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Research Article

THE MOST APPROPRIATE EARTHQUAKE RECORD GROUPS FOR DYNAMIC ANALYSIS OF A BUILDING

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ABSTRACT

In this paper, seven real earthquake records are scaled according to Eurocode 8 design acceleration spectrum by using SESCAP (Selection and Scaling Program). SESCAP is a scaling program based on time domain scaling method and developed by using MATLAB, GUI software. Real and scaled earthquake records are used for linear time history analyses of a six-storied reinforced concrete building modeled as spatial by SAP2000. Eurocode 8 allows the use of real earthquake records for linear and nonlinear time history analyses of structures. In the case of using three earthquake records in linear and nonlinear time history analyses, maximum results of structural responses are used for design of structures. If at least seven time history analyses are performed, the mean responses of the structures are taken into account rather than the maximum results. For the selection of maximum results of structural response from thirty five groups are created by calculating combination of threes of seven real and scaled earthquake records, and another group including all of the seven real and scaled earthquake records are created for selection of mean. Relative floor displacements along X axis of the building are preferred as structural response of the building in this study. It is seen that differences between mean value and maximum value of the relative floor displacements along X axis of the building induced by seven and three scaled earthquake records respectively are less than ones obtained from real earthquake records.

Keywords: Scaling of earthquake records, time history analysis, relative floor displacement, SESCAP.

1. INTRODUCTION

Numerous advances have been made in the field of engineering and technology in order to prevent or minimize losses of life and property caused by earthquakes. One of the developments in earthquake engineering is to make analyses and design of structures against recorded earthquakes or earthquakes may occur in future. Equivalent lateral force method, mode superposition method and time history method are used in the calculation of seismic forces acting on the structures. Structural behaviors obtained from time history analyses are more realistic than ones obtained other methods due to both the use of real earthquake records and the consideration of inelastic behavior of the structure in the analysis phase. Today, time history analysis is widely

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used in dynamic analysis of all kinds of structures by developments in earthquake engineering and computer technology.

In order to perform time history analysis, earthquake records having desired characteristics should be selected and then these records should be scaled to code design acceleration spectrums (Takewaki and Tsujimoto, 2011; Wood and Hutchinson, 2012; Bayati and Soltani, 2016; Pavel and Vacareanu, 2016). The most important feature of real earthquake records is that they carry all of the ground motion characteristics such as amplitude, frequency, energy content, duration and phase characteristics and reflect all of the factors that influence records such as characteristics of the source, path and site (Acevedo, 2003; Cantagallo et al., 2015). However, in some cases researchers may face difficulties in obtaining real earthquake records having desired characteristics for consideration site. In this case, international seismic codes allow the using of artificial and synthetic records for time history analyses. Selected real earthquake records should be compatible with some elements of considered site such as local soil conditions and seismicity, so compliance between scaled response acceleration spectrum and code design acceleration spectrum can be increased and the obtained results with the use of these records give more realistic structural behaviors.

The number of earthquake records should be used in the time history analyses take place in almost all seismic codes as; at least three acceleration records should be used in seismic analysis. In the case of using acceleration records less than seven, maximum results are considered to design, when more acceleration records are used, the average of the results of analysis is considered as design parameters. After appropriate earthquake records are selected, these records should be scaled to target spectrums to be guide for design of new structures, so differences of structural response changed from record to record can be minimized by reducing amplitude variability at records. Nowadays many methods that can be used in the scaling process are available. These methods are divided into two main groups as scaling in time domain and frequency domain (Ozdemir and Fahjan, 2007).

In this study, seven real earthquake records are selected from Pacific Earthquake Engineering Research Center (PEER) considering magnitude, fault distance and site condition. These records are scaled to Eurocode 8 design acceleration spectrums by using SESCAP(2013). Real and scaled earthquake records are used for linear time history analysis of a six-storied building modeled as spatial by SAP2000 software. Relative floor displacements of each floor along x axis of the building are taken into account as structural response after linear time history analysis. The mean structural responses of the building under seven real and scaled earthquake records are compared with the maximum structural responses of the building under thirty five groups created by calculating combination of threes of these earthquake records. As a result of this study, the most suitable earthquake record groups used in the design of the building are determined.

2. BACKGROUND

Several methods are used in assessing the performance of existing structure or designing of the new structure under the influence of earthquake loads. However, among these analysis methods time history analysis gives the most comprehensive and realistic results. The most important issue to be able to make linear and nonlinear time history analysis is selection and scaling of appropriate real earthquake records.

In recent years, both the developments in the technology and the expansion of data banks have made a major contribution to studies related to scaling of earthquake records. Although, a method about selection of real records accepted by the most of the researchers studying on this relatively new issue cannot be still developed, studies increasingly go on in earthquake engineering field. In general, artificial records compatible with design response spectrum, synthetic records obtained from seismological models and real earthquake records are used as inputs in time history analyses (Abrahamson, 1993), (Bommer and Acevedo, 2004). Selection of appropriate earthquake records is an important issue for the realization of linear and nonlinear time history analysis. Different methods based on seismic codes are used to select earthquake records. For example; Eurocode 8 allows the use of real earthquake records as an input for time history analyses (Iervolino et al. 2009). Hachem et al. (2010) explained guidelines and principles about how the selection of earthquake ground motion records specified by international seismic codes. Fahjan et al. (2007) summarized the basic methods and criteria on the selection of strong ground motion records and discussed whether these criteria are appropriate Iran seismic code or not in their studies. Also, Fahjan (2008) explained the fundamental methods and criteria about selection and scaling of real earthquake records compatible with the design spectrum in Turkish Seismic Code.

The most important issue in time history analysis is to obtain appropriate records. However, in some cases the lack of earthquake records with the desired characteristics forces the researchers to different ways in the development of earthquake records. For example, Kayhan et al. (2011) obtained acceleration sets compatible with design spectrums belonging to different soil classes defined in seismic codes by using harmony optimization technique in his study. Lilhanand and Tseng (1988) developed a method for generation of realistic synthetic earthquake records compatible with multiple-damping design spectra. Mukherjee and Gupta (2002) emphasized some problems about creating spectrum compatible synthetic records for linear and nonlinear analyses of the structures. Earthquake ground motions more severe than hazard in seismic codes must be taken into account in dynamic analysis of important structures such as tall buildings, so new methods are needed for the selection of design ground motions (Lee et al 2000).

That data banks which earthquake records are obtained from become widespread increases the use of time history analyses. However, the obtaining of records compatible with the design spectrum through any data bank is a very demanding job. In contrast to classical method of scaling in which a certain amount records are selected through available ground motion records and then scaled to design spectrums, genetic algorithm method investigates sets consist of thousands of ground motion records and provides records compatible with design spectrums the best (Naeim et al. 2004). Earthquake ground motion records are selected and classified by taking into account seismic parameters and soil properties of considered region. The effect of these criteria on the selection of earthquake records is an important research subject. Iervolino and Cornell (2005) investigated the effects of earthquake parameters such as magnitude (M) and distance (R) on the structural response. Selected earthquake records should be compatible with code design spectrums, and these records also should preserve the characteristics and aleatory variability of scenario earthquakes (Wang, 2010). Apart from the methods of selecting ground motion records mentioned above, Morales-Esteban et al. (2012) discussed a probabilistic method used to select real earthquake records that are necessary for dynamic analyses. Also, Shama (2012) mentioned a spectral matching method in time domain in which earthquake ground motion records can be made compatible with the design spectrum.

After the selection of the appropriate earthquake records, these records should be scaled to code design spectrums. Different methods such as time domain scaling method, spectral matching in frequency domain, spectral matching by wavelets and spectrum compatible artificial record generation are used to decrease record to record variations between spectral accelerations of earthquake records and target spectrums (Fahjan, 2010). In general, two methods are used commonly for scaling of earthquake records; scaling in time domain (Fahjan, 2008), (Iervolino et al. 2009), (Kayhan et al. 2011) and scaling in frequency domain (Bolt and Gregor, 1993). Records obtained by using scaling in frequency domain more compatible with design spectrum than ones obtained by using scaling in time domain. However, the natural properties of records are lost when they are scaled in frequency domain since their frequency content changes (Ozdemir and Fahjan, 2007). Apart from these scaling procedures mentioned above, different methods were developed by researchers. For example, Nau and Hall (1984) investigated alternative scaling methods providing less record to record variability than other scaling methods using peak ground displacement, peak ground velocity and peak ground acceleration. Also, Kurama and Farrow (2003) investigated ground motion scaling methods in terms of different soil conditions and structural characteristics.

3. STEPS OF TIME DOMAIN METHOD

Steps of time domain scaling method (Ozdemir and Fahjan, 2007) are presented by means of a flow chart diagram in Fig. 1. SESCAP software is developed by using steps illustrated in Fig. 1.

4. SCALING OF EARTHQUAKE RECORDS WITH SESCAP

Seven real earthquake records are scaled to Eurocode 8 design acceleration spectrums by using SESCAP software in this part of the paper. Records are selected from Pacific Earthquake Engineering Research Center (PEER) by considering magnitude, fault distance and site condition.

Users can arrive in subwindows where scaling procedures of records are carried out by the help of Buildings and Bridges buttons in Fig. 2.

Real earthquake records used in time history analyses are given in Table 1 with their selection criteria.

In this study, seismic zone (A_0) and building importance coefficient (I) are taken into account in time history analyses of the building, so real earthquake records are scaled to design acceleration spectrums by using scaling factors belong to spectral acceleration coefficient (A(T)). Condition of Regulation section of SESCAP informs users about whether scaled earthquake records satisfy the conditions of Eurocode 8 or not. Guidelines and requirements for buildings according to Eurocode 8 are given as below;

- minimum of 3 accelerograms should be used.
- the mean of the zero period spectral response acceleration values should not be smaller than the value of a_gS for the site in question.
- in the range of periods between $0.2T_1$ and $2T_1$, where T_1 is the fundamental period of the structure in the direction where the accelerogram will be applied, no value of the mean 5% damping elastic spectrum, calculated from all time histories, should be less than 90% of the corresponding value of the 5% damping elastic response spectrum.

Scaling results of selected real earthquake records are shown from Fig. 3 to Fig. 9. It can be seen easily in Figure 9 that the mean of spectral accelerations of scaled earthquake records shows a good harmony with design spectrum within a period range of interest.

Scaling results of earthquake records are given in Table 2.

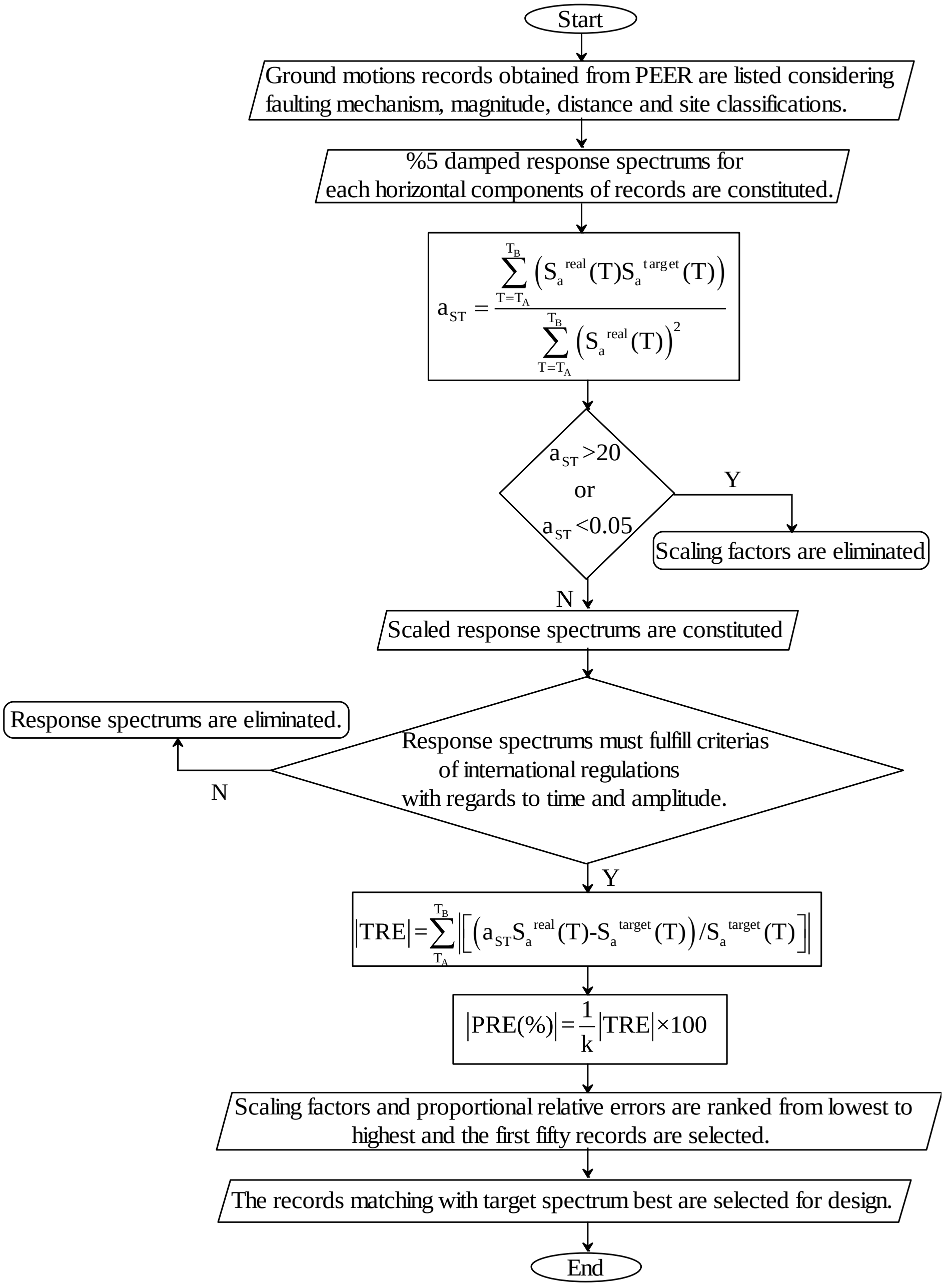

Figure 1. Flow chart diagram of time domain method

Figure 2. The main window of SESCAP

Table 1. Real Earthquake Records for Time History Analyses of Building

Record ID	Earthquake Name	Date (D/M/Y)	Recording Station	M_w	r (km)	Site Condition
P0810	Cape Mendocino	25/04/1992	89324 Rio Dell Overpass - FF	7.1	18.5	B
P1169	Chi-Chi, Taiwan	20/09/1999	CHY080	7.6	6.95	B
P1043	Kobe	16/01/1995	0 KJMA	6.9	0.6	B
P1109	Kocaeli, Turkey	17/08/1999	Sakarya	7.8	3.1	B
P0865	Landers	28/06/1992	23 Coolwater	7.4	21.2	B
P0745	Loma Prieta	18/10/1989	57007 Corralitos	7.1	5.1	B
P0530	N. Palm Springs	08/07/1986	5070 North Palm Springs	6.0	8.2	B

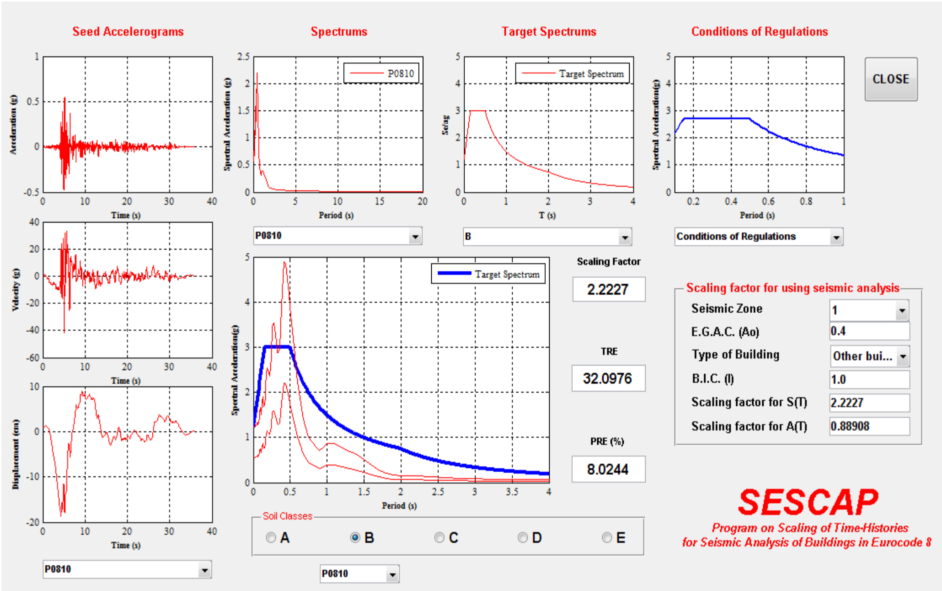

Figure 3. Scaling Results of Cape Mendocino Earthquake

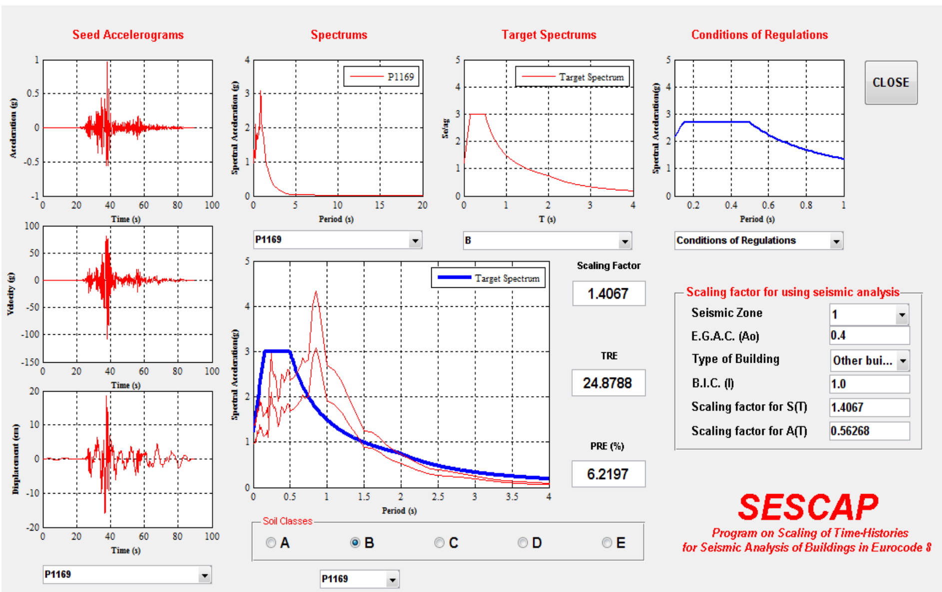

Figure 4. Scaling Results of Chi-Chi Taiwan Earthquake

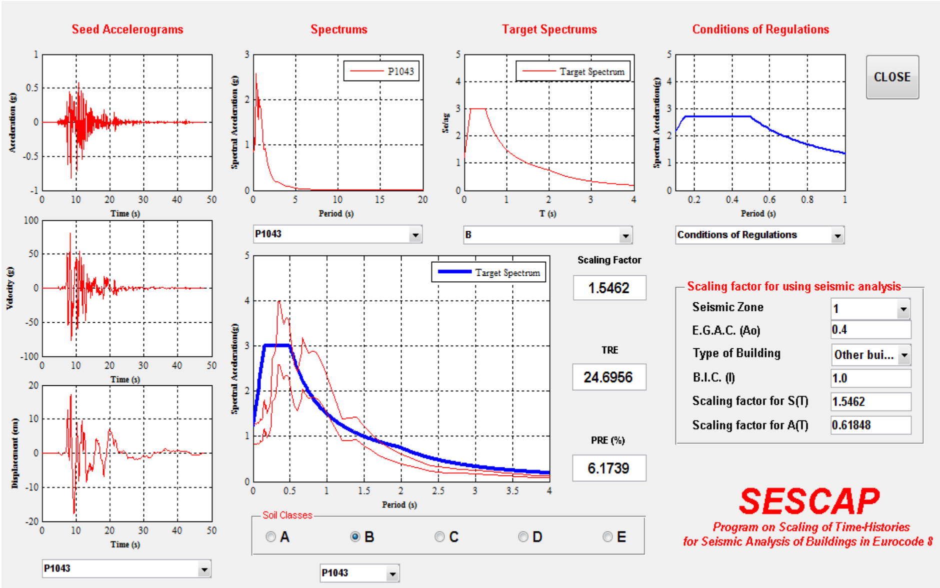

Figure 5. Scaling Results of Kobe Earthquake

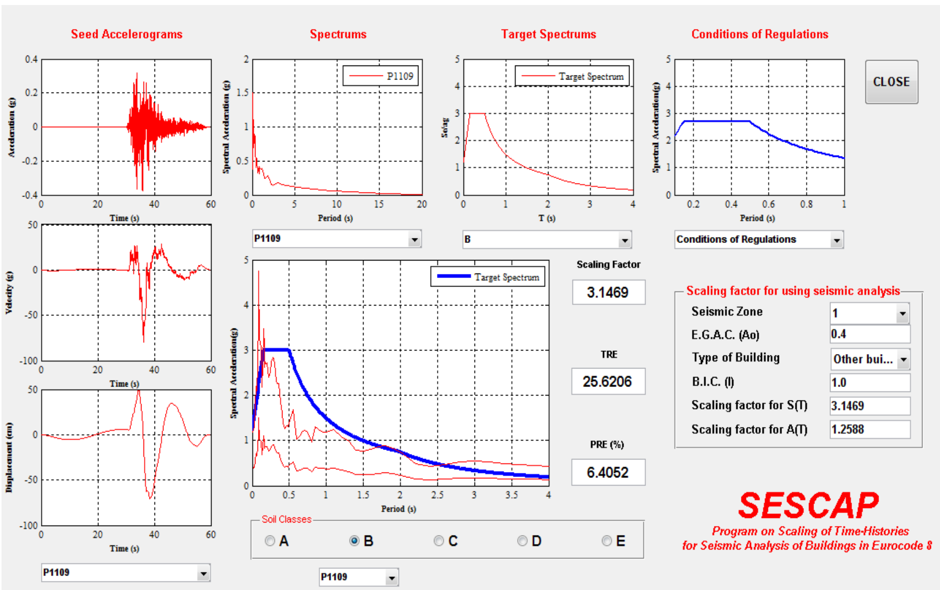

Figure 6. Scaling Results of Kocaeli Earthquake

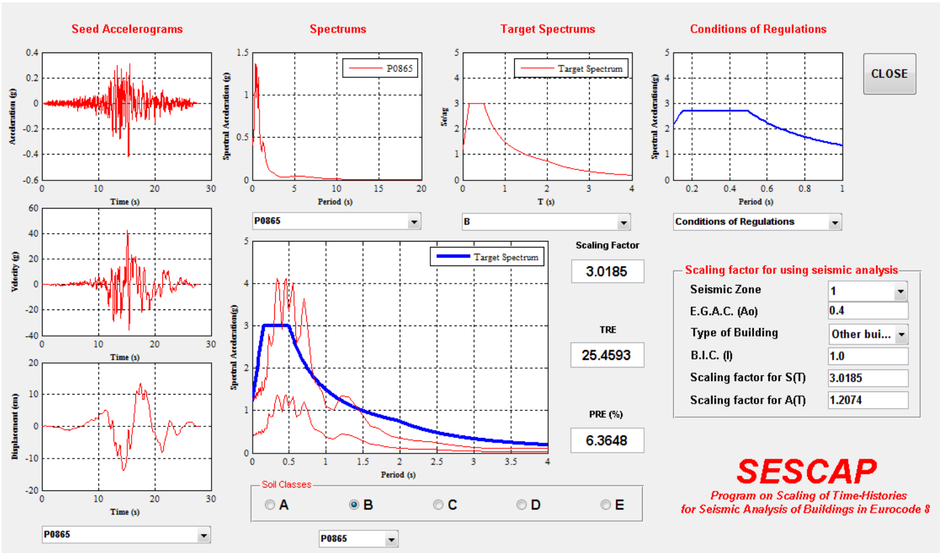

Figure 7. Scaling Results of Landers Earthquake

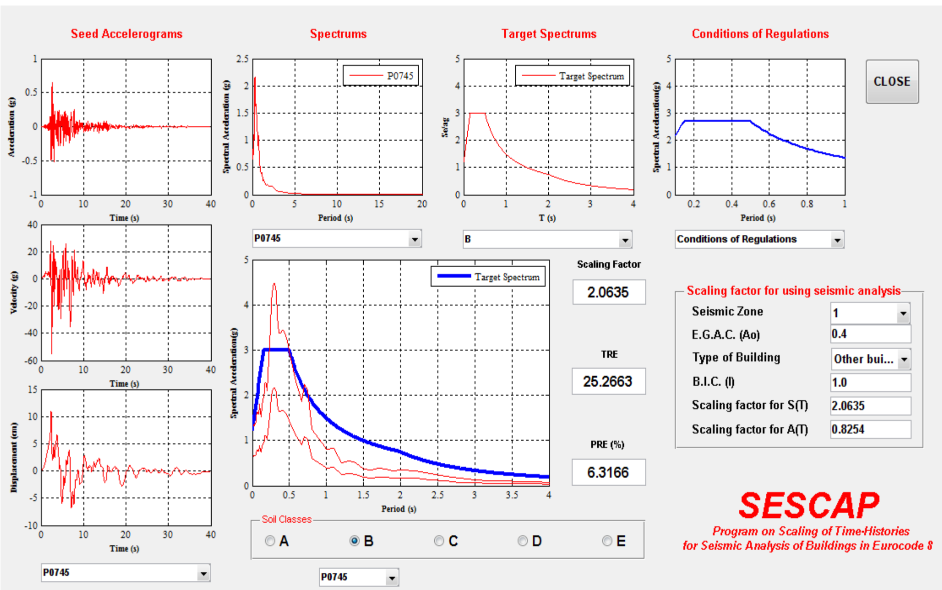

Figure 8. Scaling Results of Loma Prieta Earthquake

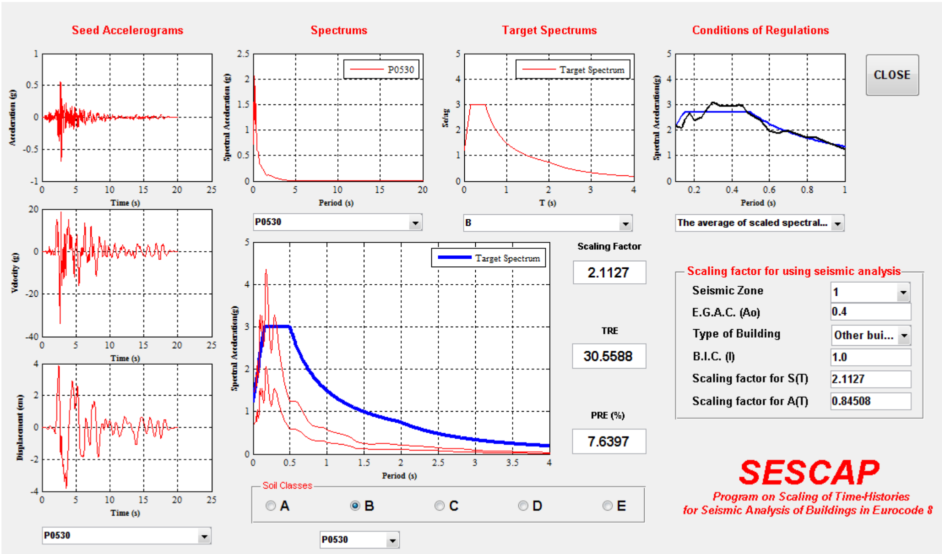

Figure 9. Scaling Results of N. Palm Springs Earthquake

Table 2. Scaled earthquake records for time history analyses of building

Record ID	Earthquake Name	Date (D/M/Y)	Recording Station	Scaling Factor (a_{ST})	Scaling Factor (a_{AT})	PRE (%)
P0810	Cape Mendocino	25/04/1992	89324 Rio Dell Overpass - FF	2.2227	0.8891	8.0244
P1169	Chi-Chi, Taiwan	20/09/1999	CHY080	1.4067	0.5627	6.2197
P1043	Kobe	16/01/1995	0 KJMA	1.5462	0.6185	6.1739
P1109	Kocaeli, Turkey	17/08/1999	Sakarya	3.1469	1.2588	6.4052
P0865	Landers	28/06/1992	23 Coolwater	3.0185	1.2074	6.3648
P0745	Loma Prieta	18/10/1989	57007 Corralitos	2.0635	0.8254	6.3166
P0530	N. Palm Springs	08/07/1986	5070 North Palm Springs	2.1127	0.8451	7.6397

PRE (%); Proportional Relative Error

5. ANALYTICAL STUDY

In this paper, relative floor displacements of each floor along x axis of the building are taken into account as structural response to be able to compare the effects of seven real and scaled records with the effects of thirty-five groups created by calculating combination of threes of seven. The building is modeled as spatial by SAP2000 software (Fig.10 and Fig. 11). Cross sections of vertical bearing elements are constant along with the building's height and height of each story is three meter. The building is located in the first degree seismic zone (A_0=0.4) and building importance coefficient (I) is one. Material and cross section properties of elements of the building are given in Tables 3 and 4.

Table 3. Material Properties of Building Elements

Concrete Grade	C20
Modulus of Elasticity (kN/m^2)	28000000
Poisson's Ratio	0.2
Weight Per Unit of Volume (kN/m^3)	25
Modulus of Subgrade Reaction (kN/m^3)	20000

Table 4. Cross-Section Properties of Building Elements

Element	Shape	b(m)	h(m)	Area(m^2)
Beam	Rectangular	0.25	0.50	0.125
Column	Rectangular	0.35	0.60	0.210
Column	Rectangular	0.35	0.70	0.245
Column	Rectangular	0.25	1.40	0.350
Column	Rectangular	0.30	1.40	0.420
Shear wall	Rectangular	0.25	3.60	0.900
Shear wall	Rectangular	0.25	1.80	0.450
Shear wall	Rectangular	0.25	2.00	0.500
Shear wall	Rectangular	0.25	2.40	0.600

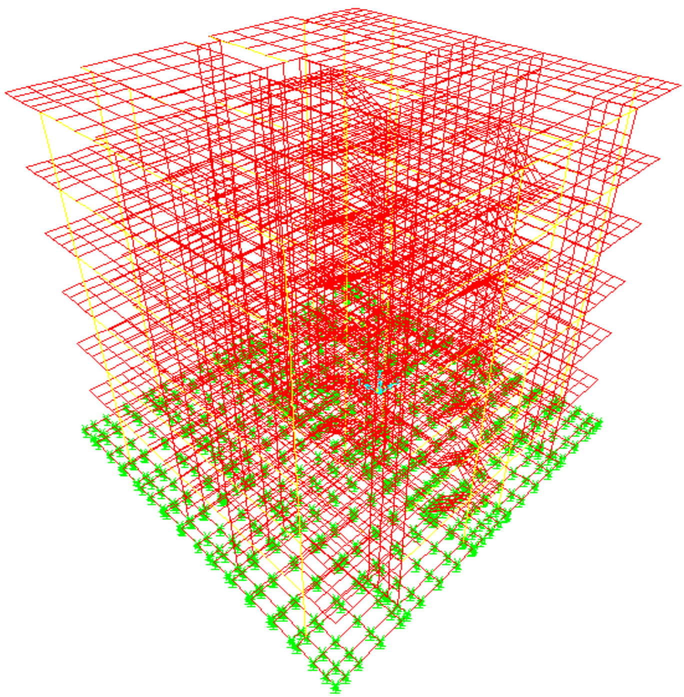

Figure 10. Three-dimensional analytical model of the building

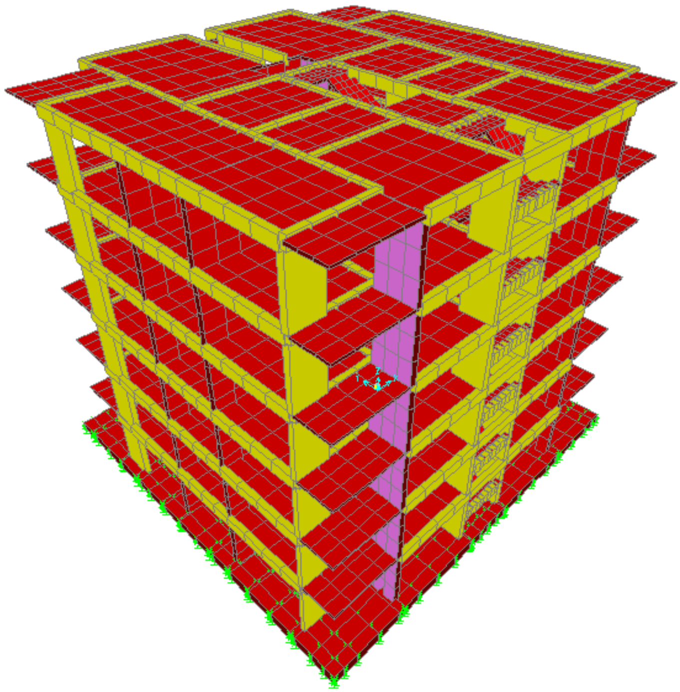

Figure 11. Three-dimensional finite element model of the building

6. NUMERICAL RESULTS

In this section, the results of for linear time history analysis of a six-storied building under seven real and scaled earthquake records are given. Relative floor displacements of each floor along x axis of the building are taken into account as structural response after linear time history analysis. The mean structural responses of the building under seven real and scaled earthquake records are compared with the maximum structural responses of the building under thirty five groups created by calculating combination of threes of these earthquake records.

6.1. The mean structural responses under seven earthquake records

The relative floor displacement of the building obtained from linear time history analysis made by using seven real and scaled earthquake records are shown in Fig. 13 (a) and (b), respectively. The mean of these results is shown in Fig. 13 (c). It can be seen easily in Fig. 13 that the mean of relative floor displacement obtained from scaled earthquake records is smaller than real records. • Maximum differences between mean of seven scaled and real earthquake records in point of relative floor displacement along X axis of the building is 23% on the second floor.

6.2. The maximum structural responses under thirty five groups

The relative floor displacement of the building obtained from linear time history analysis made by using thirty five record groups created by calculating combination of threes of seven earthquake records is shown from Fig. 14 to Fig. 48. To determine the difference between the mean values of seven real and scaled earthquake records and maximum values of thirty five record groups mean value of real and scaled records are added the figure of thirty five record groups.

The relative floor displacement of the building obtained at twenty-five of thirty-five groups were greater than the mean relative floor displacement obtained at seven earthquake records and the other ten records group values close to mean values. The numbers of these nine groups are 20, 21, 23, 24, 25, 32, 33, 34, and 35.

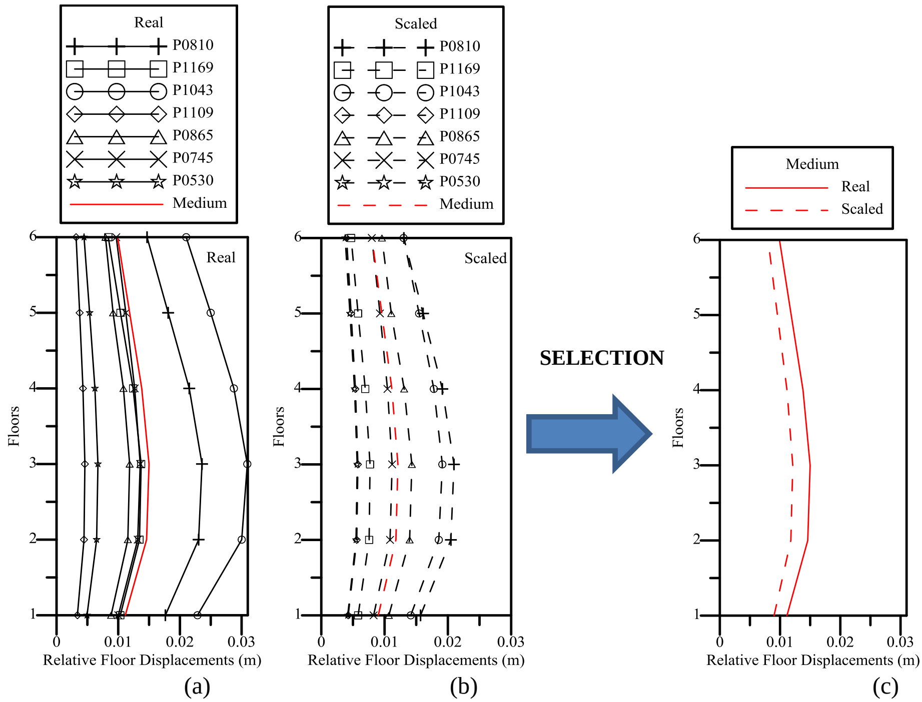

Figure 13. Relative floor displacement for real, scaled seven records and mean of them

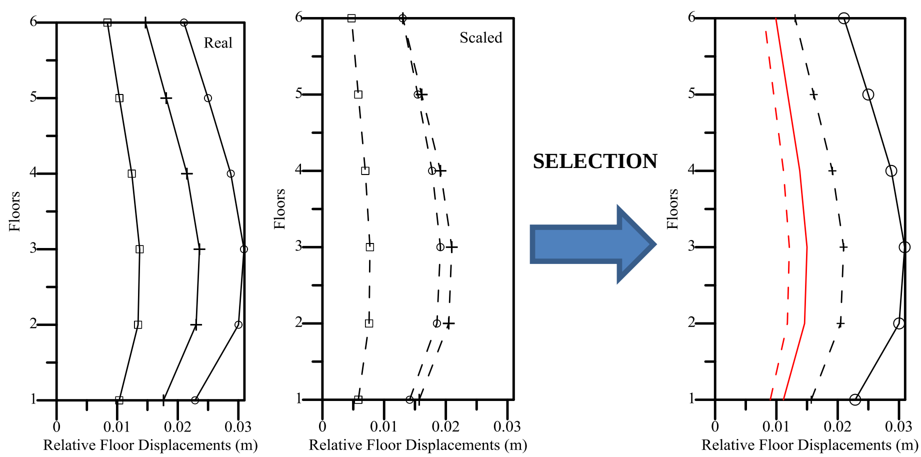

Figure 14. Relative floor displacement for group1 records (P1169-P0810-P1043)

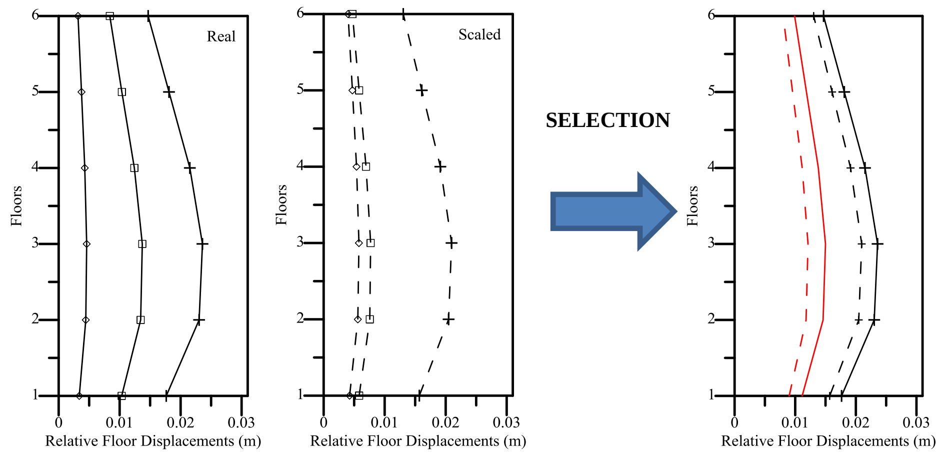

Figure 15. Relative floor displacement for group2 records (P1109-P1169-P08010)

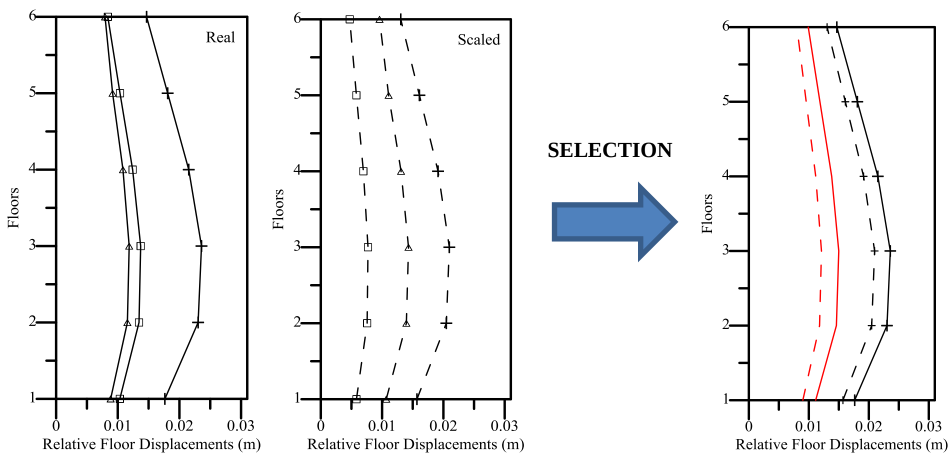

Figure 16. Relative floor displacement for group 3 records(P0865-P1169-P0810)

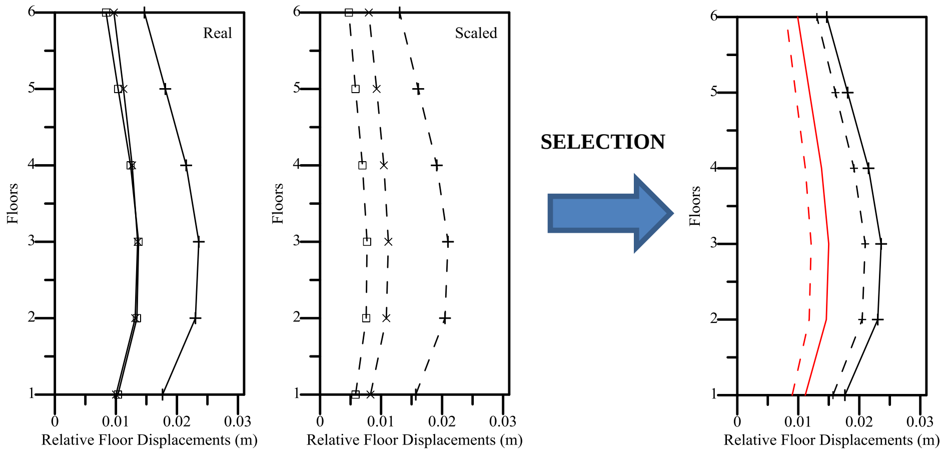

Figure 17. Relative floor displacement for group 4 records (P1169-P0745-P0810)

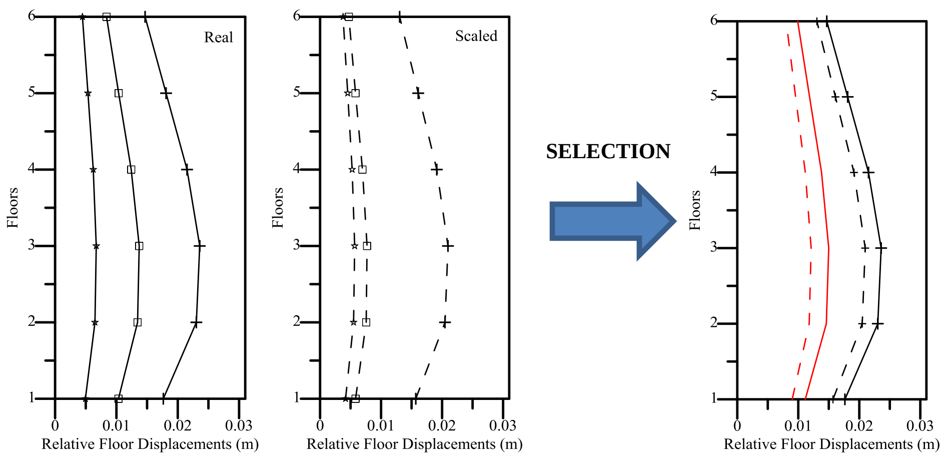

Figure 18. Relative floor displacement for group 5 records (P0530-P1169-P0810)

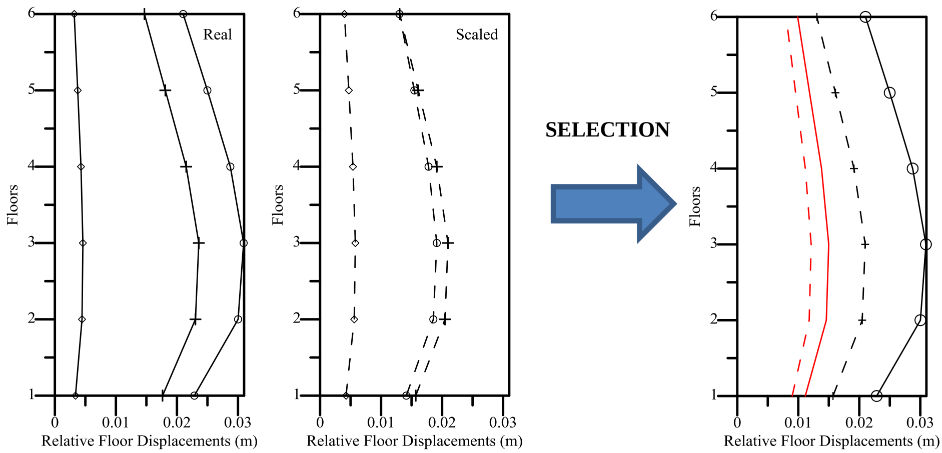

Figure 19. Relative floor displacement for group 6 records (P1109-P0810-P1043)

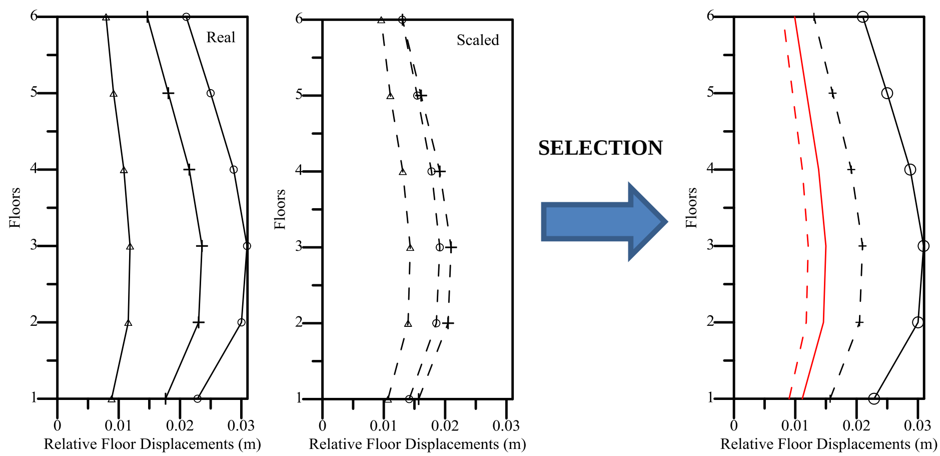

Figure 20. Relative floor displacement for group 7 records (P0865-P0810-P1043)

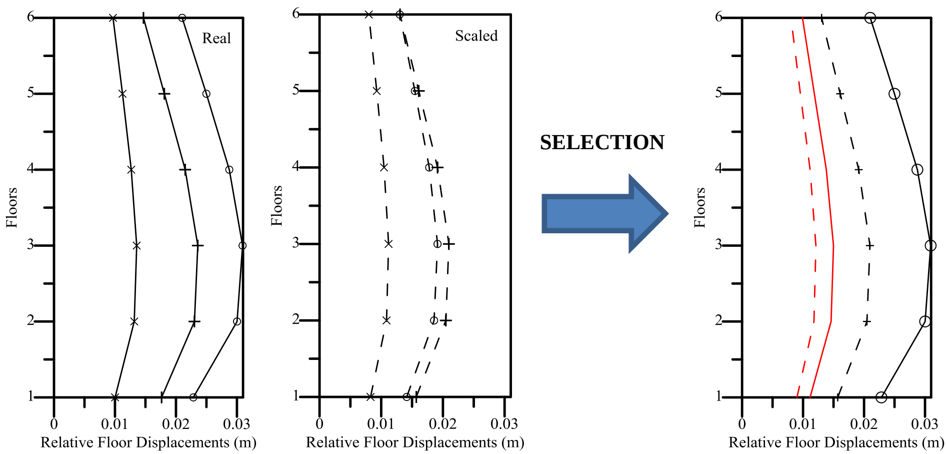

Figure 21. Relative floor displacement for group 8 records (P0745-P0810-P1043)

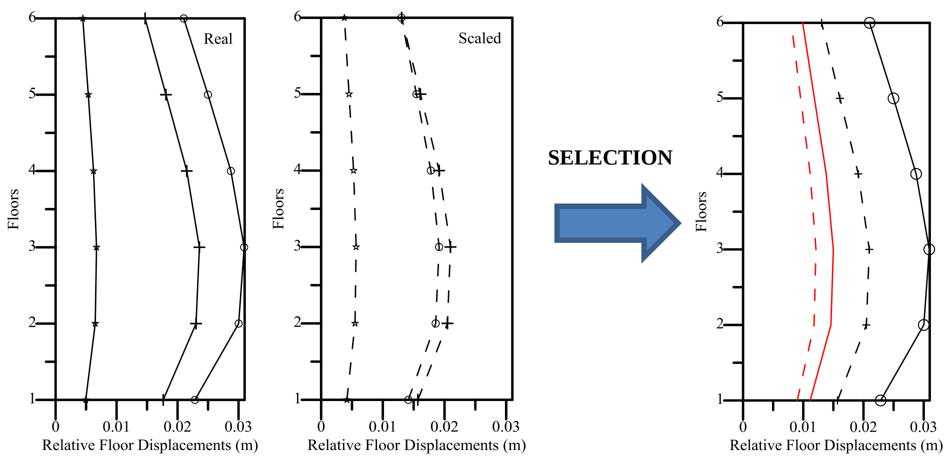

Figure 22. Relative floor displacement for group 9 records (P0530-P0810-P1043)

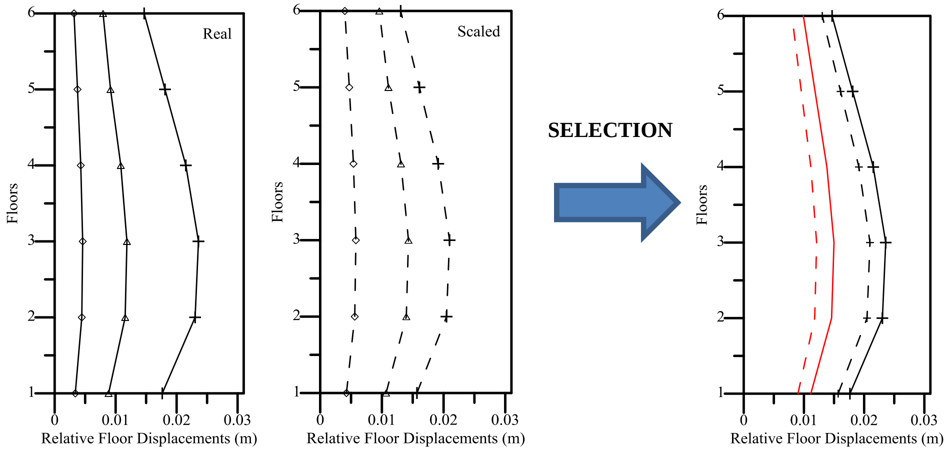

Figure 23. Relative floor displacement for group 10 records (P1109-P0865-P0810)

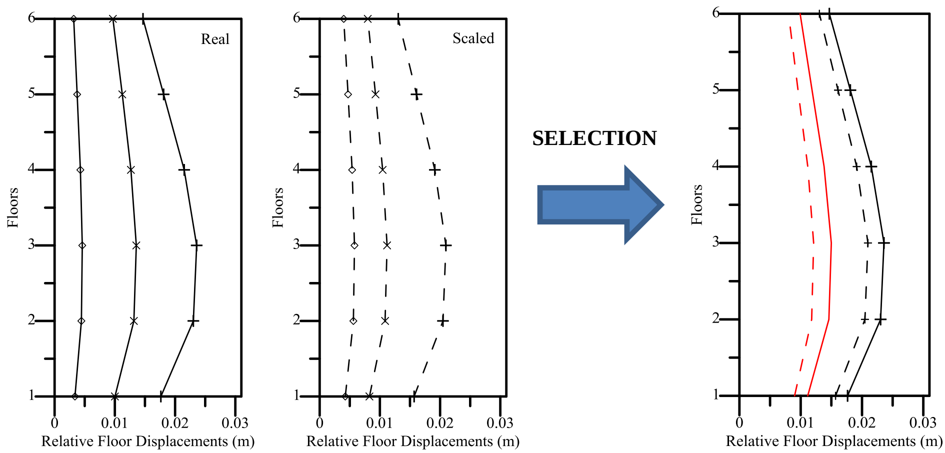

Figure 24. Relative floor displacement for group 11 records (P1109-P0745-P0810)

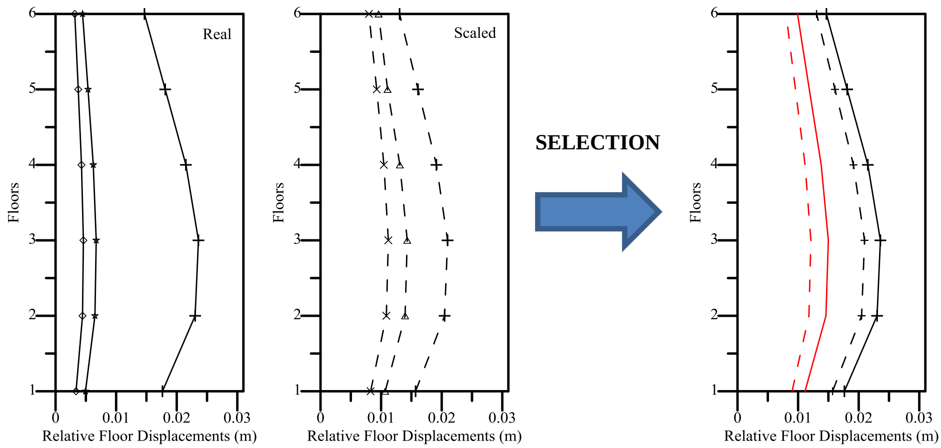

Figure 25. Relative floor displacement for group 12 records (P1109-P0530-P0810)

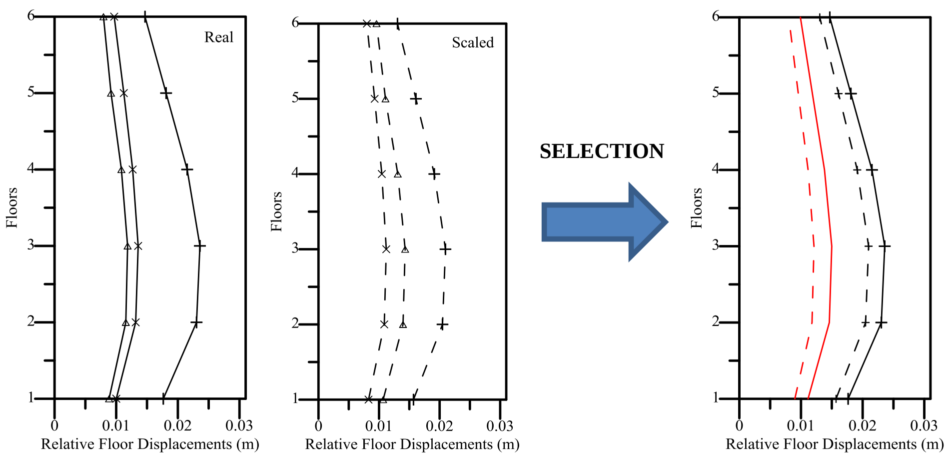

Figure 26. Relative floor displacement for group 13 records (P0865-P0745-P0810)

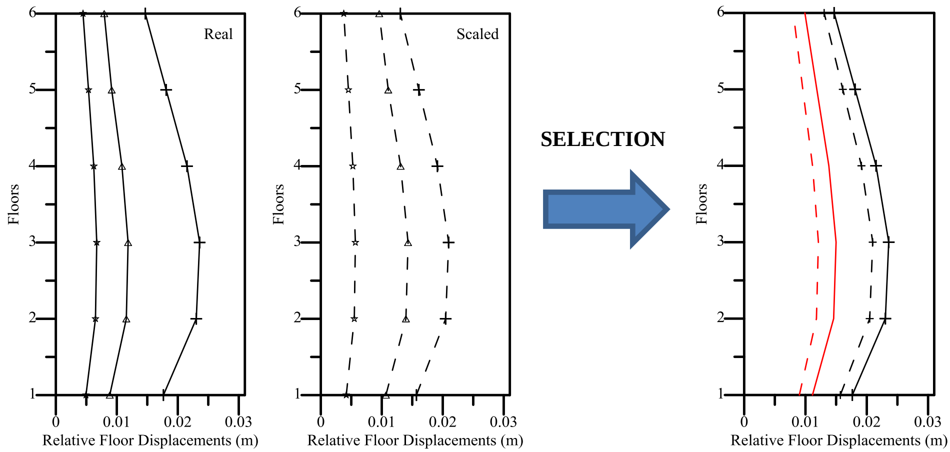

Figure 27. Relative floor displacement for group 14 records (P0530-P0865-P0810)

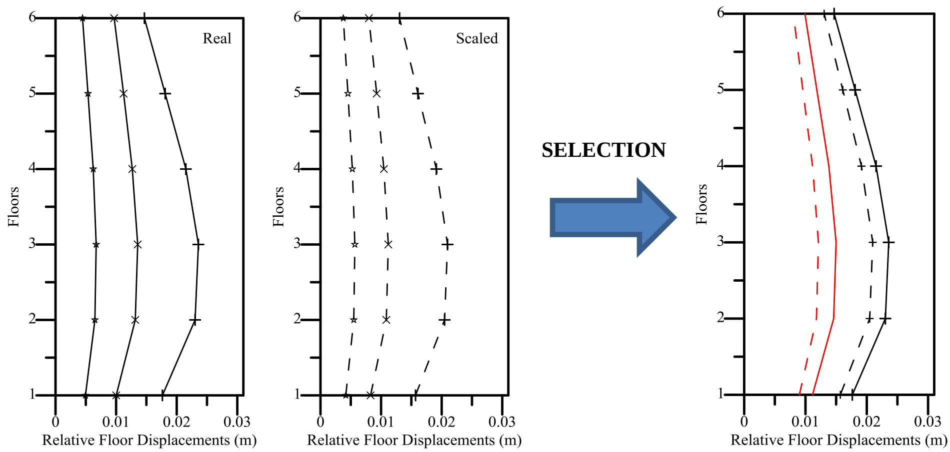

Figure 28. Relative floor displacement for group 15 records (P0530-P0745-P0810)

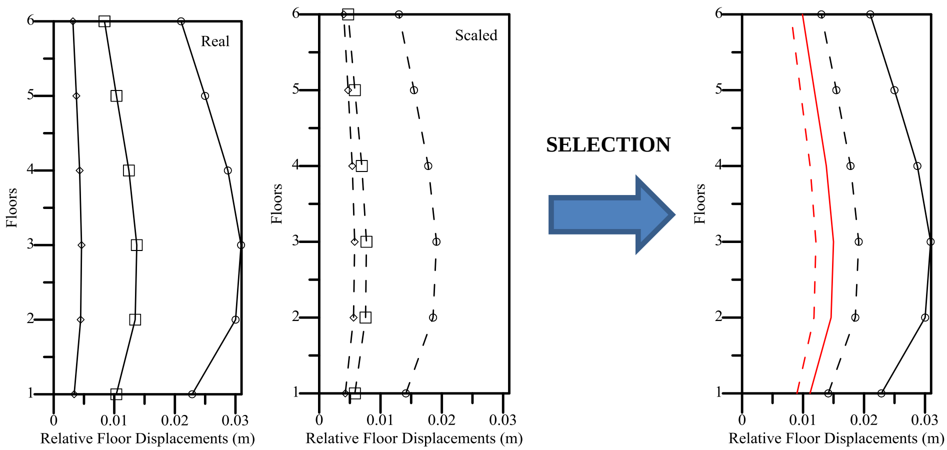

Figure 29. Relative floor displacement for group 16 records (P1109-P1169-P1043)

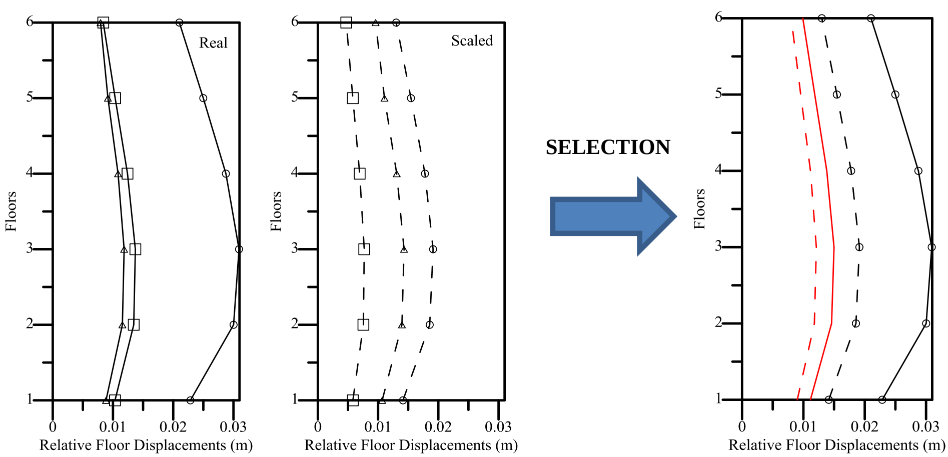

Figure 30. Relative floor displacement for group 17 records (P0865-P1169-P1043)

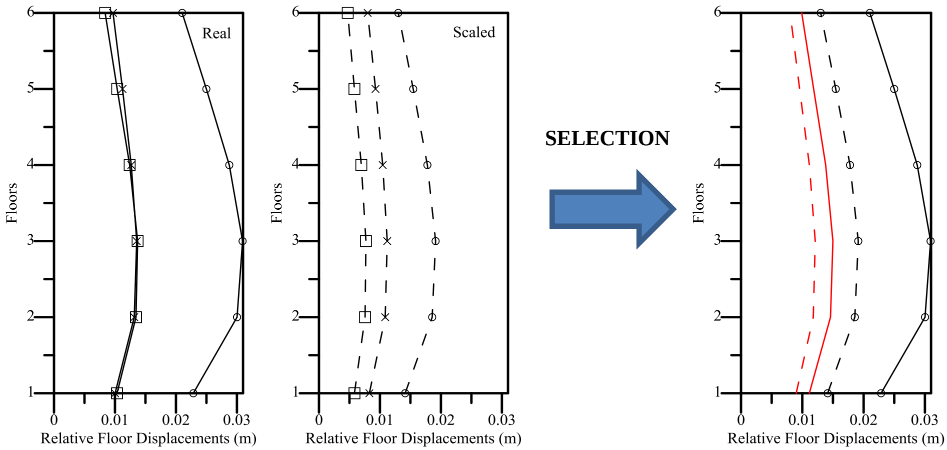

Figure 31. Relative floor displacement for group 18 records (P1169-P0745-P1043)

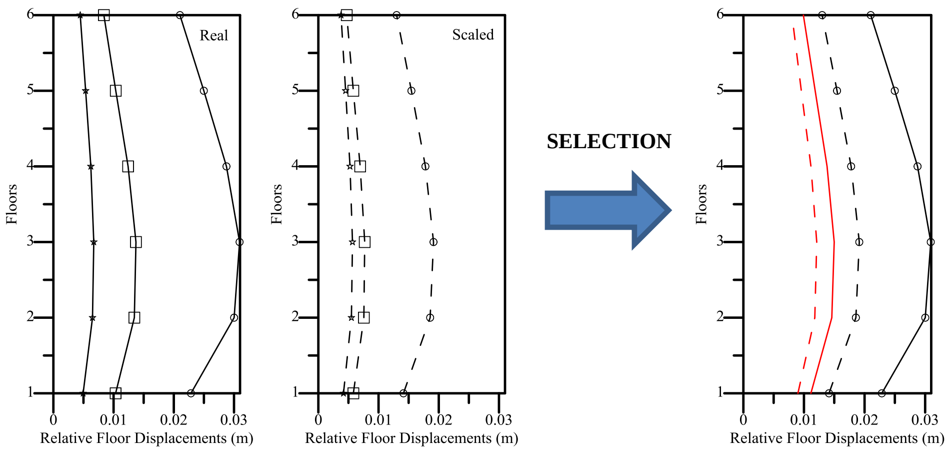

Figure 32. Relative floor displacement for group 19 records (P0530-P1169-P1043)

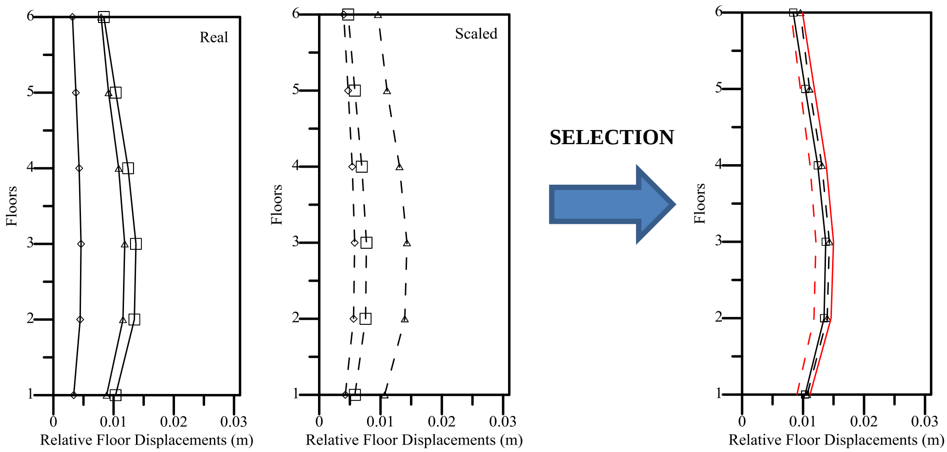

Figure 33. Relative floor displacement for group 20 records (P1109-P0865-P1169)

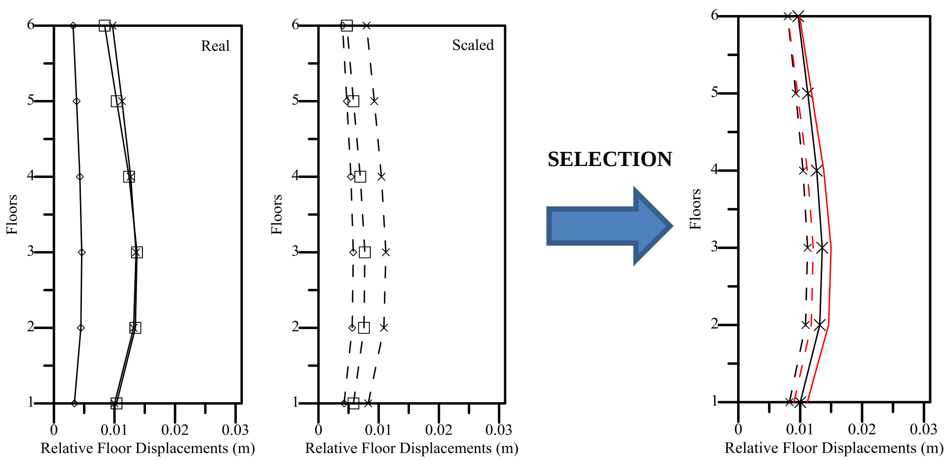

Figure 34. Relative floor displacement for group 21 records (P1109-P1169-P0745)

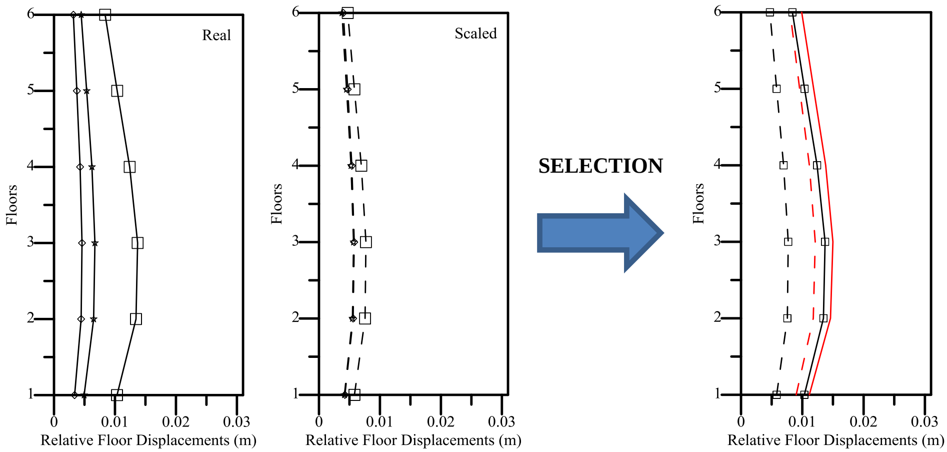

Figure 35. Relative floor displacement for group 22 records (P1109-P0530-P1169)

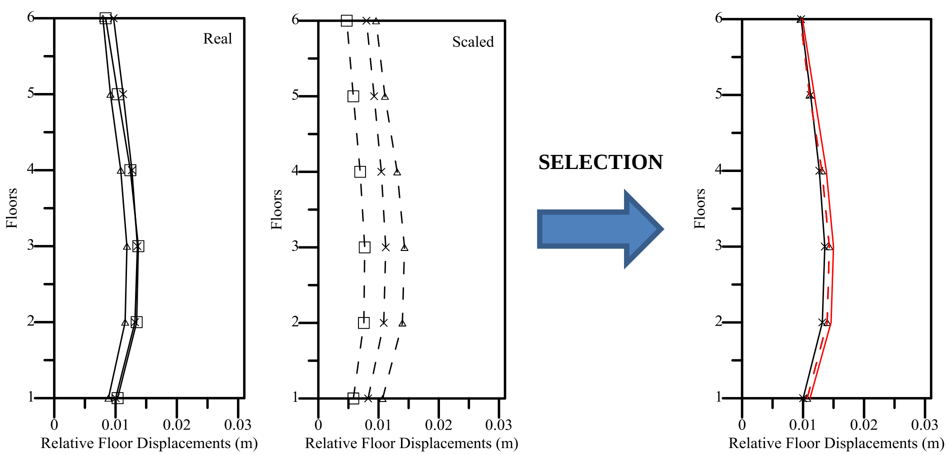

Figure 36. Relative floor displacement for group 23 records (P0865-P1169-P0745)

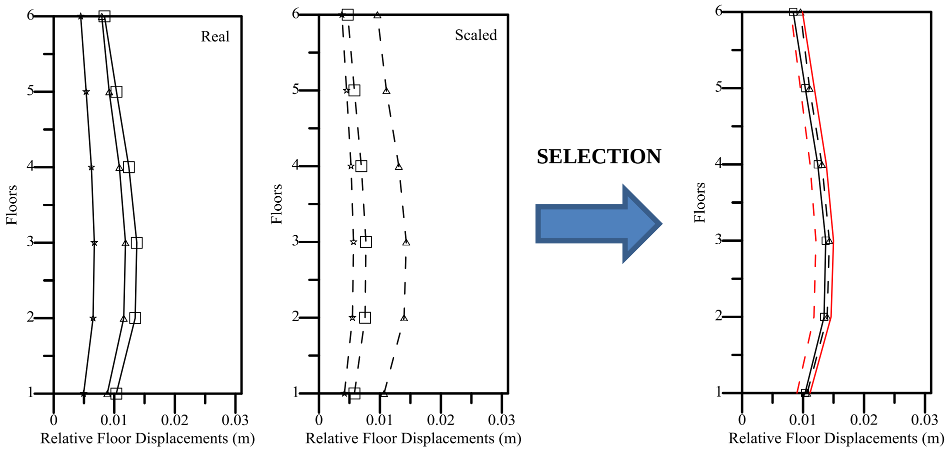

Figure 37. Relative floor displacement for group 24 records (P0530-P0865-P1169)

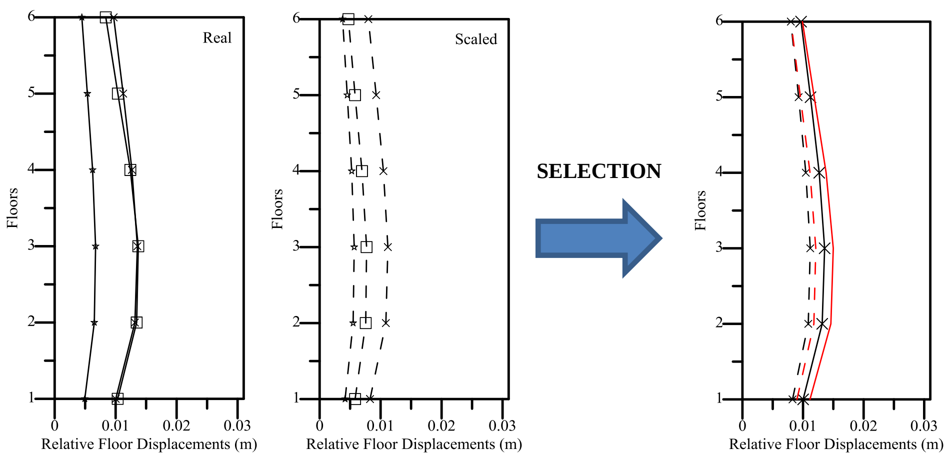

Figure 38. Relative floor displacement for group 25 records (P0530-P1169-P0745)

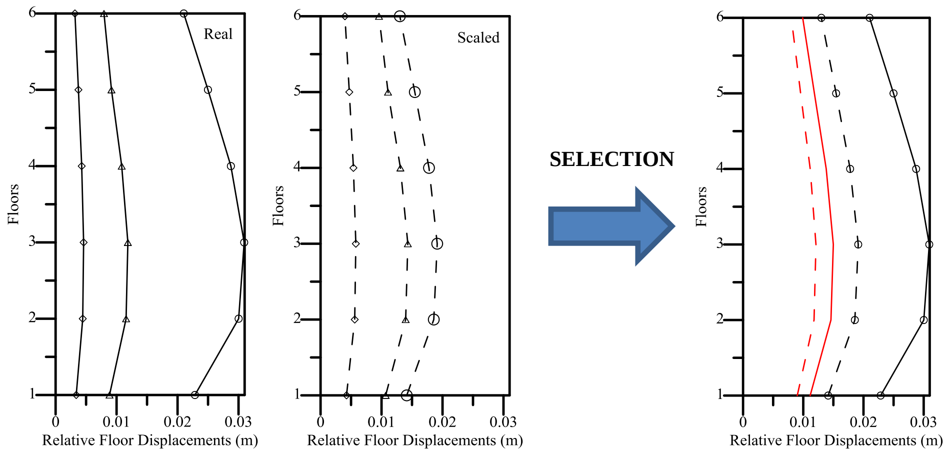

Figure 39. Relative floor displacement for group 26 records (P1109-P0865-P1043)

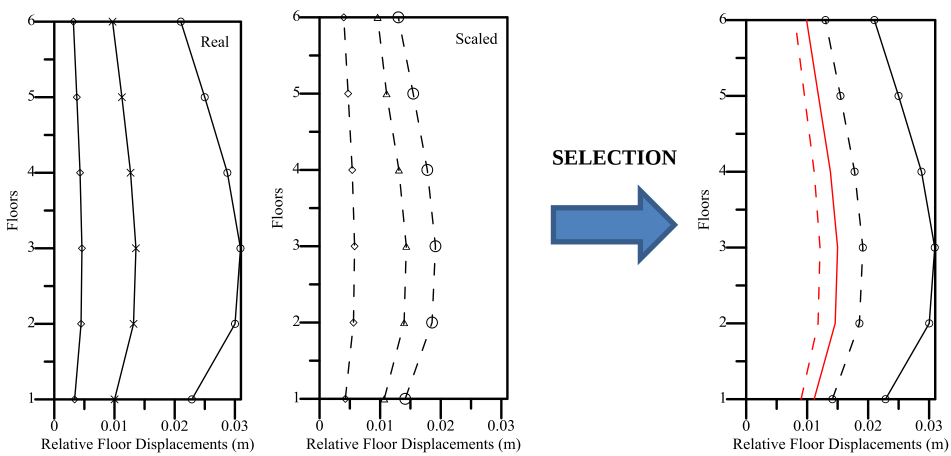

Figure 40. Relative floor displacement for group 27 records (P1109-P0745-P1043)

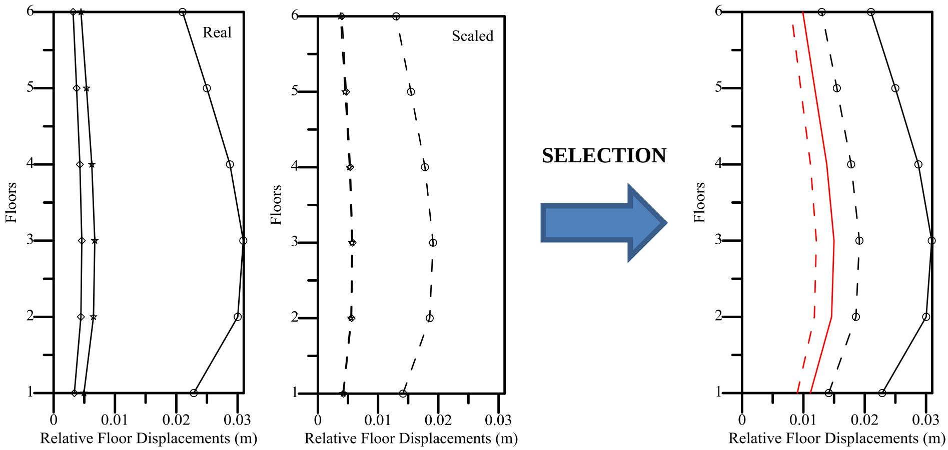

Figure 41. Relative floor displacement for group 28 records (P1109-P0530-P1043)

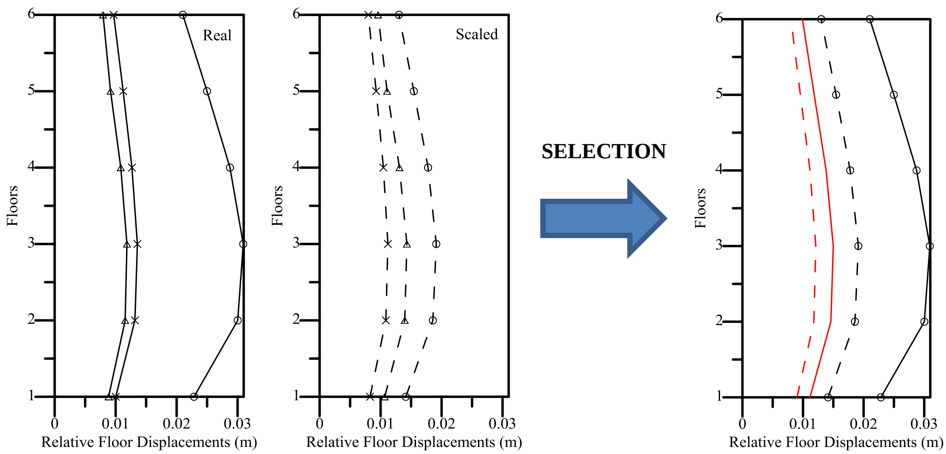

Figure 42. Relative floor displacement for group 29 records (P0865-P0745-P1043)

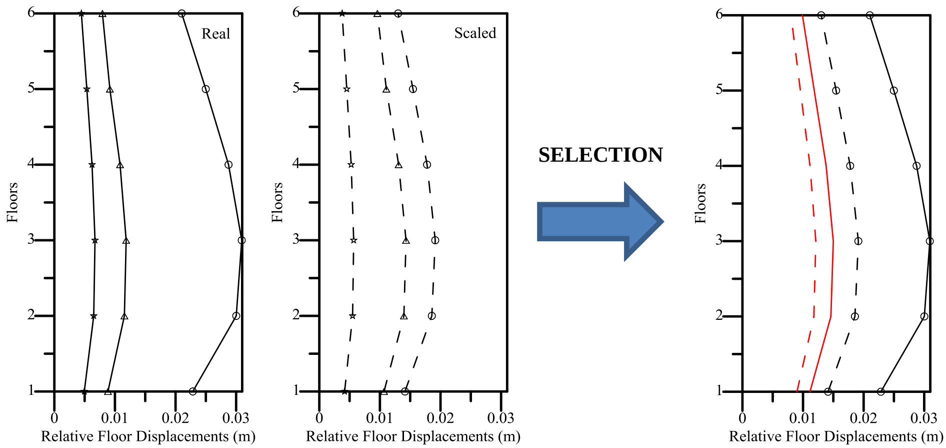

Figure 43. Relative floor displacement for group 30 records (P0530-P0865-P1043)

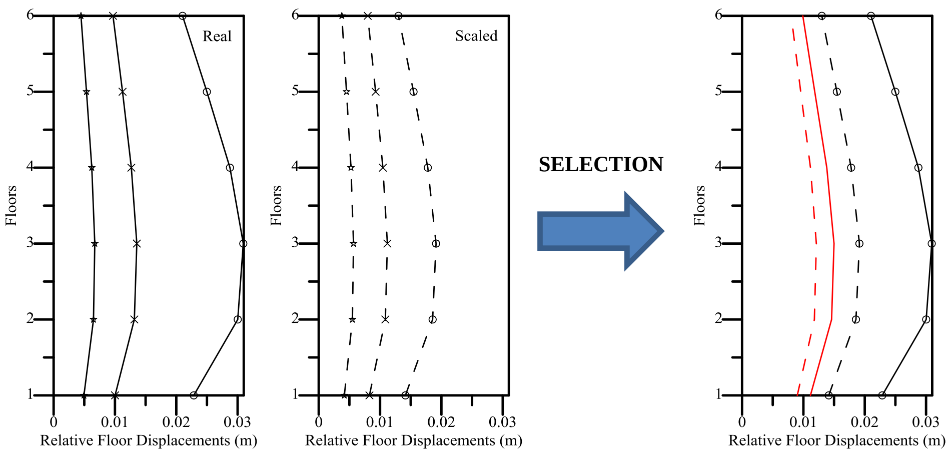

Figure 44. Relative floor displacement for group 31 records (P0530-P0745-P1043)

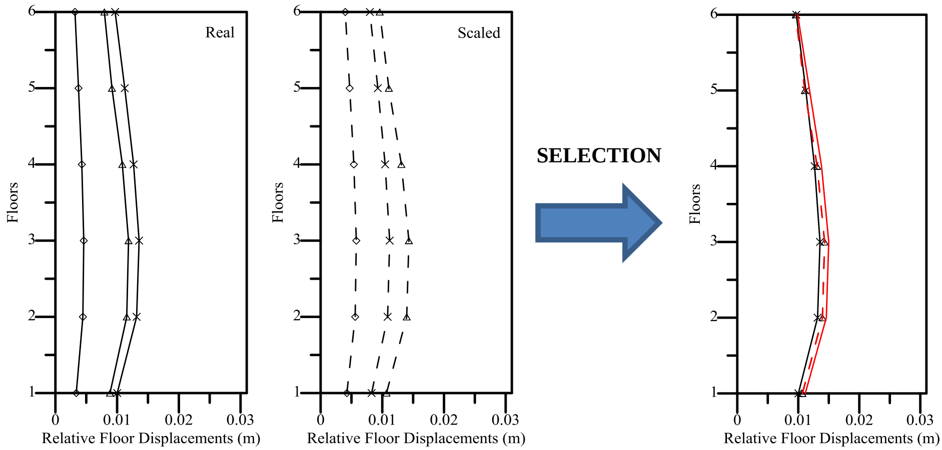

Figure 45. Relative floor displacement for group 32 records (P1109-P0865-P0745)

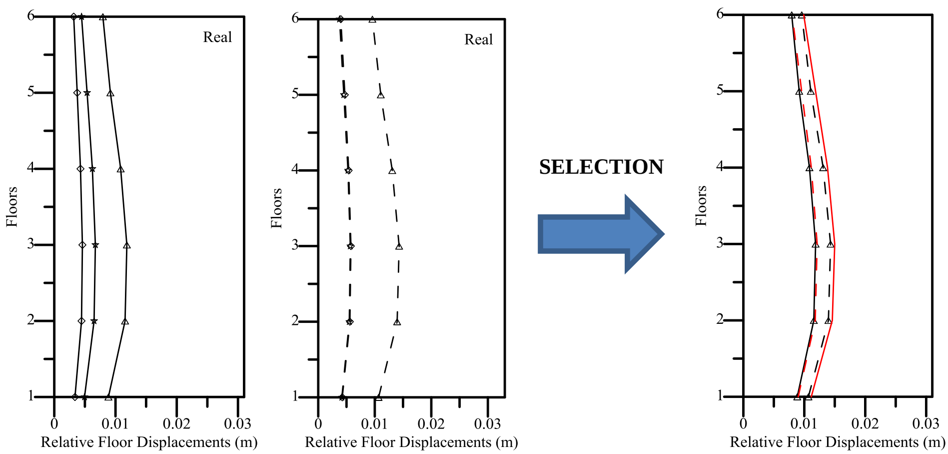

Figure 46. Relative floor displacement for group 33 records (P1109-P0530-P0865)

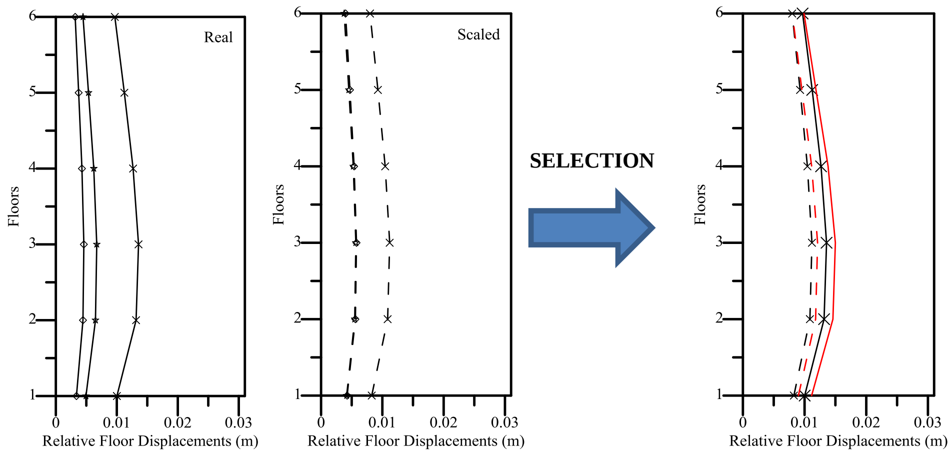

Figure 47. Relative floor displacement for group 34 records (P1109-P0530-P0745)

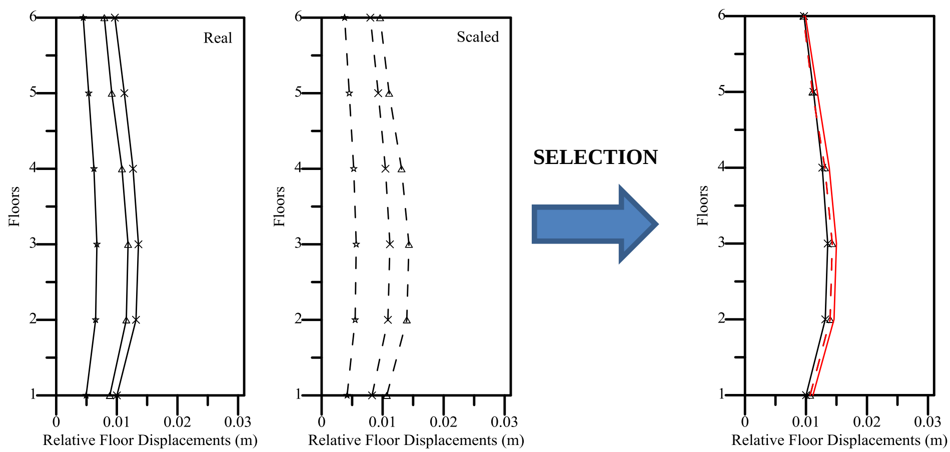

Figure 48. Relative floor displacement for group 35 records (P0530-P0865-P0745)

7. CONCLUSIONS

The aim of this paper is determine the most suitable earthquake record groups for using the design of the building and the effects of scaling of earthquake records on this phenomenon. In many countries code such as Turkish code there are two ways of selection. In the first way it is selected maximum values if used three records. In the last way it is selected mean values if used seven or more records. For this reason seven earthquake ground records are selected and scaled according to Eurocode 8 design spectrum by using SESCAP (Selection and Scaling Program). Real and scaled earthquake are used for linear time history analyses of a six-storied reinforced concrete building modeled as spatial by SAP2000 software. Relative floor displacements along X axis of the building are preferred as structural response of the building against the earthquake ground motions. The mean of the relative floor displacement calculated and selected for seven records. Thirty-five different record groups including three records are created for selection of maximum values. From the results of this study, the following observations can be made:

- Maximum differences between mean of seven scaled and real earthquake records in point of relative floor displacement along X axis of the building is 23% on the second floor.
- When the maximum values of records selected from thirty-five groups and the mean values of scaled and real seven records are shown in the same figure; the values of ten groups are close to each other with the mean value of real and scaled seven records. The values of other twenty-five groups are higher than mean values.
- It is seen obviously that the difference between the maximum values of three scaled records and the average values of seven scaled records is less than the difference obtained from real earthquake records when all figures are taken into consideration.
- The differences of structural responses caused by scaled earthquake records are less than ones caused by real earthquake records when variation of relative floor displacements thought the height of building is considered.

It is seen that differences between mean value and maximum value of the relative floor displacements along X axis of the building induced by seven and three scaled earthquake records respectively are less than ones obtained from real earthquake records.

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