EFFECT OF IMPROVING SOIL AS A COUNTERMEASURE FOR LIQUEFACTION

O.Mavituna[1] and B. Teymur[2]

[1] *Civil Engineer, Baytur, Almaty Site, Kazakhistan*
[2] *Assistant Professor, Faculty of Civil Engineering, Istanbul Technical University, Istanbul, Turkey*
Email: bteymur@ins.itu.edu.tr

ABSTRACT :

Liquefaction causes soil failures and therefore damages to structures. Liquefaction prevention is usually done by estimating the liquefaction susceptibility and then reducing or preventing damage by evaluating its effects. Prevention of liquefaction methods are based usually on improving the soil properties like the density. In this paper, the effect of improving soil properties especially its density as a countermeasure for liquefaction is evaluated. For this purpose, some liquefiable soil profiles which belong to the city of Adapazarı were analyzed using the strong motion data from 1999 Kocaeli Earthquake and its aftershock on September 13th by employing the Equivalent-linear Earthquake site Response Analyses (EERA) program. Soil profiles were analyzed initially in their natural conditions and then analyzed as if improvement was done. According to the analysis results, before and after soil improvement, changes in acceleration, shear stress-strain and response spectra are compared. The analysis results are evaluated and the effectiveness of densification is discussed.

KEYWORDS: Densification, Kocaeli earthquake, liquefaction

1. INTRODUCTION

Liquefaction is one of the most important, interesting and discussed subject in geotechnical earthquake engineering. Although the marks of liquefaction were observed after many earthquakes in the past and described as a term in 1936 by Cassagrande, systematic research on liquefaction did not start until after the two devastating earthquakes in 1964: Alaska and Niigata earthquakes. After that time, 1971 San Fernando, 1989 Loma Prieta, 1995 Kobe, 1999 Kocaeli, 1999 Chi – Chi, 2001 Bhuj (India), 2005 Pakistan and 2008 Wenchuan (China) earthquakes continue to show the destructive effects of liquefaction. In all these earthquakes, settlements, lateral spreading, lateral displacements were observed due to liquefaction and severe damages occurred in structures. These earthquakes emphasize the necessity of soil remediation against liquefaction. As the effects of liquefaction can be destructive, research is carried out to assess liquefaction potential and liquefaction prevention methods.

Although today lots of remediation techniques are used, there are a few case histories showing the effectiveness of them against liquefaction. Past experiences show that remediation techniques like reinforcement, densification, grout injection and stone columns reduce the liquefaction risk, but not remove the risk at all. In this paper, densification is studied, two different highly liquefiable soil profiles which belong to the city of Adapazarı were analyzed using the strong motion data from 1999 Kocaeli Earthquake and its aftershock on September 13th using Equivalent-linear Earthquake site Response Analyses (EERA, 2000) program. 1999 Kocaeli Earthquake and its aftershock had magnitudes of 7.4 and 5.8 respectively. Soil profiles were analyzed initially in their natural conditions and then analyzed as if densification was done. The analysis results are evaluated and the effectiveness of densification is discussed.

2. ANALYSIS OF SOIL PROFILES

In 1999, Kocaeli and the Marmara region of Turkey were shaken by an earthquake with a moment magnitude of 7.4 on the Richter scale with its epicentre in Gölcük. Damage due to liquefaction, surface subsidence, and fault rupture were observed. Peak lateral ground accelerations of 0.41g were measured in Adapazarı. The Adapazari city is located on an alluvial plain which overlies Quaternary Age alluvial deposits with alternating layers of gravel, sand, silt and clay. The groundwater level is shallow and between 0.5m to 3.0m below ground level.

During the 1999 Kocaeli Earthquake and its aftershock in Golcuk on September 13th , lots of strong motion stations recorded the acceleration data. In this paper, strong motion data used in analyses was obtained from Bursa Car Factory (BUR) which was logged by Kandilli Observatory and Earthquake Research Institute. BUR station was the closest station to Yalova which was one of the most damaged regions. The two highly liquefiable soil profiles used in analyses were taken from the studies of Sancio (2003) in Adapazarı. Idealized soil profiles are shown in figure 1. Soil profile B consists of loose clayey silt layer followed by loose silt, soft clay, medium dense sandy silt and loose silt layers. Soil profile C consists of soft silty clay, loose silt, medium dense sandy silt and soft clay layers. For the analysis, the soil profile was extended to 30m where it was assumed, it was resting on rock, and Standard Penetration Test (SPT)-N values were increased by 10 for loose layers and by 5 for dense layers to analyze profile as if densification was done. These increments were decided based on work done by Duzceer and Gokalp (2002) where they present the results of SPTs done to soil before and after stone columns were constructed as soil improvement. This could be seen in figure 2. Figure 3 shows the change of shear wave velocity calculated from the SPT-N values according to Turkish design code, with depth for the natural and densified soil conditions. As seen in the figure when the soil profile was densified, shear wave velocities have increased with depth.

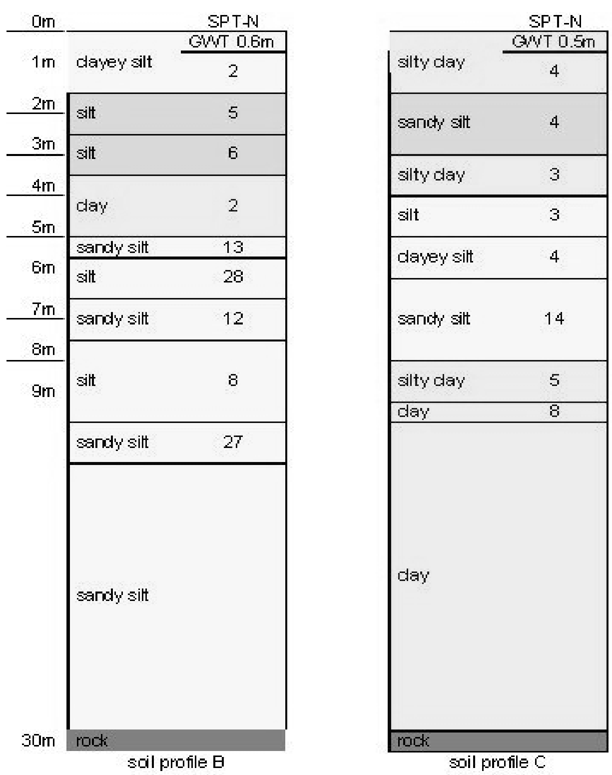


Figure 1 Idealized soil profiles B and C (modified after Sancio, 2003)

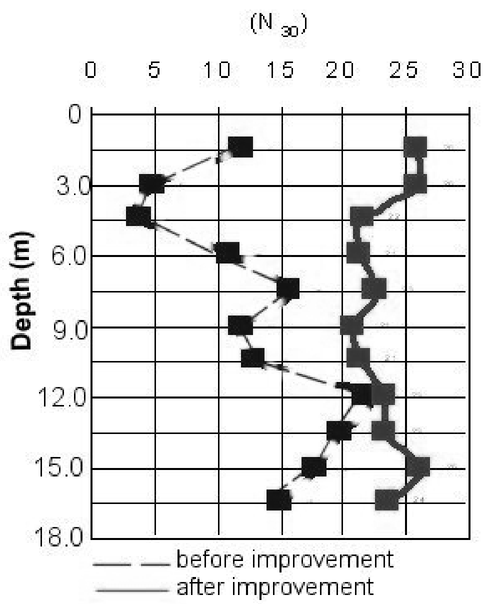


Figure 2 SPT results before and after stone column application (after Duzceer and Gokalp, 2002)

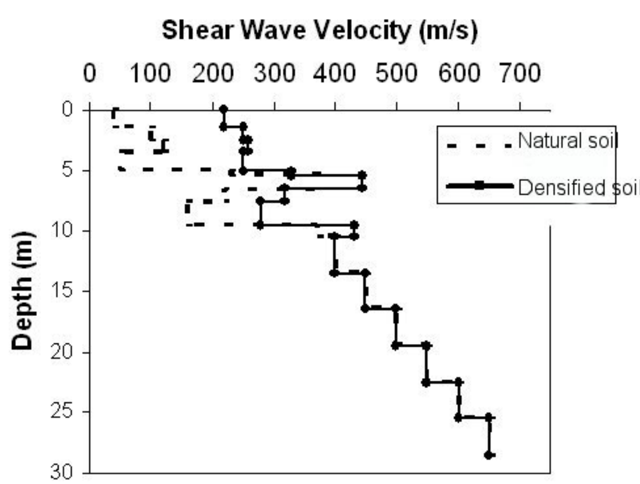


Figure 3 Change of shear wave velocity of natural and densified soil profile B

2.1. Analysis of Soil Profiles with 1999 Kocaeli Earthquake BUR Strong Motion Data

The acceleration time history obtained from the strong motion data is shown in figure 4. Both of the N-S and E-W components of this station recorded peak ground acceleration as 0.1 g during the earthquake. This was used for the analysis and was input as outcrop value. For the natural soil and dense soil conditions on profiles B and C, acceleration-time plots are presented in figure 5. Decrease in volume of spaces between soil particles by densification means less deformation during an earthquake which also means elimination of liquefaction risk. The acceleration was compared in figure 5 for the natural and improved ground conditions using the soil profile given in figure 1. As can be seen from the acceleration-time history, peak acceleration has decreased after densification. Because of the fact that acceleration is the trigger mechanism of liquefaction, decrease of this after improvement shows the success of densification against liquefaction. In soil profile B as seen in figure 5a, the input acceleration has amplified to 0.22g and after densification; it has amplified to 0.14g. In the dense soil, only

30% amplification has occurred. Therefore the soil improvement process has worked in decreasing the acceleration observed at surface. In soil profile C, acceleration has amplified to 0.18g and after densification only to 0.12g where only 10% amplification has occurred in the denser soil as seen in figure 5b.

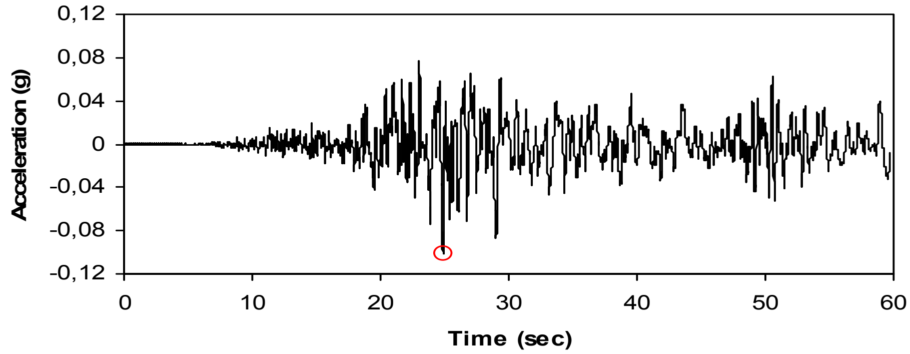
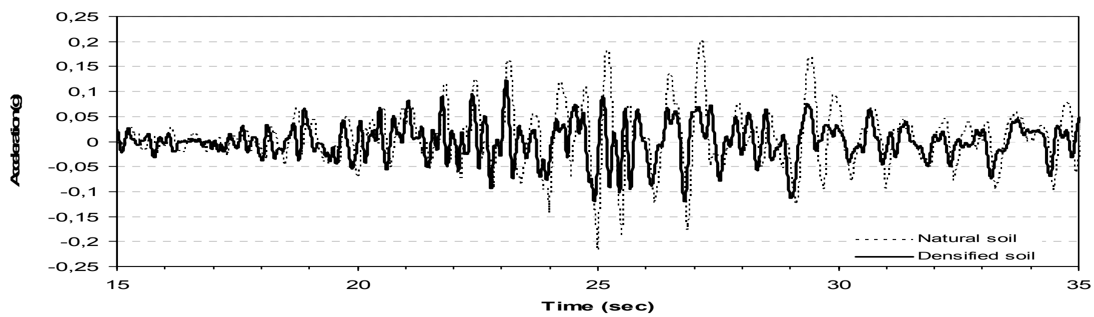
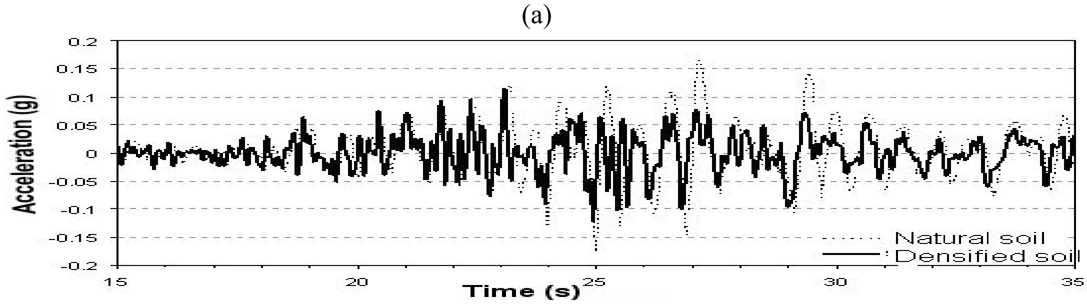


Figure 4 Acceleration data obtained from Bursa Car Factory(BUR) strong motion station



(a)



(b)

Figure 5 For the natural soil and dense soil conditions acceleration – time graphs for a) soil profile B and b) soil profile C.

For the natural and dense soil conditions on profile B, shear stress – strain plots are drawn in figure 6. Figure 6 shows the ratio of stress – strain decreasing and the slope of the curve increasing after densification. The reason of such an increase in slope is the increase of shear modulus by densification. For the natural soil and dense soil conditions on profiles B and C, for 5% damping, response spectra is presented. They are compared with the design response spectra given in the Specifications for Structures to be Built in Disaster Areas (Turkish Design Code, 2007) in figure 7. Figure 7 shows that response spectra changes with densification, but still stays over the design response spectra. Decrease in peak spectral acceleration and its period means elimination of liquefaction risk.

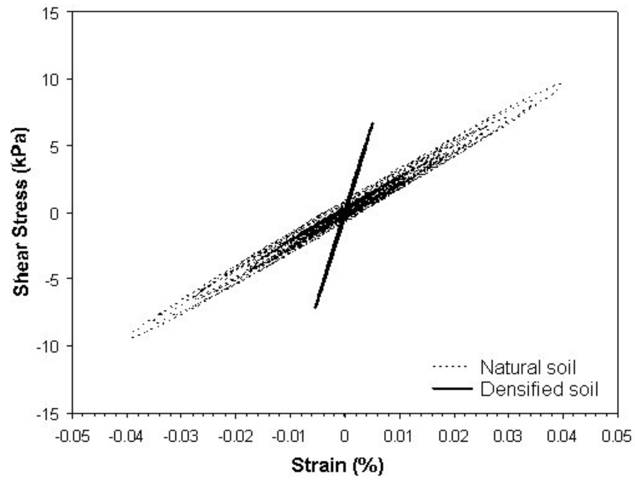
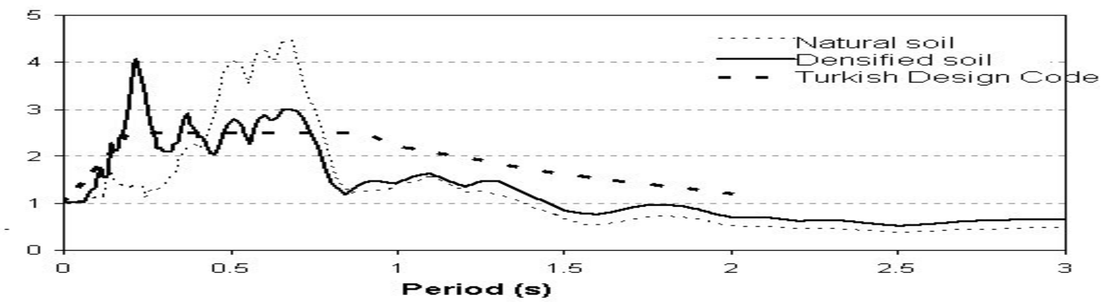
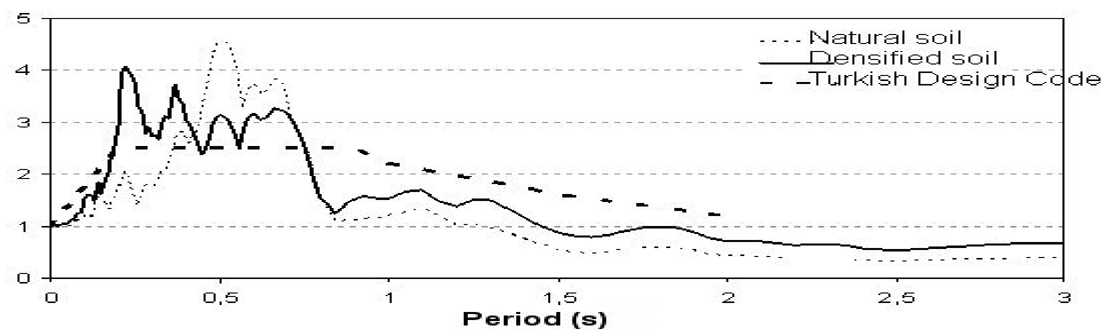


Figure 6 For the natural soil and dense soil conditions shear stress – strain plot for soil profile B



(a)



(b)

Figure 7 For the natural soil and dense soil conditions response spectra compared with design response spectra of Turkish Design Code (2007) (5% damping), a) soil profile B and b) soil profile C.

2.2. Analysis of Soil Profiles with September 13th Aftershock BUR Strong Motion Data

Peak ground acceleration recorded in BUR station in the aftershock was 0.05 g which is used as an input in the analysis. Recorded acceleration data is shown in figure 8. For the natural soil and dense soil conditions on profiles B and C, acceleration – time plots are drawn in figure 9 which show that peak acceleration decreases after densification. In soil profiles B and C, the input acceleration has amplified to 0.1g and after densification; it has amplified to 0.07g and 40% amplification has occurred. Therefore the soil improvement process has worked in decreasing the acceleration observed at surface.

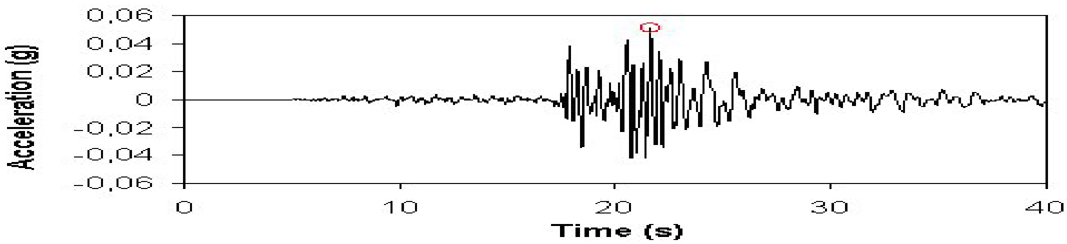
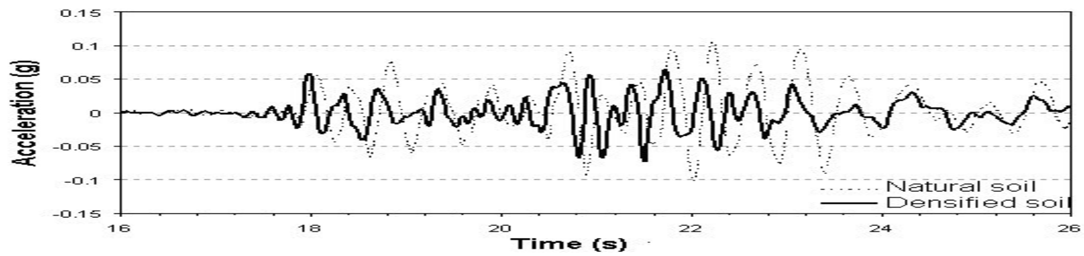
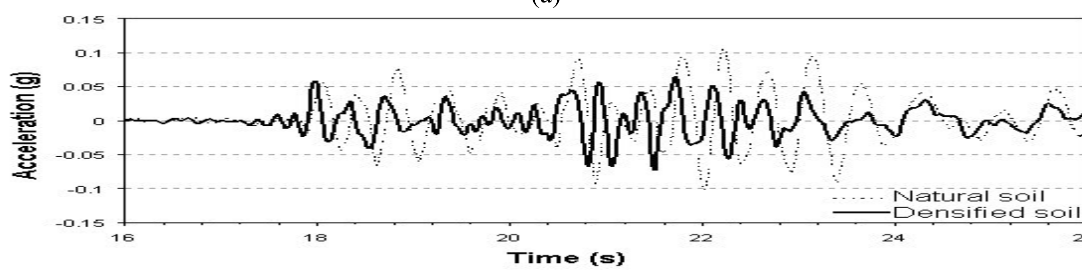


Figure 8 Acceleration data obtained from BUR strong motion station



(a)



(b)

Figure 9 For the natural soil and dense soil conditions acceleration – time graphs for a) B profile and b) C profile

For the natural soil and dense soil conditions on profile C, shear stress – strain plots are drawn in figure 10. Figure 10 shows that peak strain decreases after densification and that ratio of stress – strain decreases, and the slope of the curve increases after densification. The less strong earthquake has shown the same behaviour as in the stronger earthquake.

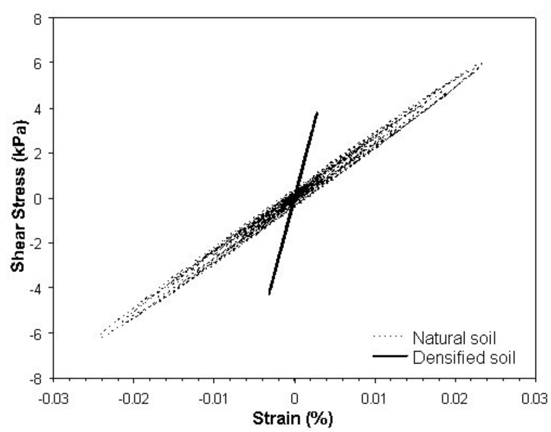
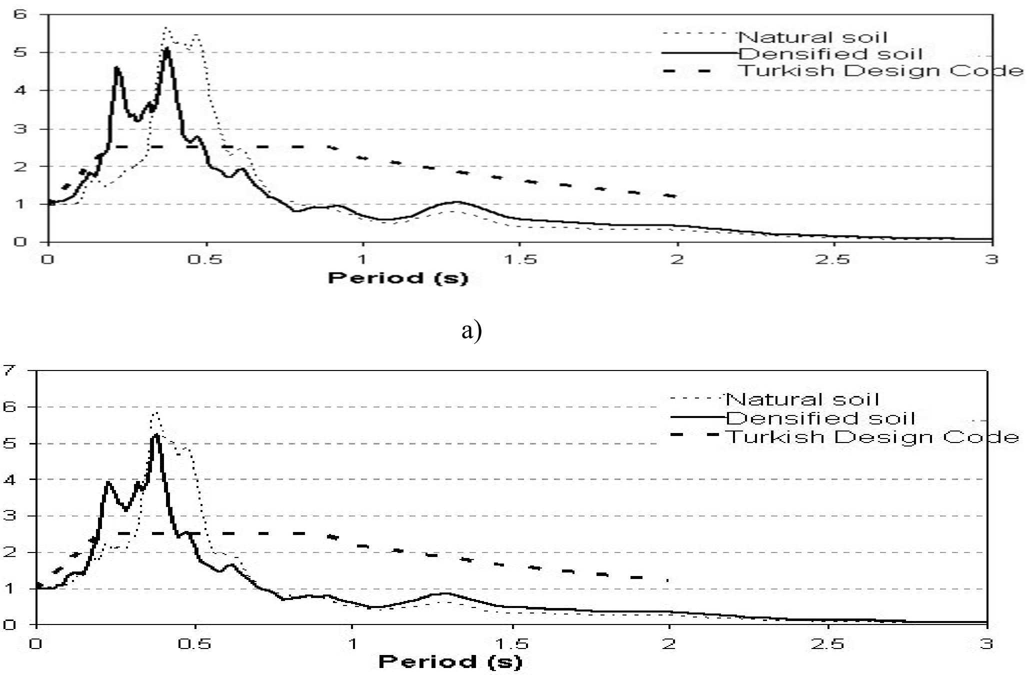


Figure 10 For the natural soil and dense soil conditions shear stress – strain plot for soil profile B

For the natural soil and dense soil conditions on profiles B and C, spectral acceleration – period plot (for 5% damping) is drawn in figure 11. The design response spectra for 5%damping, which is given by the Turkish Design Code is also drawn in figure 11. Figure 11 shows that peak spectral acceleration and its period decreases, but stays over the design response spectra. This behaviour is in agreement with the one observed in the stronger earthquake.



b)

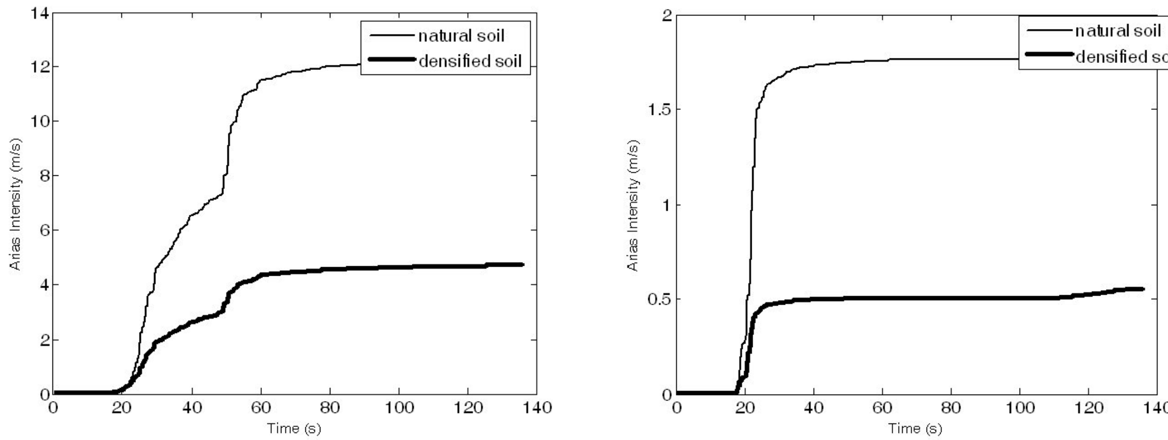
Figure 11 For the natural soil and dense soil conditions normalized response spectra compared with design response spectra of Turkish Design Code (2007) for a) soil profile B and b) soil profile C.

3. DISCUSSIONS

Arias Intensity values were calculated to represent earthquakes delivering the same amounts of energy or having the same earthquake intensity for the different soil profiles. The Arias Intensity index is the measure of the total energy which is delivered during an earthquake to a unit mass of soil. This is expressed following Arias (1970) as:

$$I_a = \frac{\pi}{2g}\int_0^T a^2(t)dt \qquad (3.1)$$

where T is the total duration of the earthquake and a(t) is the acceleration at time, t. The energy build-up can be seen in figure 12, which were constructed by Arias intensity of accelerations. Using the figures a comparison of energy distribution can be made and it can be seen that densified soil has less intensity than a natural soil. When the earthquake strengths are compared, in the less strong earthquake, intensities decrease as well. As the soil is compacted, Arias intensity has decreased by 30% in a strong earthquake and in the less strong earthquake, this has decreased by 35% for soil profile C.



(a) (b)

Figure 12 Arias Intensity graphs for BUR signals for a) Kocaeli earthquake and b) its aftershock for soil profile C.

Settlement percentages were calculated before densification, and it was found that 7% settlement would occur in the soil profiles, and after the improvement this has reduced to 2.4% which shows the success of soil improvement.

4. CONCLUSIONS

The aim of this study was to obtain the effectiveness of densification which is widely used for liquefaction remediation. For this purpose, two different highly liquefiable soil profiles which belong to the city of Adapazarı were analyzed using the strong motion data from 1999 Kocaeli Earthquake and its aftershock. Soil profiles were analyzed initially in their natural conditions and then analyzed as if densification was done. According to the analysis results, after the densification, it could be seen that liquefaction risk has decreased. In strong and weak earthquakes the behaviour of liquefiable soils were compared. Liquefaction prevention with densification improves the soil's properties and decreases the liquefaction potential. Data show that percentage of liquefaction risk has reduced by 20% in both earthquakes, and it was observed that the effect of densification is more effective in a less strong earthquake than a stronger one.

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