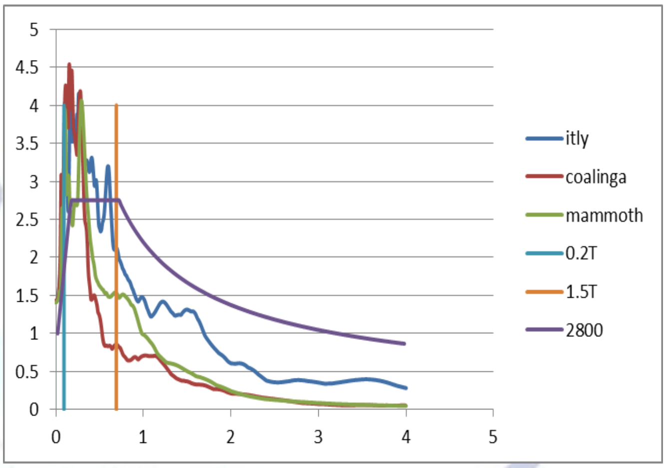

Figure 4 The spectrum of the design of early accelerograms of type 3 soil for near distance and for a 4-storey building

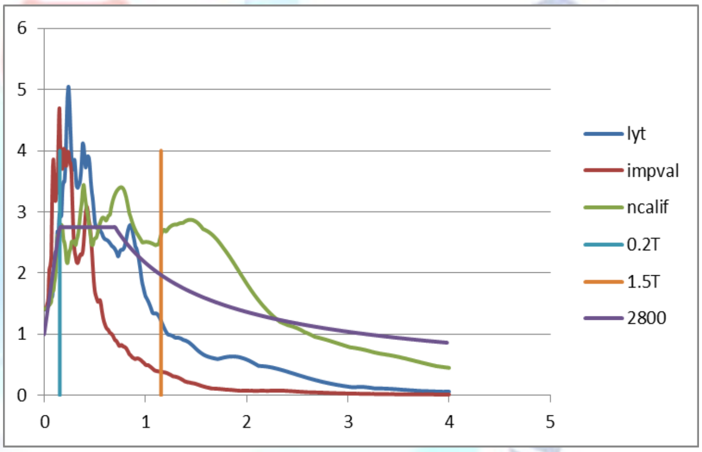

Figure 5 The spectrum of the design of early accelerograms of type 3 soil for near distance and for a 7-storey building

Table 4 The characteristics of the selected mapping to nonlinear analysis of time history

Station name	City or country of occurrence	Year of occurrence	RecordSeq Number or station area at the site peer	Magnitude	The distance from the center
sfern 1	San Fernando	1971	63	6.6	30.14
sfern 2	San Fernando	1971	70	6.6	24.12
italy 1	italy	1980	292	6.9	10.84

Mammoth	California	1980	253	4.7	6.25
coalinga	California	1991	414	5.7	11.42
holister	California	1974	99	5.1	9.39
chichi 1	thailand	1999	753	6.9	3.85
chichi 2	thailand	1999	2753	6.2	39.32
chichi 3	thailand	1999	271	6.2	38.62
nearLivermm ore	California	1980	211	5.8	15.33
Livermmore	California	1980	212	5.8	24.95
manguna	New Guinea	1972	95	6.2	4.06
friuli	italy	1976	131	5.9	41.39
Northern calif	hcalif	1954	20	6.5	27.02
Lyt1	Lytly greek1	1970	44	5.3	30.11
Lyt2	Lytly greek2	1970	48	5.3	30.02
Lyt3	Lytly greek3	1970	43	5.3	19.35
imperial	London	1951	10	5.6	25.24
Park	Parkfield	2004	4062	6	109.51
whitter	alaska	1987	592	5.9	17.42
whitter	alaska	1987	593	5.9	32.56
duzce	Turkey	1999	1613	7.1	25.88
griva	Greece	1990	814	6.1	33.29
griva	Greece	1990	815	6.1	29.2

III. Result and Discussion

In order to quantify vulnerability of different structural and non-structural components in terms of seismic risk about any kind of structures or non-structural components which are sensitive to relative displacement and non-structural components which are sensitive to accelerate, the probability of occurrence or being over from a particular amount of damage could be expressed by a characteristic of earthquake such as PGD, PGV, PGA. The repeat of this process to different amounts of PGA or other single parameters leads to produce normalized curves known as fragility curves. Fragility curves distribute the damage between minor, moderate, heavy and complete states. These curves, which could be shown asa diagram, are plotted for every state of damage in every movement of earth, separately and enter as the input in the compute of structural damage.

Figure 6, figure 7 and figure 8 show the fragility curves for 7-storey building and 4-storey building under the selected mapping.

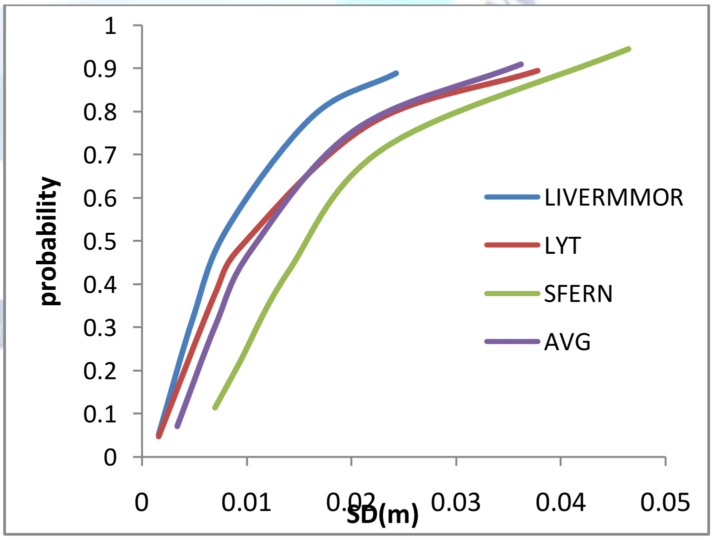

Figure 6 (a)The fragility curves of type 3 soil for far-field mapping and for a 7-storey building

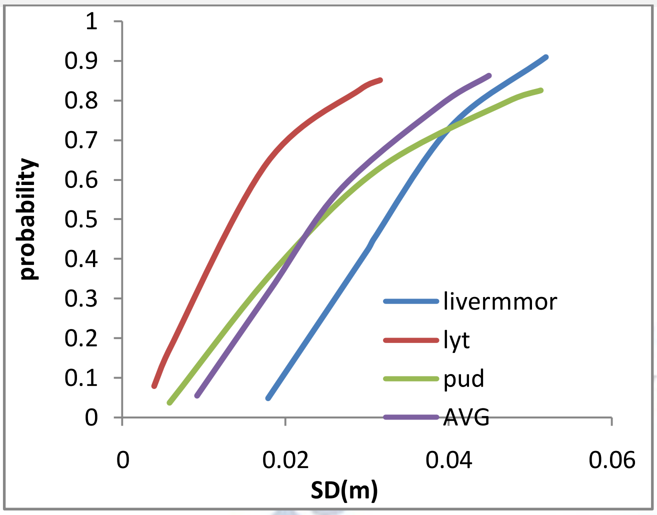

Figure 6 (b) The fragility curves of type 1 soil for far-field mapping and for a 7-storey building

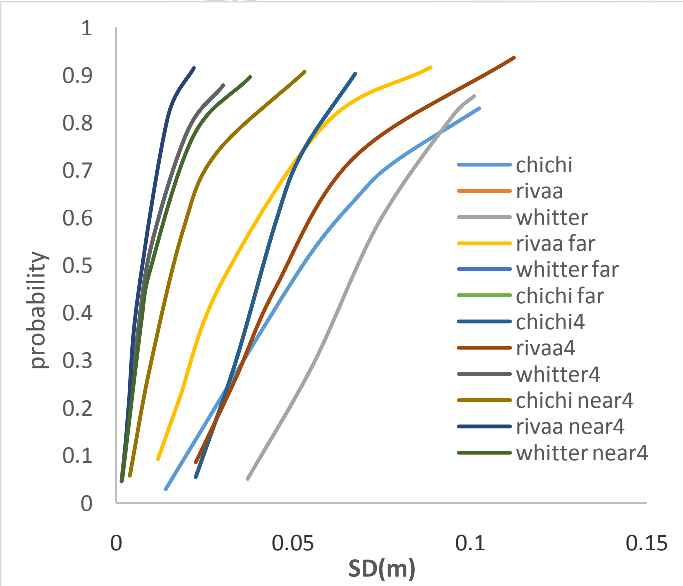

Figure 7 (a) The fragility curves for far-field mapping and for a 7-storey building

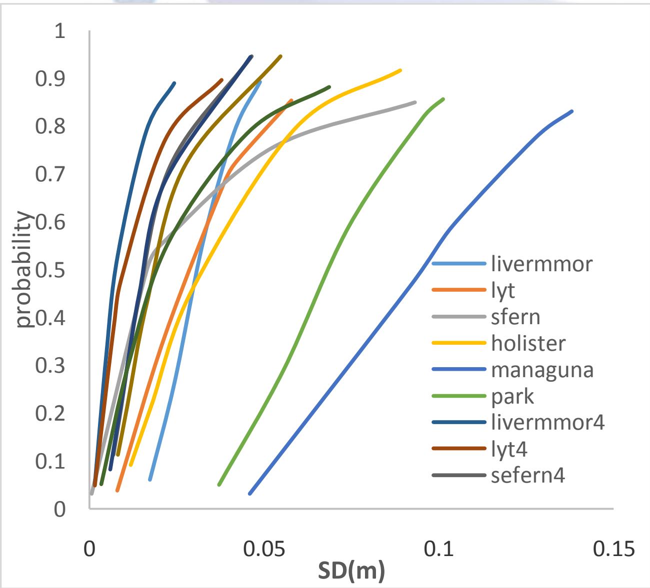

Figure 7 (b) The fragility curves for far-field mapping and for a 4-storey building

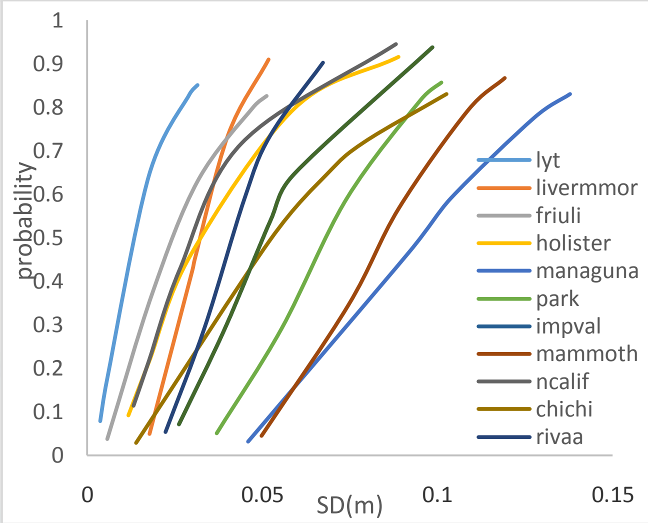

Figure 8 (a) The fragility curves for far-field mapping and for a 4-storey building

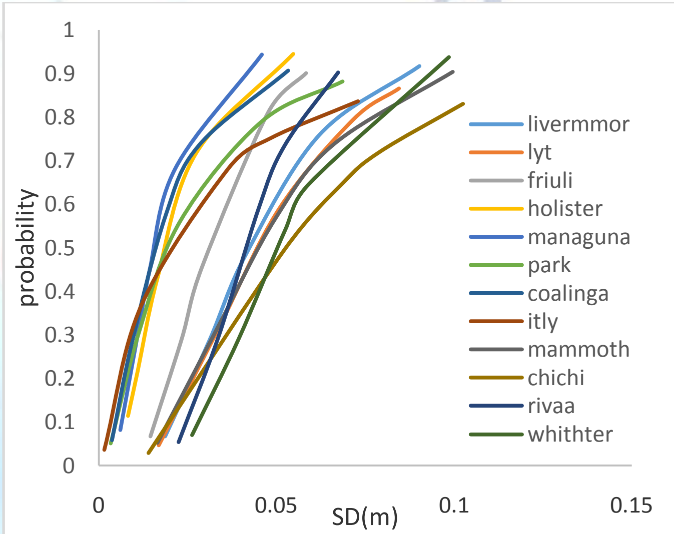

Figure 8 (b) The fragility curves for near-field mapping and for a 4-storey building

In less *Sd*, the probability level is very close to each other and, with that increase, the probabilities go apart. Two 4- and 7-storey buildings have been investigated. By comparing the seismic fracture curves of structures with concrete skeletons, the probability of failure in a 4-storey building (2800 designed) is less than that of a 7-storey building, and this difference depends on several factors. Also, the characteristics of the earthquake have had a significant effect on the results, so that, as compared with the highest displacement in the seventh record in both concrete and seven-story buildings, the exacerbation of the resonance record caused the most displacement in the structures. By increasing the number of classes, the difference between the results of the IDA method is increased. Thus the earthquakes presented in this research for the short structures with the period have had the least displacement, but with an increasing number of classes' displacement in the probability of its collapse are increased in percentages. Due to that, the intensity of ground motion is one of the factors affecting the response of the structure, in the resulting fragility curves; the acceleration and size of the earthquake have a direct impact. Obviously, with the increase of the height of the structures, the periods increase their displacement, as well as the capacity of the structures at the functional levels, is reduced. In the fragile curves under the influence of near-mapping maps, more displacement is shown. At the end of the four-storey building on type 1 soil, the most probable fracture curve and the seven-storey structure of the fourth type soil, have the highest probability in the fracture curve.

IV. Conclusion

In order to give fragility curves of the concrete moment-resisting frame, structures have been studied modeling and studying their behavior under the accelerogramsof the near-far field domain. In this study, the spectral displacement factor (*sd*) is used as a measure of earthquake intensity. Finally, the effects of soil type and selected mapping types from the near and far field of the fragility curves were analyzed through a comparative study. For analyzing nonlinear time histories, three records for long-range mapping and three records for close mapping, corresponding to the standard conditions of standard 2800, have been selected and are scaled with a spectrum corresponding to a high level of the hazard and a variety of soils. The records have been enhanced by the IDA method and applied to various types of soils in both 4 and 7-storey buildings. The earthquakes presented in this research for the short structures with the rotational time have minimal displacement, but with an increasing number of stories, displacement takes place its collapse is increased in percentages.

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