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THE EFFECTS OF FAULT TYPE FOR THE SELECTİON OF INPUT ACCELERATİON RECORDS FOR SİTE RESPONSE ANALYSİS

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ABSTRACT

In seismic hazard provisions, a uniform hazard acceleration response spectrum on the ground surface is the main component for designing structures and evaluating seismic vulnerabilities in city planning. This purpose requires a probabilistic local seismic hazard analysis. One of the primary factors affecting the results of site response analysis is the selection of acceleration time histories as an input motion compatible with the regional hazard concerning fault type, magnitude, and distance ranges. The objective of the present study is to use DEEPSOIL (Hashash et al., 2016) site response analysis code to compare results from hazard compatible acceleration records concerning magnitude, fault, distance, and the equivalent shear wave velocity V_{s30} of the recording stations for three possible fault types (strike-slip, normal and reverse) to evaluate the effect of fault type in the selection of hazard compatible input acceleration time histories. Site response analysis will be conducted for three different soil profiles to evaluate the importance of the fault type in the selection of the input earthquake records.
Keywords: Site response analysis, uniform hazard acceleration response spectrum, fault type, earthquake hazard

1. INTRODUCTION

The aim of a probabilistic site-specific response analysis is to evaluate the expected levels of peak ground acceleration and uniform hazard acceleration spectrum in order to reduce vulnerability of structures and improve the life safety. Several factors affect the results of site-specific response analysis such as the selected acceleration time histories as input motions, soil properties, their stratifications, and method of analysis. However, selecting and scaling acceleration time histories are the primary and critical factor which may lead to significant variations in the amplitude, duration, and frequency content of the acceleration time histories on the ground surface. Large number of acceleration time histories compatible with the uniform hazard spectra in terms of fault mechanism (Normal, strike-slip and reverse fault), magnitude and distance range recorded on stiff site conditions need to be selected as input motion for site-specific response analysis.

According to "Türkiye Bina Deprem Yönetmeliği, 2018" at least eleven recorded horizontal ground motion acceleration time histories on rock outcrop are needed. It was also demonstrated that usage of limited number of times histories may lead to erroneous results (Ansal and Tönük, 2007; Papaspiliou and Kontoe, 2013).

One possible option to minimize the scatter in the results is to perform site response analyses using a large number of hazard compatible acceleration time histories by adopting a probabilistic procedure to approximate earthquake characteristics on the ground surface for design and vulnerability assessments. It was shown that 20-22 acceleration time histories are necessary to reduce the scatter in the results (Ansal et al., 2012).

In this study, 20 real earthquake acceleration time histories from Peer Data Bank (2020) with the magnitude range of M=5-7, distance range of R_{jb}=20-30 km and three fault categories (Normal, reverse, and strike-slip) were selected.

One dimensional (1D) site response analysis were conducted using DEEPSOIL (Hashash et al. 2016) to estimate earthquake characteristics such as peak ground acceleration concerning fault types. DEEPSOIL (Hashash et al. 2016) can perform linear, equivalent linear, and non-linear analysis in the 1D approach. In this study an equivalent linear model was used, hence the program assumes an elastic, damped soil with the maximum shear modulus (G_{max}) and minimum damping ratio (D_{min}) by predicting effective strain through linear analysis and estimates shear modulus (G) and damping ratio (D) for effective strain and then using modulus reduction and damping curves and iterate until convergence.

In this case study, the purpose is to evaluate the effect of different fault types for input strong motions set used in 1D site response analyses on the result of the ground surface. Thus, scaled set of strong motion records that are most compatible with the selected outcrop uniform hazard spectrum (with a return period of 475) obtained from regional hazard study, with respect to fault type, earthquake magnitude, distance and average shear wave velocity of the recording stations.

2. SELECTION OF INPUT ACCELERATION RECORDS

It would be preferable to adopt real strong ground motion records for site-specific response analysis (Bommer and Acevedo 2004) and (Bommer et al., 2000). besides Ansal and Tonuk (2007) recognized that using simulated ground motions may cause over-conservative results on the ground surface which maybe not very useful in some cases.

There are uncertainties related to the selection of real input ground motions in conducting site-specific response analysis. The option of choosing and scaling of input acceleration time histories is the primary controlling factor in site response analysis (Ansal et al., 2015), (Tönük and Ansal, 2010), (Tönük et al., 2014), (Kottke and Rathje, 2008), (Haase et al., 2011).

Due to regional geology and tectonic, the investigated site may be affected by different types of fault mechanisms; normal, reverse, and strike-slip during earthquakes. In the present study, the main concern is to select acceleration time histories recorded under three different tectonic conditions (Normal, strike-slip and reverse faults) within the specific range of magnitude (Mw) that may occur within the range of the estimated fault distance. Therefore, 20 acceleration time histories compatible with the rock outcrop uniform hazard acceleration spectrum were selected from PEER data bank (2020) for magnitude (M=5.0-7.0), Joyner-Boore distance to rupture plane (R_{jb}=20-30km) and three fault mechanisms (Strike-slip, normal, and reverse) recorded on stiff site conditions with average shear wave velocities V_{s30} ≥500 m/s as earthquake input motions.

It is assumed that these selected earthquake ground motions are possible scenarios that may happen near the investigated site. Thus, the effects of various types of faults can be evaluated concerning the design level.

3. SCALING OF INPUT ACCELERATION GROUND MOTION

The purpose of scaling the acceleration time histories, (a) to determine the best fit with the rock outcrop target uniform hazard acceleration spectrum using an optimization algorithm, (b) in the desirable period range, to have better conformity with the target uniform hazard acceleration spectrum, (c) to reduce the scattering of the acceleration spectra after scaling.

The algorithm applied in this study for scaling is an optimization algorithm without modifying the frequency content and linearly scaling with respect to peak acceleration to determine the best fit with the target uniform hazard acceleration spectrum, hence for each ground motion, a specific scale factor was calculated. These scaled acceleration time history ground motions were applied as input record as rock outcrop motion on the engineering bedrock.

The effects of selecting and scaling of earthquake records ground motions for 1D equivalent linear site response analyses were investigated and observed that if this method of scaling procedure is adopted, it may have a significant effect on-site response analysis (Ansal et al.,2015; 2012; Ansal and Tönük, 2007).

A parametric study is conducted with DEEPSOIL (Hashash et al. 2016) to have 1D equivalent linear site-specific response analysis for three various categories of faults (Normal, strike-slip and reverse) on three various soil profiles with selected 20 acceleration records compatible with the site-specific earthquake hazard for each fault type, in terms of expected fault mechanism, magnitude, and distance.

The general spectra scaling method for three categories of faults with selected 20 input acceleration time histories from the Peer database (2020) is shown in Figure 1.

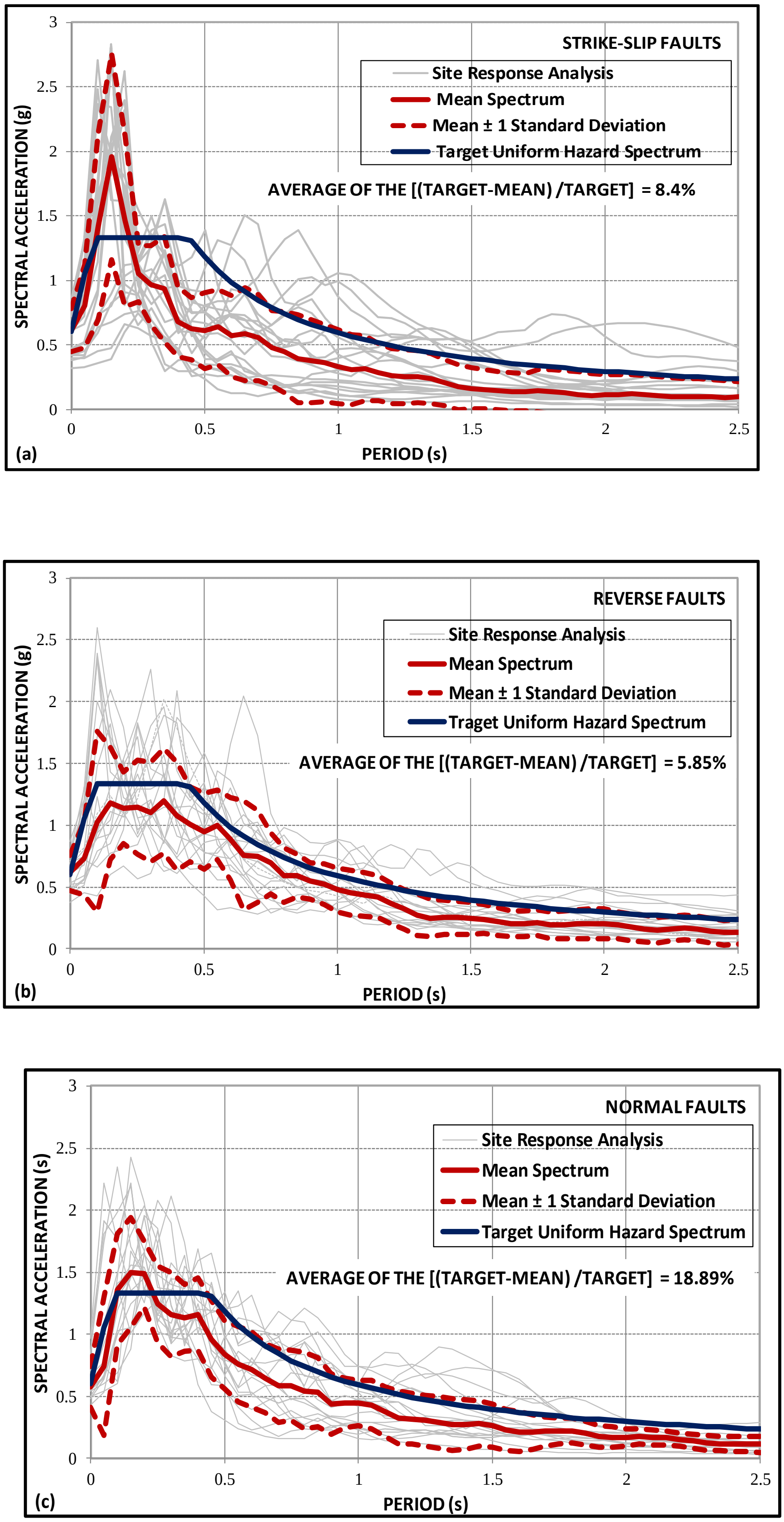

Figure 1. Spectra scaling of 20 input ground motions for a) Strike-slip fault, b) Reverse fault and c) Normal fault.

Figure 1 shows the average of all scaled 20 acceleration input motions for three types of faults with mean and mean ±1 standard deviation.
In the case of RP=475 years, for a strike-slip fault, the average of the difference ratio (The ratio of the difference between spectral accelerations calculated based on 10% exceedance probability and median+1 standard deviation to median acceleration) within the period range of zero to four seconds was calculated as 8.4%. for reverse and normal fault this ratio was calculated as 5.85% and 18.89%.

Table 1. Locations and properties of the selected input acceleration records

Earthquake Name	Station Name	Year	Mechanism	Magnitude	Rjb(km)	Rrup(km)	Vs30(m/s)	components
Irpinia_ Italy-01	Brienza	1980	Normal	6.9	22.54	22.56	561.04	H1-H2-V
Irpinia_ Italy-01	Rionero In Vulture	1980	Normal	6.9	27.49	30.07	574.88	H1-H2-V
Irpinia_ Italy-02	Rionero In Vulture	1980	Normal	6.2	22.68	22.69	574.88	H1-H2
Little Skull Mtn_NV	NTS Control Pt. 1	1992	Normal	5.65	23.83	24.66	593.35	H1-H2
Umbria-03_ Italy	Umbertide	1984	Normal	5.6	26.33	26.98	574.32	H1-H2
Umbria Marche_Italy	Norcia-Zona Industriale	1997	Normal	5.7	27.78	28.65	551	H1-H2
L'Aquila_ Italy	Fiamignano	2009	Normal	5.6	26.15	29.36	638.39	H1-H2
L'Aquila_ Italy	Leonessa	2009	Normal	5.4	29.36	33.18	649.67	H1-H2
L'Aquila _ Italy	Antrodoco	2009	Normal	5.4	21.79	26.71	525.95	H1-H2
Niigata_ Japan	NIG023	2004	Reverse	6.63	25.33	25.82	654.76	H1-H2
Chuetsu-oki_ Japan	Joetsu Yasuzukaku Yasuzuka	2007	Reverse	6.8	20.65	25.52	655.45	H1-H2
Chuetsu-oki_ Japan	Joetsu Yanagishima paddocks	2007	Reverse	6.8	28.07	31.43	605.71	H1-H2
Chuetsu-oki_ Japan	Tokamachi Chitosecho	2007	Reverse	6.8	25.35	30.65	640.14	H1-H2
Chuetsu-oki_ Japan	Yamakoshi Takezawa Nagaoka	2007	Reverse	6.8	22.23	28.12	655.45	H1-H2
Iwate_ Japan	Tamati Ono	2008	Reverse	6.9	28.9	28.91	561.59	H1-H2
Iwate_ Japan	Yamauchi Tsuchibuchi Yokote	2008	Reverse	6.9	25.61	28.41	561.59	H1-H2
Iwate_ Japan	Yuzawa Town	2008	Reverse	6.9	22.41	25.56	655.45	H1-H2
Iwate_ Japan	Yuzama Yokobori	2008	Reverse	6.9	27.1	29.75	570.62	H1-H2
Iwate_ Japan	Yuzawa	2008	Reverse	6.9	22.41	25.56	655.45	H1-H2
Livermore-01	APEEL 3E Hayward CSUH	1980	strike slip	5.8	29.19	30.59	517.06	H1-H2
Chi-Chi_ Taiwan-04	CHY029	1999	strike slip	6.2	25.75	25.79	544.74	H1-H2
Chi-Chi_ Taiwan-04	CHY035	1999	strike slip	6.2	25.01	25.06	573.04	H1-H2
Chi-Chi_ Taiwan-04	TCU084	1999	strike slip	6.2	26.83	27.13	665.2	H1-H2
Tottori_ Japan	OKYH08	2000	strike slip	6.61	24.84	24.84	694.21	H1-H2
Tottori_ Japan	OKYH09	2000	strike slip	6.61	21.22	21.22	518.92	H1-H2
Tottori_ Japan	OKYH14	2000	strike slip	6.61	26.51	26.51	709.86	H1-H2
Tottori_ Japan	SMNH02	2000	strike slip	6.61	23.64	23.64	502.66	H1-H2
Potenza_ Italy	Brienza	1990	strike slip	5.8	25.89	26.2	561.04	H1-H2
Darfield_New Zealan	LPCC	2010	strike slip	7	25.21	25.67	649.67	H1-H2

4. SITE RESPONSE ANALYSIS FOR SITE SPECIFIC DESIGN SPECTRUM

A comprehensive site response investigation was conducted using DEEPSOIL (Hashash et al. 2016) for three sites with relatively deep, medium, and shallow soil layers down to the engineering bedrock. The variations of shear wave velocities with depth were determined from in hole PS logging tests as shown in Figure 2. Shear wave velocity for the studied case was observed to vary between 110 m ⁄s and 650 m ⁄s, also the groundwater table was encountered at a depth of 5 meters.

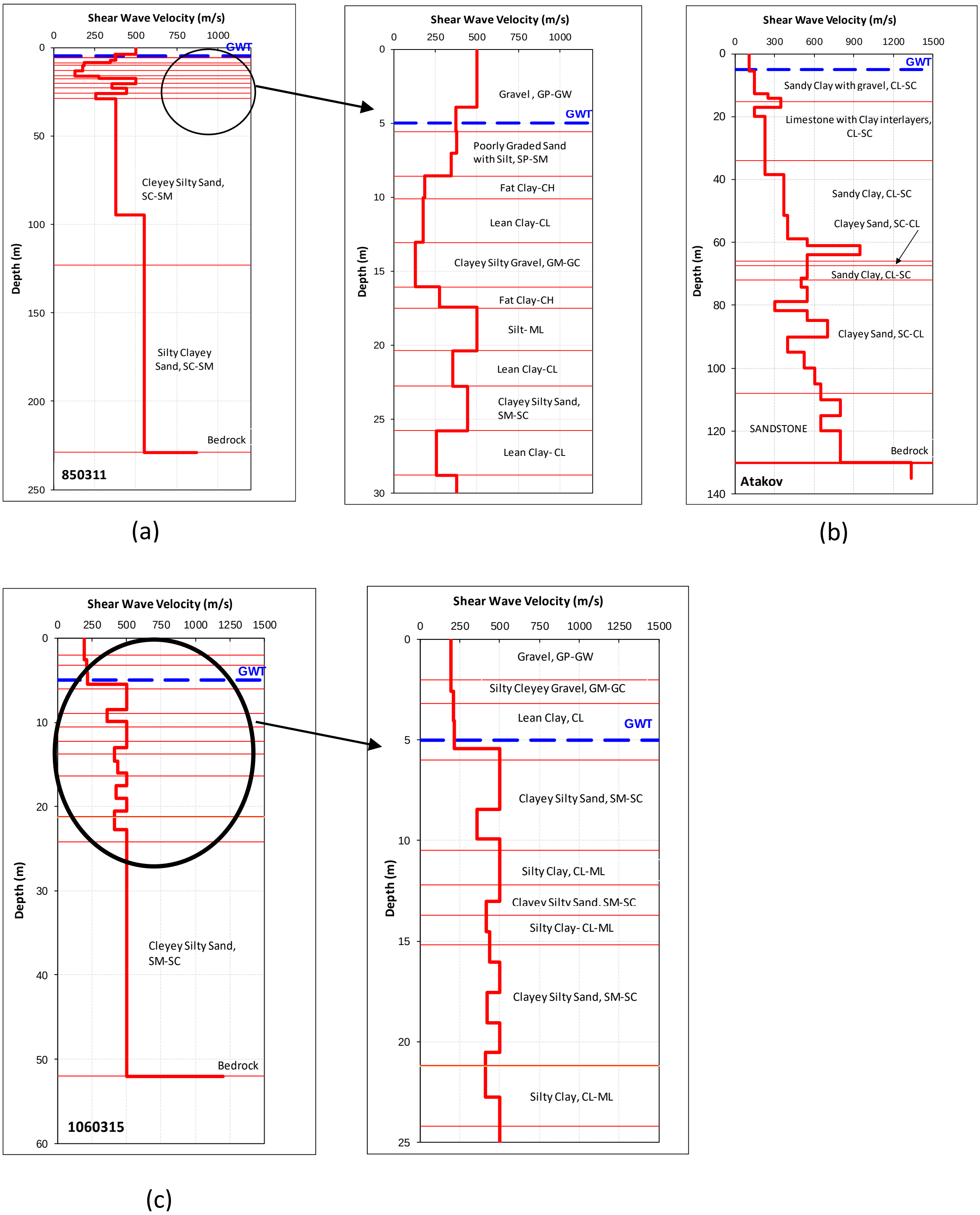

Figure 2. Variation of shear wave velocity with depth for the investigated soil profiles; (a) Deep, (b) Medium, and (c) shallow cases.

20 input real acceleration time histories for three categories of faults (Normal, strike-slip and reverse) compatible to uniform hazard spectra with 475 years return period, and magnitude of M=5.0-7.0 and R_{jb}=20-30 km were chosen from PEER (Center 2020) earthquake data bank and shown below in Figure 3. They were applied to the investigated borings. Equivalent linear site response analysis was conducted for investigated sites to evaluate the effect of fault types on the ground surface responses. Individual site responses and the median values are plotted in Figure 3,4 and 5.

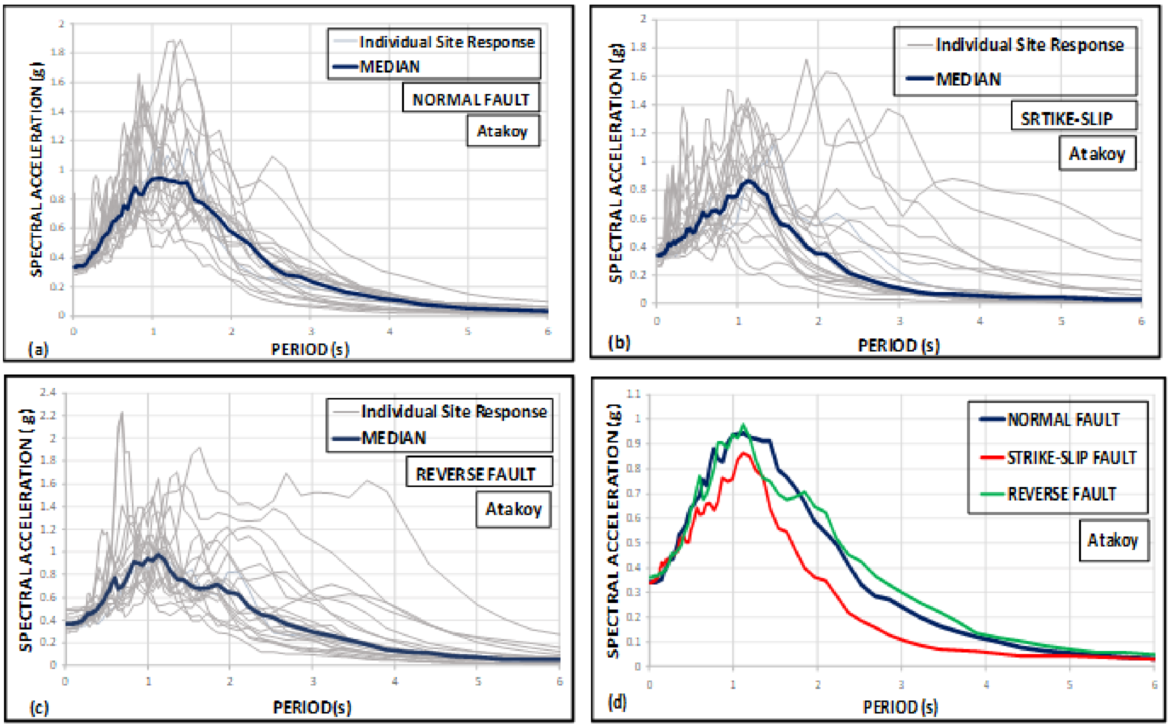

Figure 3. Individual site responses and the median values for deep site

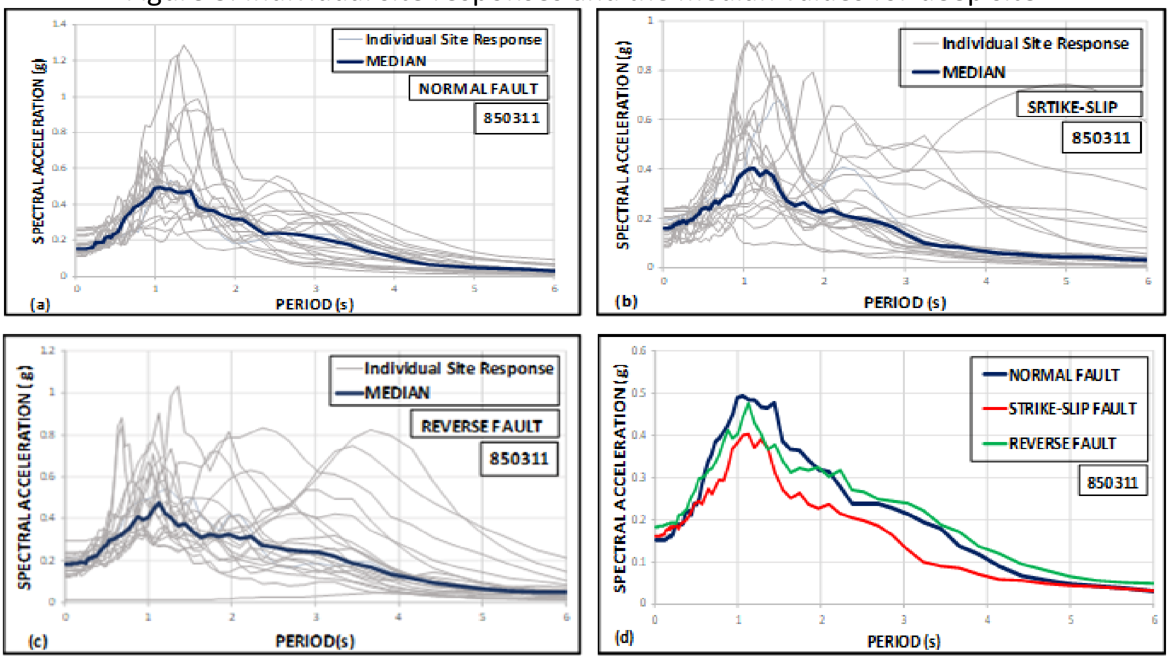

Figure 4. Individual site responses and the median values for site with medium depth

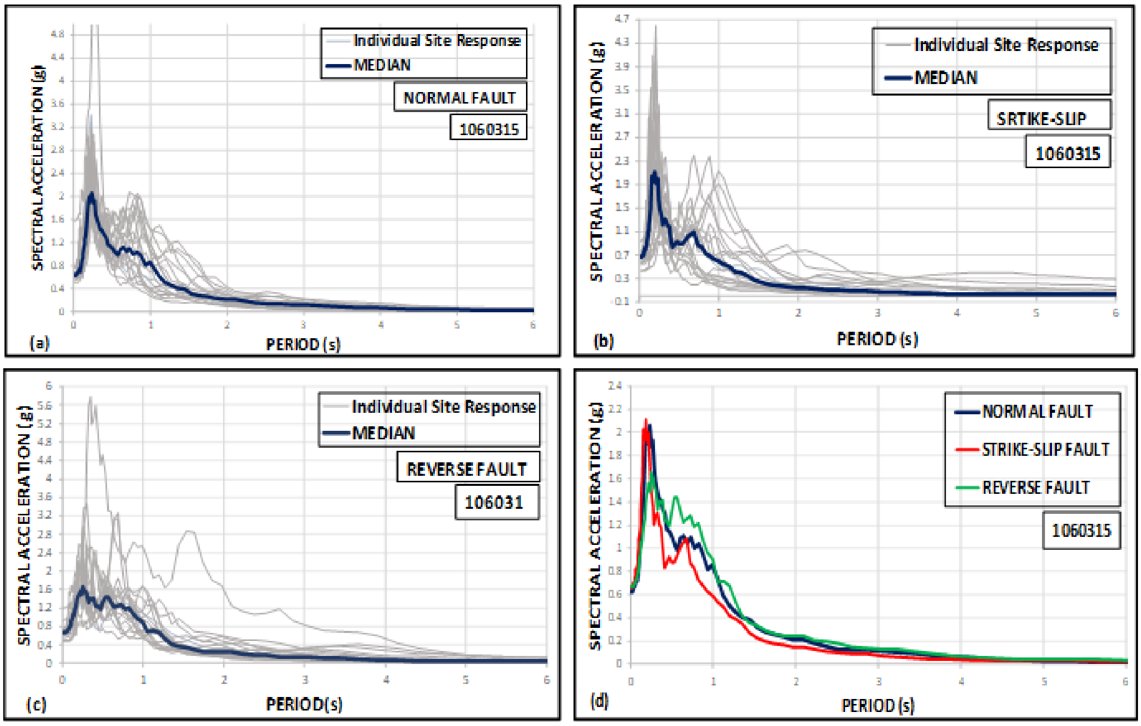

Figure 5. Individual site responses and the median values for site with shallow depth

Figure 3,4 and 5 shows the results of 20 site response analysis results on the ground surface with average spectra of results for (a) Normal fault, (b) Strike-slip fault, (c) Reverse fault and (d) Comparison of median values of faults

It is appealing to find out the average results on the ground surface for seismic hazard analysis for three existing soil profiles, did not lead to notable variations compared with fault types. therefore, for 1D equivalent linear site response analysis, with a return period of 475 years for based on studied cases, it would be advisable to not consider fault types influence individually on the rock outcrop motions.

As shown in Figure 3d, 4d and 5d the variation of average results of input scaled motions did not led to significant variations on the spectral accelerations. moreover, acceleration record from strike-slip faults have yielded lower spectral accelerations compared to the acceleration records obtained from normal and reverse fault.

5. CONCLUSION AND RECOMMENDATIONS

According to the geology of a site, during a probable earthquake, the type of fault that may be effective on the project site may be considered as normal, strike-slip, or reverse fault. In this case study, for three selected borings with different depths, 1D equivalent linear analysis were conducted to compare the results of the analysis on the ground surface. 20 acceleration time history records were selected for each fault type (Normal, strike-slip, reverse) and were spectrum scaled based on a specific algorithm and then were used as input motions for the site-specific response analysis, the average acceleration spectra were plotted on the ground surface.

The geotechnical results consist of three soil profiles and three different sets of scaled input motions of normal, strike-slip and reverse faults, do not indicate significant differences within the average level of ground shaking in terms of spectral accelerations which were calculated with DEEPSOIL (Hashash et al. 2016). Considering the nature of equivalent linear 1D seismic site response analysis, it appears that it may not be necessary to take into account the effect of different fault types in the selection of the input time histories.

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