THE EFFECT OF SOIL CHARACTERISTICS ON NFGM AND FFGM GROUND MOTION RESPONSE SPECTRA

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ABSTRACT

This study aims to achieve the following goals: 1- To distinguish between the inelastic responses of buildings under earthquakes with NFGM and FFGM. 2- To inspect the effect of soil shear velocity on the response spectra. Several earthquake events, with different characteristics, are brought from the PEER website for "Pacific Earthquake Engineering Research" and analyzed using PRISM software to achieve these goals.

The research found that the acceleration, velocity, and displacement response of the selected near-fault ground motions on the structure has a higher effect than the far-field ground motion response in both types of soils and this difference is displayed more noticeably in long periods (periods after 0.2 sec). And when comparing responses of the two types of soils (the soft soil type and the rock type) it shows that the geological and geotechnical aspects of the soil deposits majorly affect the response spectra of the free field surface motions

KEYWORDS

Earthquake, near-fault ground motion, far-field ground motion, shear velocity, response spectra, PEER, PRISM.

PAPER INDEX

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INTRODUCTION

The concentration in this paper is on the seismic ground motion of a general single-degree-of-freedom structural system by comparing the change in the produced responses when varying several parameters like distance to the rupture plane, average soil shear velocity, earthquake components, etc.

From the "Pacific Earthquake Engineering Research Center" (PEER) Various numbers of earthquake events were taken to study, evaluate, process and compare with each other. These ground motions were divided into four groups. Each group is different from the other group in a certain aspect. the dynamic response spectrum is then calculated using PRISM software for all the ground motions in these groups and then a graph is drawn to better illustrates the results. Finally, the results will be discussed to get a broad understanding of the behavior of the structure under seismic ground motion.

An earthquake is an inevitable natural phenomenon that poses a great danger with the uncertainty of what time it is going to strike. Though, with preparation measures in place, the effects of disaster-destruction can be retained to a minimum and the effects of damage can be restricted, whereby emergency response and rescue labors can be made more effective during the outcome with a mixture of aid facilities, public spaces and shelters [1].

Tectonics-induced earthquakes are common and critical earthquakes. They will happen anyplace within the earth where adequate stored elastic strain energy is present to enterprise breakage propagation lengthwise a fault plane, and typically initiate by an initial rupture at a point on the fault plane [2].

Near-fault ground motions can be well-defined as the ground motions that occur near the fault of the earthquake. Near fault motions that get noted close to the epicenter are called near-epicenter records, whereas the ones that get recorded along the fault of the earthquake in the rupture direction can be arbitrated to being forward directivity [3].

Far-field ground motion is known as the ground motion that occurs far away from the fault of the earthquake. The distance by which the earthquake can be defined as NFGM or FFGM can vary from research to research but mostly we can take 20 m as an acceptable number to divide between the two. Even though in this paper the search is tightened to get a better result and to show the difference between the two types of GM better.

Zhang and Iwan (2002) discussed that the near-fault ground motions produce twice as high a dynamic response as the far field ground motion, and they also found that the damage resulting from NFGM earthquakes is done due to a small number of large inelastic deformation cycles, but the damage resulting from by FFGM earthquakes is due to many high-frequency cycles [4].

Anil K. Chopra and Chatpan Chintanapakdee studied the difference between the NFGM and FFGM. They studied two groups of ground motions, one with the characteristics of NFGM and the other with FFGM. They choose 15 NFGM and 15

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FFGM and studied them concerning the linear response spectrum of pseudo-acceleration, pseudo-velocity, and displacement. And figured out that sensitivity regions in the cases of NFGM are much wider [5].

The research done by Hall et al. (1995) discussed that structures with a significant height are very weak against severe NFGM. The increase of the effect of high mode shapes and the wave propagation with its outcome on the deformation of the structure is reported, due to the exposure of the tall building to the 1994 Northridge earthquake [6].

Ali A. Muhsin and Hussam K. Risan also did a paper on the elastic response of a 35 stories reinforced concrete building under NF and FF excitation. And the results show that the NF excitations will cause the structure to surpass its life safety performance level. Also, the near-fault (NF) earthquake intensity measurements were explored in this paper for three different frame buildings with 6, 13, and 20 stories. And found that the building's vibration period and the equation that was used to calculate the IM highly affect the accuracy of the IM [7].

In this paper, a great number of earthquake events were taken randomly as a sample to evaluate this paper's goals. Four earthquake groups were made, each with specific characteristics. And analyzing these GM using PRISM to result in the responses that will be reviewed and discussed in this research.

METHOD OF RESPONSE SPECTRUM

The RSM expression is used to refer to the "Response spectrum method" and is known as the first logical act of scientific development of the design for earthquake-resistant. It can also be defined as an outline of absolute values of the structure's maximum response (that consist of displacement, accelerations, velocities, etc.) which is known as a function of the natural time period of the structure.

This method is the first actual technique for developing earthquake resistance design. For a structure to withstand an earthquake, it is required to be built around the notion that it is adept to endure a force equal to $m \times Sa_{max}$. where m is the mass of the structure and Sa_{max} is the maximum expected acceleration that a structural body will be subjected to under a specific ground acceleration, and it is also the function of the individual time period of the structural body [8].

If a building system is considered an elastic system with MDOF (multiple degrees of freedom), then we can separate it into singular components of an SDOF (single degree of freedom). for each of these singular components, it is probable to find the peak response if we can measure the ground acceleration resulting from a shock-like earthquake, then The overall response can then be calculated by the superimposition of these singular responses. Using this method [8].

Fig.1 shows the acceleration time history of an NFGM for the " El Mayor-Cucapah" earthquake recorded in Mexico in 2010. This record is taken from PEER, having magnitude (Mw = 7.2), epicentral distance (Rrup = 11.44 Km), and PGA of 0.255g acceleration time history (near-fault). This acceleration time history is converted to an

https://doi.org/10.17993/3ctic.2023.121.29-44

elastic spectrum response using PRISM software to get the spectral (acceleration, velocity, and displacement) as in Fig.2. Three Damping ratios (ξ) values of 3%, 5%, and 10% to be used in the spectrum analysis and different values are taken because damping depends on the material used to build the structure as well as the number of joints and restraints. As for a typical value, 5% is correct for most concrete structures.

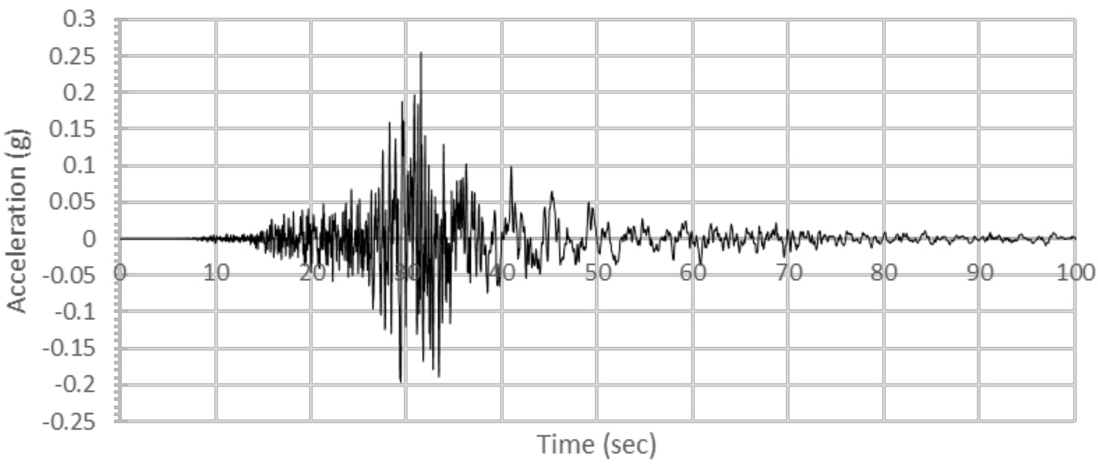

Figure 1. Acceleration time history of El Mayor-Cucapah (2010) earthquake

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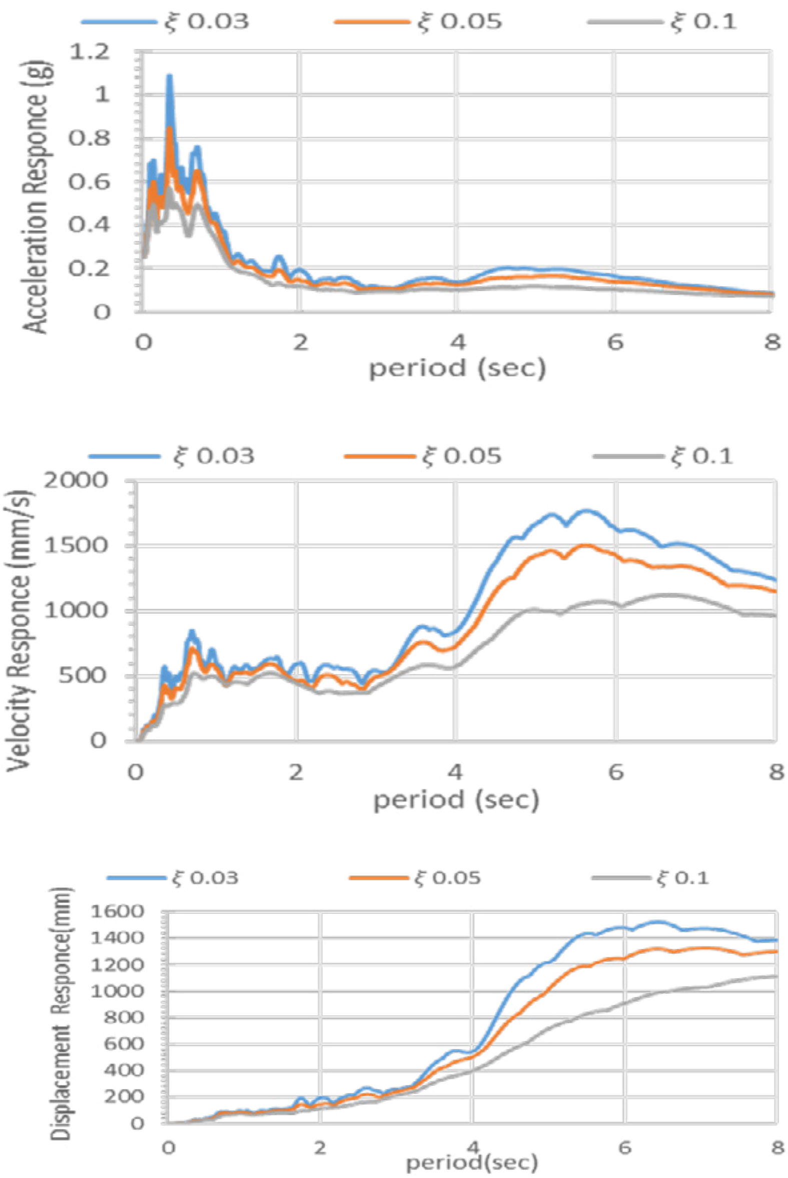

Figure 2. Acceleration, velocity, and displacement response spectrum of El Mayor-Cucapah (2010) earthquake

CHOSEN GROUND MOTION RECORDS OF SPECIFIC EARTHQUAKES

The data selected in this research are all shallow earthquakes in active tectonic areas (Shallow earthquakes are between 0 and 70 km deep) with a moment magnitude (Mw) in the range of (4-9) and all types of fault mechanisms were considered. Two soil types were chosen for this chapter with Vs30 (soil shear velocity) values of (100-300) m/s for the first type (soft soil) and (600-800) m/s for the second type (soft rocks). Those ranges were taken because most of the shear velocity values for the Iraqi soils stand in those ranges. And for every type of soil NFGM and FFGM records are considered. For the NFGM distance of < 15 km and the events had to have a noticeable peak-like record to be considered whereas for the FFGM distance

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of >50 km with no apparent peak was taken and this is to have a better comparison between the two ground motions.

By applying the conditions mentioned previously on the PEER search page four different groups of earthquake records are found, and the criteria for those groups as well as the number of events taken are listed in Table 1. To avoid the control of earthquakes with a large number of station records and satisfy the independent conditions, only one station was chosen for each earthquake event.

These earthquake event characteristics for groups 1 to 4 are listed in Tables 2 to 5 respectively. Groups 1 and 2 are built for Vs30 ranging from 100-300 m/s for both NFGM and FFGM. While groups 3 and 4 are built for Vs30 ranging from 600-800 m/s for both NFGM and FFGM. The fault type in all four groups was irrelevant to this research and that's why it was not specified.

Table 1. Ground motion groups' criteria

Group	Magnitude	Vs30	GM	No. of records
1	4-9	100-300	NFGM	15
2			FFGM	11
3		600-800	NFGM	20
4			FFGM	10

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Table 2. the first group's earthquakes events

NO.	Earthquake event	Year	Station	Magnitude	Rrup	Vs30
1	"Central Calif-02"	1960	"Hollister City Hall"	5.00	09.02	198.77
2	"Managua_ Nicaragua-02"	1972	"Managua_ ESSO"	5.20	04.98	288.77
3	"Hollister-03"	1974	"Hollister City Hall"	5.14	09.39	198.77
4	"Mammoth Lakes-09"	1980	"Hot Creek (HCF)"	4.85	12.01	295.93
5	"Westmorland"	1981	"Westmorland Fire Sta"	5.90	06.50	193.67
6	"Coalinga-02"	1983	"SUB (temp)"	5.09	12.31	270.41
7	"Imperial Valley-06"	1979	"EC County Center FF"	6.53	07.31	192.05
8	"Loma Prieta"	1989	"Gilroy Array #2"	6.93	11.07	270.84
9	"Chi-Chi_ Taiwan"	1999	"CHY101"	7.62	09.94	258.89
10	"Duzce_ Turkey"	1999	"Bolu"	7.14	12.04	293.57
11	"Tottori_ Japan"	2000	"TTR008"	6.61	06.88	139.21
12	"Parkfield-02_ CA"	2004	"Parkfield - Stone Corral 1E"	6.00	03.79	260.63
13	"Christchurch_ New Zealand"	2011	"Christchurch Resthaven "	6.20	05.13	141.00
14	"El Mayor-Cucapah_ Mexico"	2010	"El Centro Array #12"	7.20	11.26	196.88
15	"Darfield_ New Zealand"	2010	"TPLC"	7.00	06.11	249.28

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Table 3. the second group's earthquakes events

NO.	Earthquake	Year	Station	Magnitude	Rrup	Vs30
1	"Yorba Linda"	2002	"Calstate Bakersfield"	4.265	199.89	275.00
2	"Parkfield-02_ CA"	2004	"Milpitas Fire Station 4"	6.000	195.59	263.76
3	"El Alamo"	1956	"El Centro Array #9"	6.800	121.70	213.44
4	"Borrego Mtn"	1968	"LB - Terminal Island"	6.630	199.84	217.92
5	"Tabas_ Iran"	1978	"Kashmar"	7.350	194.55	280.26
6	"San Fernando"	1971	"Bakersfield - Harvey Aud"	6.610	113.02	241.41
7	"Landers"	1992	"Anaheim - W Ball Rd"	7.280	144.90	269.29
8	"Duzce_ Turkey"	1999	"Bursa Tofas"	7.140	166.07	289.69
9	"Hector Mine"	1999	"Newhall - Fire Sta"	7.130	198.13	269.14
10	"Chi-Chi_ Taiwan-03"	1999	"KAU066"	6.200	123.57	214.97
11	"Chi-Chi_ Taiwan-04"	1999	"KAU015"	6.200	109.50	233.21

https://doi.org/10.17993/3ctic.2023.121.29-44

Table 4. the third group's earthquake events

No.	Earthquake	Year	Station	Magnitude	Rrup	Vs30
1	"Morgan Hill"	1984	"Gilroy Array #6"	6.19	09.87	663.31
2	"L'Aquila_ Italy"	2009	"L'Aquila - Parking"	6.30	05.38	717.00
3	"10319993"	2008	"Hector"	4.14	06.41	726.00
4	"21522424"	2006	"Anderson Dam"	4.30	13.62	600.00
5	"Umbria Marche Italy"	1997	"Nocera Umbra-Salmata"	5.50	12.45	694.00
6	"Fruili_ Italy-03"	1976	"Tarcento"	5.50	06.30	629.08
7	"Chi-Chi_ Taiwan-02"	1999	"TCU089"	5.90	12.02	671.52
8	"Gilroy"	2002	"Gilroy Array #6"	4.90	14.39	663.31
9	"San Juan Bautista"	1998	"Hollister - SAGO Vault"	5.17	07.04	621.20
10	"14239764"	2006	"Joshua Ridge: China Lake"	4.02	13.75	623.00
11	"30226086"	2003	"Geyserville; Warm Springs Dam; Downstream"	4.00	08.38	760.00
12	"14282008"	2007	"Joshua Ridge: China Lake"	4.11	06.72	623.00
13	"21455182"	2005	"Atlas Peak"	4.14	12.85	652.29
14	"Sierra Madre"	1991	"Mt Wilson - CIT Seis Sta"	5.61	10.36	680.37
15	"Oroville-01"	1975	"Oroville Seismograph Station"	5.89	07.99	680.37
16	"Coyote Lake"	1979	"Gilroy Array #6"	5.74	03.11	663.31
17	"Anza (Horse Canyon)-01"	1980	"Anza - Terwilliger Valley"	5.19	12.28	617.78
18	"Mammoth Lakes-09"	1980	"USC McGee Creek"	4.85	09.18	653.56
19	"Coalinga-07"	1983	"Sulphur Baths (temp)"	5.21	12.11	617.43
20	"Hollister-04"	1986	"SAGO South - Surface"	5.45	12.32	608.67

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Table 5. the fourth group's earthquake events.

No.	Earthquake	Year	Station	Magnitude	Rrup	Vs30
1	"Chi-Chi_ Taiwan-05"	1999	"TAP081"	6.20	155.66	671.52
2	"San Simeon_ CA"	2003	"Frazier Park - Post Office"	6.52	186.24	643.91
3	"El Mayor-Cucapah_ Mexico"	2010	"Silent Valley - Poppet Flat"	7.20	167.65	659.09
4	"Niigata_ Japan"	2004	"SIT012"	6.63	156.93	710.53
5	"Darfield_ New Zealand"	2010	"ODZ"	7.00	180.55	638.39
6	"Christchurch_ New Zealand"	2011	"RDCS"	6.20	172.19	628.04
7	"Parkfield-02_ CA"	2004	"Saint Joseph's Hill"	6.00	181.51	690.97
8	"Chi-Chi_ Taiwan-02"	1999	"TTN025"	5.90	106.03	704.96
9	"Molise-01_ Italy"	2002	"Norcia"	5.70	183.86	678
10	"L'Aquila_ Italy"	2009	"Cassino"	5.40	116.68	630

ELASTIC RESPONSE OF NFGM AND FFGM

Elastic Seismic responses for the NFGM and FFGM are computed by scaling the chosen records in the four groups mentioned in the tables previously to a similar PGA (peak ground acceleration) which is chosen to be 0.3g then after processing all the data, the response spectra are then determined using Prism software as mentioned before. An average value of the SDOF response results of the spectral acceleration, spectral velocity, and spectral displacement ground motions for the earthquake events is done. Finally, the responses spectra are graphed using excel to better illustrate the results and to show the difference between NFGM and FFGM in acceleration, velocity, and displacement in elastic conditions.

Fig. 3 shows the differences in the Far-field ground motion and the near-fault ground motion for the soft soils (groups one and two). While Fig. 4 shows the difference in the Far-field ground motion and the near-fault ground motion for the soft rocks (groups three and four).

As illustrated above in Fig. 3 we can see that the general response of the near-fault ground motion in all three figures is much higher than the responses of far-field ground motion. Both the start of NFGM and FFGM are approximately equal in the short period where T is less than 0.3 sec. then, they start to depart from each other as the NFGM response starts to escalate until the end of the 4 sec period. It's obvious that the NFGM has the higher response on the structure with max NFGM acceleration, velocity, and displacement values being 18%, 182%, and 265% higher than the responses of FFGM for soft soils. As for the values of acceleration, velocity, and displacement of NFGM are 7%, 200%, and 501% higher than for FFGM for rocks as in fig. 4.

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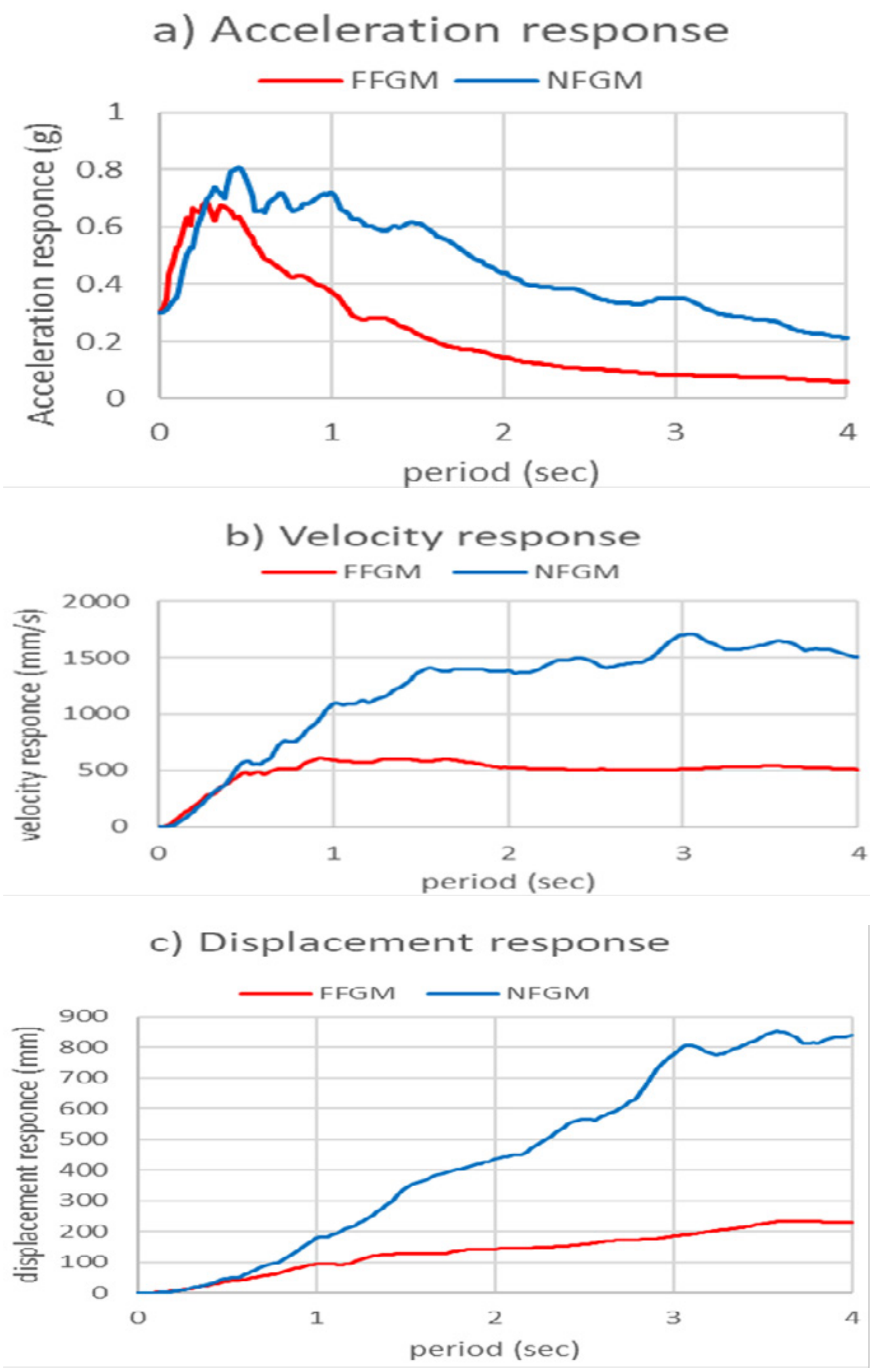

Figure 3. Comparison between NFGM and FFGM elastic response spectrum for the soft soils a) Acceleration response, b) Velocity response, and c) Displacement response

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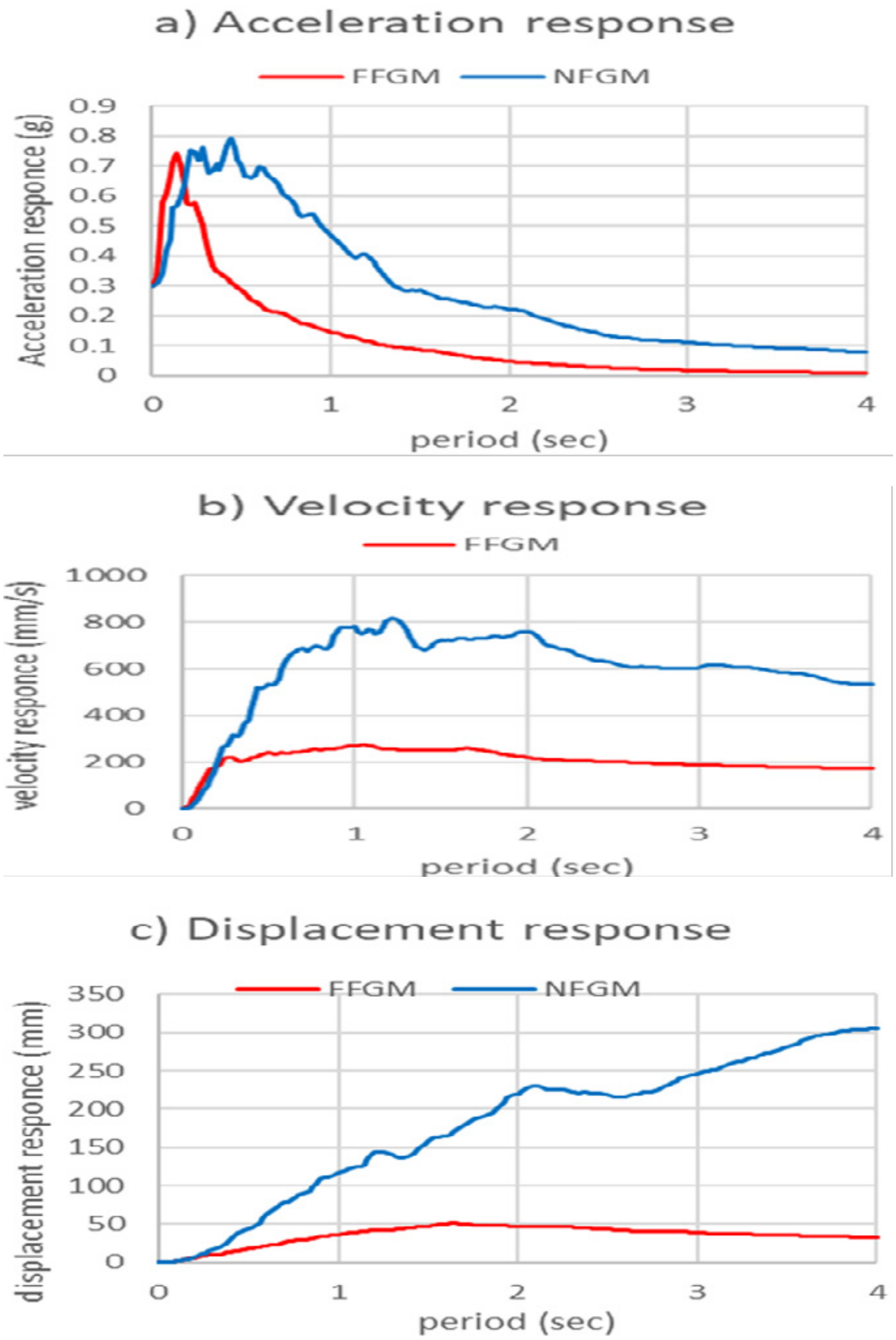

Figure 4. Comparison between NFGM and FFGM elastic response spectrum for the rock soil a) Acceleration response, b) Velocity response, and c) Displacement response

THE EFFECT OF SOIL TYPE ON SDOF ELASTIC SEISMIC RESPONSE

For the last two decades, the studies of numerous travelling wave solutions to the nonlinear development equations have appealed the attentions of many scientist from all over the world. Nonlinear evolution equations (NLEEs) are used in explaining several complex phenomena that ascend on daily basis in the various fields of nonlinear sciences, such as, quantum mechanics, plasmas physics, earthquake waves and so on [9].

Seismic waves can cause shaking which can result in damage or failure of the structures. There are many characteristics of free field motion that can be considerably modified by the Local soil deposits such as the amplitude, duration, and frequency content. The nonlinear response of the site is displayed during the transmittal of high-intensity ground motion waves through the horizontal soil layers [10].

The records of acceleration in the near-field region are attained during earthquakes at somewhat short distances from the desired site and records in the far-field regions occurring far from the site demonstrated the huge influence of geotechnical site conditions such as properties of soil layers and soil stratification on strong motion characteristics at the ground surface.

In the near-field zones, the soil characteristics are very dominant and affect the directional properties of the earthquake GM. So the forward-directivity ground motions will enforce high deformation and high energy demands on structures.

As we can see in Fig.5, we can notice that the soft soil responses are much higher than the responses of the rock because the ground motion gets amplified much more in the regions where the soils are soft thus resulting in a higher structural response.

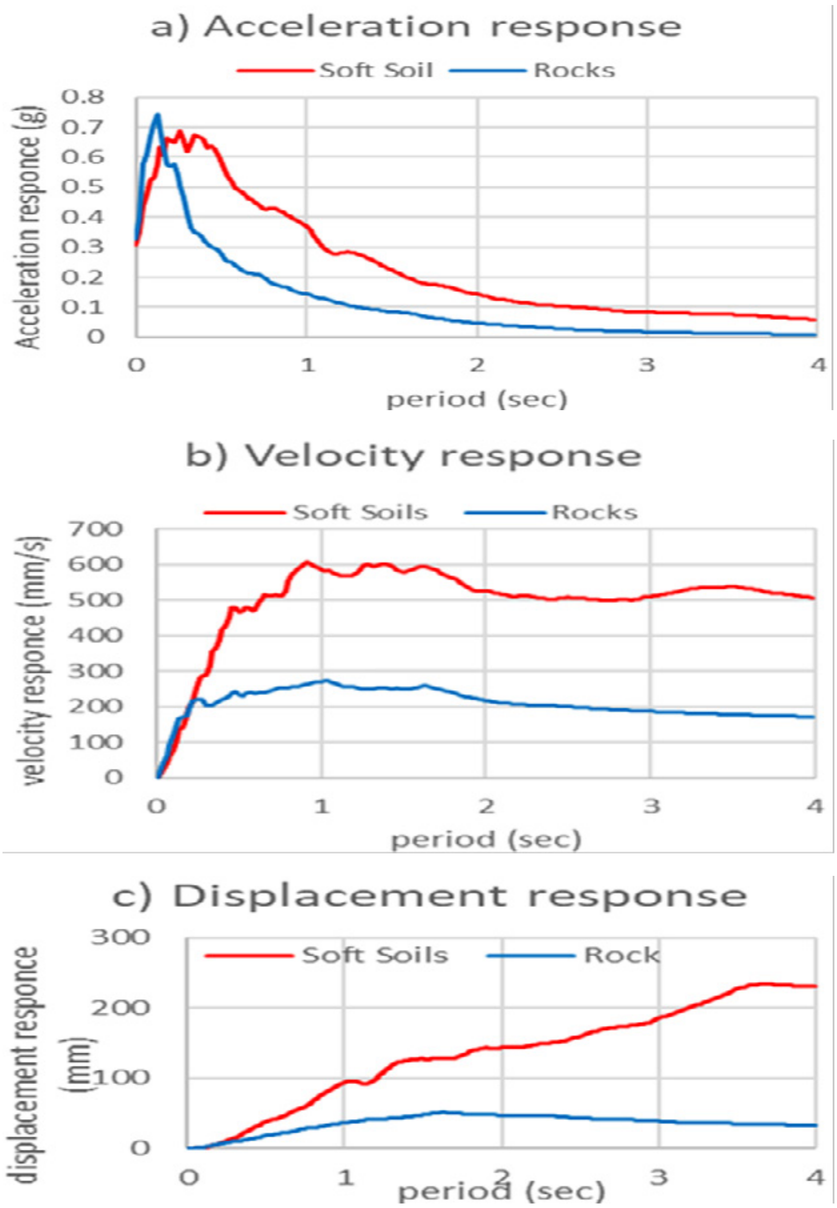

Figure 5. comparison between soft soils and rocks elastic response spectrum for NFGM in a) Acceleration response, b) Velocity response, and c) Displacement response.

CONCLUSIONS

from all the previous sections of the paper the following points are concluded:

1) The overall response of the near-fault ground motion in all three parameters (acceleration, velocity, displacement) is much higher than the responses of far-field ground motion in all conditions.

2) The start of NFGM and FFGM response graphs are roughly equal in the short period where T is less than 0.3 sec. after that, they begin to depart from each other as the NFGM response jumps to escalate until the end of the 4 sec period.

3) For both soft soils and rocks the NFGM responses are higher than the FFGM responses and the percentages of these differences are 18%, 182%, and 265% (acceleration, velocity, and displacement) higher for soft soils. As for the values of

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acceleration, velocity, and displacement of NFGM are 7%, 200%, and 501% higher than for FFGM for rocks.

4) In the near-field regions, the soil characteristics are extremely governing and affect the directional properties of the earthquake GM.

5) The soft soil responses are more advanced than the responses of the rock because the ground motion becomes amplified further in the regions where the soils are soft thus causing a higher structural response.

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