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Effect of Fill Material Density under Structures on Ground Motion Characteristics Due to Earthquake

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***Abstract*—**Due to limited areas and excessive cost of land for projects, backfilling process has become necessary. Also, backfilling will be done to overcome the un-leveling depths or raising levels of site construction, especially near the sea region. Therefore, backfilling soil materials used under the foundation of structures should be investigated regarding its effect on ground motion characteristics, especially at regions subjected to earthquakes. In this research, 60-meter thickness of sandy fill material was used above a fixed 240-meter of natural clayey soil underlying by rock formation to predict the modified ground motion characteristics effect at the foundation level. Comparison between the effect of using three different situations of fill material compaction on the recorded earthquake is studied, i.e. peak ground acceleration, time history, and spectra acceleration values. The three different densities of the compacted fill material used in the study were very loose, medium dense and very dense sand deposits, respectively. Shake computer program was used to perform this study. Strong earthquake records, with Peak Ground Acceleration (PGA) of 0.35 g, were used in the analysis. It was found that, higher compaction of fill material thickness has a significant effect on eliminating the earthquake ground motion properties at surface layer of fill material, near foundation level. It is recommended to consider the fill material characteristics in the design of foundations subjected to seismic motions. Future studies should be analyzed for different fill and natural soil deposits for different seismic conditions.

***Keywords*—**Fill, material, density, compaction, earthquake, PGA.

I. Introduction

In many construction sites, leveling sometimes is necessary under different types of constructions. Most of leveling works are needed while there is soft soils or problematic soils, or limited of lands in a special region. Leveling is performed using backfilling material of different thicknesses, types, and properties. In the region subjected to seismic motions from earthquakes, the using of fill material could affect the seismic motions behavior [1]-[3]. Fill material could change the spectral acceleration propagates from earthquake through soil layers till reach the foundation level [4]. This spectral acceleration can be changed from site to site depending on the fill material thickness or property above the natural soil and bed rock formation [5]. The present study is an attempt to predict the effect of using fill material of different characteristics on the earthquake motions at foundation level. In our study, layer of 60-m sandy fill material is used with three different densities. The three different compaction stages of fill material consist of very loose, medium dense, and very dense densities. Fill material is underlying by a natural clayey soil deposit of 240-m above the rock formation. The sum of both of the fill material and the natural soil deposit is of about 300-m depth above bedrock formation. Evaluation of site spectra and amplification influence for the different fill material densities compared to the base rock stratum is studied [6], [7]. The effect of fill material on the characteristics of a higher strong earthquake motion was carried out assuming a horizontally stratified soil deposits and vertically propagating seismic waves. Also, the fill material property is assumed to remain constant in horizontal direction for each compaction ratio. Generation of acceleration time histories, frequency content, spectral accelerations, and amplification factors related to bed rock are performed for each fill material density above bedrock, using SHAKE91 program [8]-[11]. The control motions have been specified at the bedrock as datum for the analysis. The zero-period ground acceleration for these earthquakes is assumed as 0.10 g during this study. The recording data at surface fill material normally reflect the seismic characteristics due to the different degrees of compaction of fill material. Therefore, to obtain the response of any fill material soil deposit, the following items should be studied: determination the fill material and natural soil properties and topography, determination of the underlying rock configuration, dynamic module and damping ratio properties of the fill material, natural soil and rock formations, the characteristics of earthquake motions.

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II. Soil and Earthquake Records Used in the Study

A. Soil Surface Topography

To conduct our study, three different compaction ratios of the fill material are used in the analysis. The fill material is chosen to be compacted to a depth of 60 m above the natural soil of the site. The compaction ratios of the fill material are chosen in the present study to be consisted of three different densities of very loose, medium dense, and very dense categories, used separately. The fill material consists of sandy soil deposit compacted above the natural clayey soil till it reaches the foundation level. This was done to represent the actual case of execution of any higher thickness of fill material at the site. According to that, different shear wave velocities were used to represent the actual compacted behavior of the sandy formation above the natural soil deposit. The shear wave velocities were 140, 285, and 430 m/s for the three different compaction ratios of fill materials having densities of very loose, medium dense, and very dense, respectively. The total depth of soil formation above bed rock was chosen to be of 300 m in depth (includes both the fill material which is 60 m in height and the natural clayey soil deposit which is of 230 m in height). Geotechnical data regarding to the dynamic module and damping ratio properties of the both soil materials are chosen from previous researches [12]-[14]. Table I shows the dynamic module and damping ratio for fill material, while Table II shows the corresponding data for the natural clayey soil deposit above bed rock formation.

B. Earthquake Ground Motion Records

A strong earthquake ground motion of a peak acceleration of 0.35 g is used in the present study. The earthquake records are normalized to 0.1 g for comparison between the surface layer below the foundation and at the outcrop (bedrock layer). Then, the spectral displacement curves are plotted for 5% damping. Table III shows the El-Centro (ELC-S60E) earthquake records used in the analysis.

III. Study and Analysis

Our study was performed to get the effect of using different compaction ratios of fill material on the seismic ground motions and how the waves will transfer to the upper surface layers. Three different compaction ratios of fill material are used in the study to predict the change of the earthquake time history acceleration, frequency content, spectrum acceleration curves, amplification factors, and Fourier amplitude between bed rock and surface fill layer.

A. Earthquake Time History

The selected earthquake motion is used as input motion at the bed-rock formation. Then, the acceleration time histories are then computed at surface layer of each thickness layer of the fill material using shake program. Earthquake motion at bed rock (outcrop) is illustrated in Fig. 1, while Figs. 2 (a)-(c) shows the varying time history acceleration of earthquake wave propagation at surface layer of fill material for the three different densities of fill material, separately. By comparing Figs. 1 and 2, it was obvious that the acceleration time histories had been filtered during passing through the natural soil deposit and the fill material till the surface layer.

B. Earthquake Response Spectrum

The response spectrums are plotted in Figs. 3 (a)-(c) for fill material of very loose, medium dense, and very dense, respectively in comparison with bed rock. These figures give indication of the potential effects of the ground motions with the different compaction densities of the fill material. Comparing these three figures for the three densities, it was illustrated that the acceleration at zero-time periods was reduced by using the fill material. The reduction in the spectrum was ranged between 13%, 20%, and 23% for the three fill material densities of very loose, medium dense, and very dense, respectively compared to the control motion at the bedrock. Fig. 4 illustrated the comparison between the spectrum acceleration behaviors for the three different densities of fill material with time. Amplification factors between surface layer and bed rock are founded in decreasing status with increasing the fill material density or compaction ratio as shown in Fig. 5.

TABLE I
Dynamic Module and Damping Ratio of Fill Material (Sandy Soil)

Modulus of Sand		Damping of Sand	
Strain	G/G max	Strain	Damping
0.0001	1.000	0.0001	0.240
0.0003	1.000	0.0003	0.420
0.0010	0.990	0.0010	0.800
0.0030	0.960	0.0030	1.400
0.0100	0.850	0.0100	2.800
0.0300	0.640	0.0300	5.100
0.1000	0.370	0.1000	9.800
0.3000	0.180	0.3000	15.50
1.0000	0.080	1.0000	21.00
3.0000	0.050	3.0000	25.10
10.0000	0.035	10.000	28.00

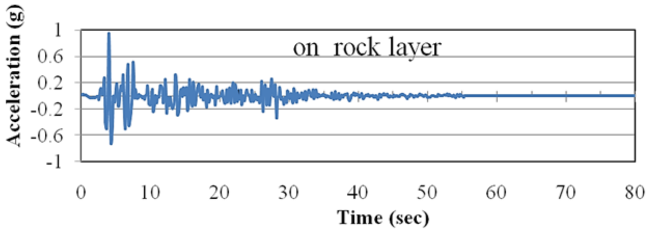
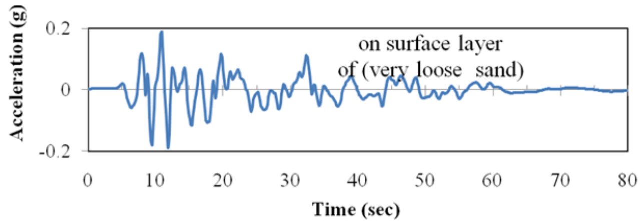
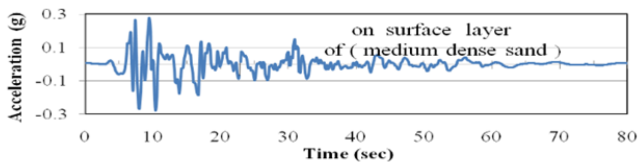


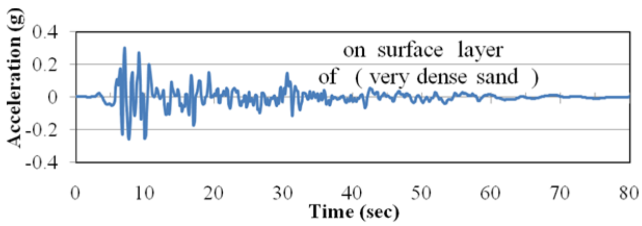
Fig. 1 Acceleration time history of earthquake at bedrock- outcrop



(a) Very loose fill material



(b) Medium dense fill material



(c) Very dense fill material

Fig. 2 Acceleration time histories for fill material at surface layer of different densities

TABLE II
DYNAMIC MODULE AND DAMPING RATIO OF SOIL (CLAYEY DEPOSIT)

Modulus of Sand		Damping of Sand	
Strain	G/G max	Strain	Damping
0.003	1.000	0.003	1.600
0.004	0.990	0.004	1.800
0.005	0.985	0.005	2.100
0.006	0.980	0.006	2.300
0.007	0.970	0.007	2.400
0.008	0.965	0.008	2.700
0.009	0.960	0.009	3.000
0.010	0.955	0.010	3.700
0.020	0.905	0.020	4.200
0.030	0.850	0.030	4.600
0.040	0.815	0.040	5.000
0.060	0.750	0.060	5.200
0.080	0.710	0.080	5.700
0.100	0.670	0.100	6.100
0.200	0.565	0.200	8.000
0.300	0.480	0.300	9.200
0.500	0.385	0.400	10.100
0.600	0.350	0.500	10.900
0.800	0.300	0.700	12.200
1.000	0.250	1.000	13.500

TABLE III
CHARACTERISTICS OF EL-CENTRO EARTHQUAKE GROUND MOTION

Peak Acceleration (% of g)	Ground Velocity (mm/sec)	Ground Displacement (mm)	Duration Time (sec)
0.348	334	124	55.76

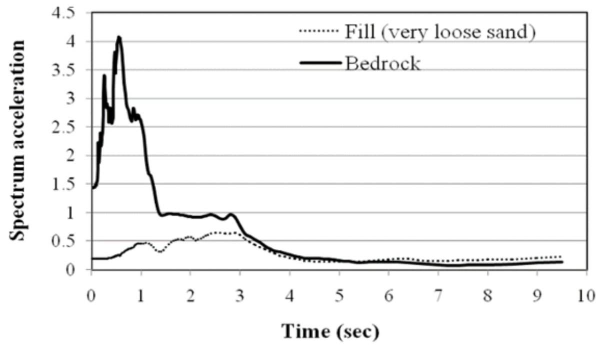


Fig. 3 (a) Comparison between acceleration response spectrums at surface of very loose fill material compared to bedrock

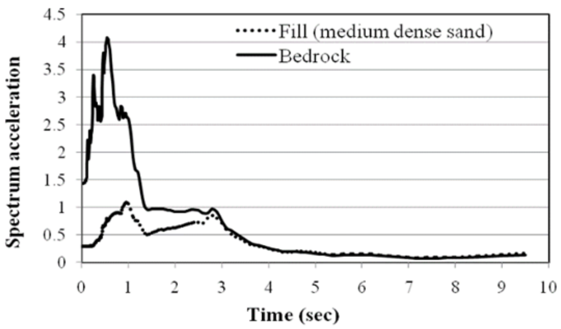


Fig. 3 (b) Comparison between acceleration response spectrums at surface of medium dense fill material compared to bedrock

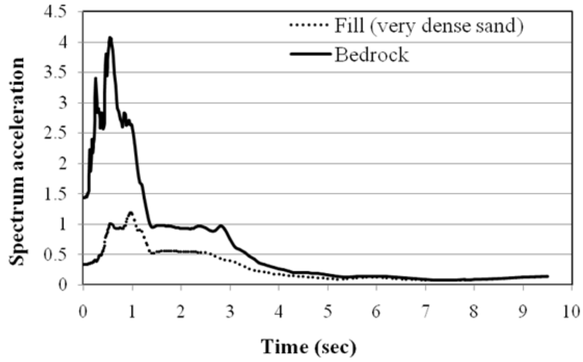


Fig. 3 (c) Comparison between acceleration response spectrums at surface of very dense fill material compared to bedrock

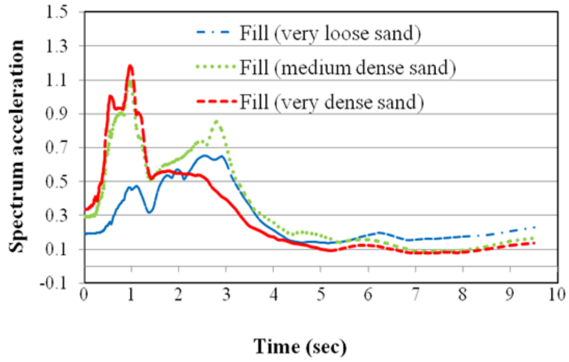


Fig. 4 Comparison between acceleration response spectrums at surface for the different densities of fill material

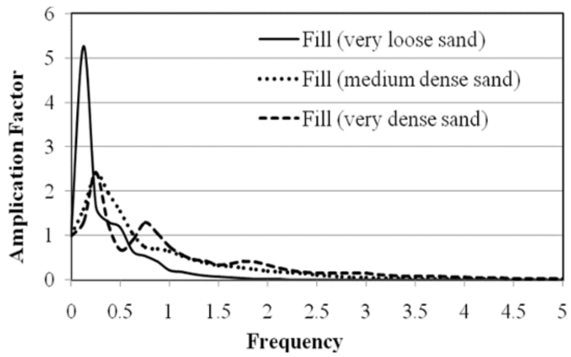


Fig. 5 Amplification spectrum between bed rock and fill material at surface for different compaction ratios

C. Earthquake Fourier Spectrum

As shown in Figs. 6 (a)-(c), the Fourier spectrum is a plot of amplitude versus frequency for fill material of different compaction ratios, respectively with that for bed rock formation. The Fourier amplitude spectrum curves illustrate the frequency content of the motion for each fill material density. It is appeared that there is a big difference in the amplitude by using fill material compared to bed rock data. Thus, using fill material will lower the earthquake Fourier spectrum amplitude and its frequency due to the far distance from rock seismic motion. It is obvious that using of the fill material in general lowers the frequency of seismic motion spectrum amplitude at surface layer.

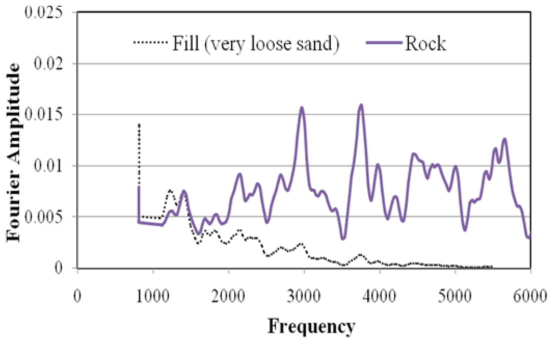


Fig. 6 (a) Fourier spectrum between bed rock and very loose fill material of 60-m thickness

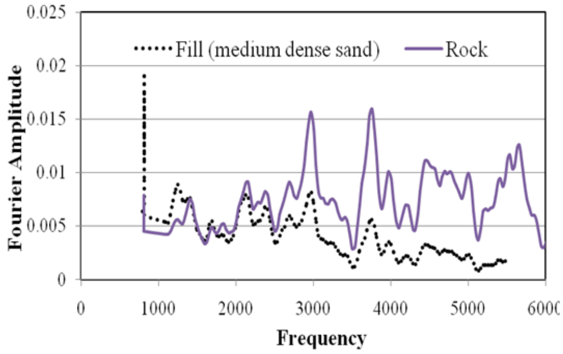


Fig. 6 (b) Fourier spectrum between bed rock and medium dense fill material of 60-m thickness

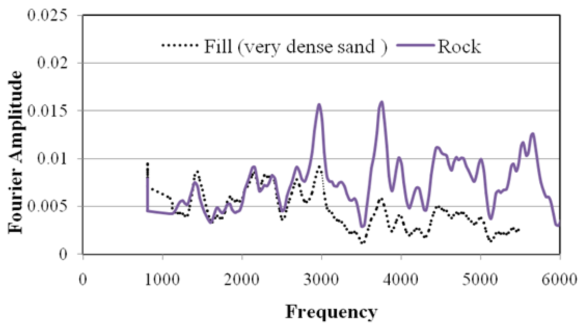


Fig. 6 (c) Fourier spectrum between bed rock and very dense fill material of 60m thickness

IV. Conclusion

Using fill material of different compaction ratios under structures and above natural soil deposit underlain by bed rock formation for construction will affect the seismic motion characteristics at surface. The present study illustrated the following issues:

(1) The acceleration time histories were filtered during passing through the natural soil deposit and then through the fill material.

(2) The reduction in the spectrum was ranged between 13%, 20%, and 23% for the three fill materials of very loose, medium dense, very dense, respectively at zero time periods compared to that for control motion at the bedrock.

(3) Amplification factors between the surface layers of fill material and the bed rock stratum decreased with using the fill material. The higher reduction in amplification factors was achieved in the case of using the very dense compacted layers of fill material.

(4) Using the fill material will lower the earthquake Fourier spectrum amplitude and its frequency. According to that, the fill material will lower the frequency of seismic motion spectrum amplitude at surface layer below foundation.

According to that, site characterization should be taken into consideration at seismic locations regions where design structures against earthquake and especially fill material are used with different compaction ratios.

Authors recommended for more additional further studies which should be done taking into consideration the effect of using different characteristics of fill material and different site conditions.

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