Behaviour of Sandy Slopes under Earthquake Loadings

B. Teymur & O.T. Yakar
Istanbul Technical University, Istanbul

SUMMARY:
Slope stability is one of the major research subjects in geotechnical engineering. Slope failures can be triggered by static and dynamic conditions. When liquefaction occurs due to repeated shear stresses as a consequence of earthquakes, it results in a quick loss in shear strength of soils. Liquefaction can lead to various damages. In this paper, behaviours of the slopes under the seismic loads have been investigated. In this paper, slopes with different relative densities, angles and ground water table levels, but with the same height are investigated with the 1999 Kocaeli earthquake acceleration data. Displacement results achieved show that relative density of the soil is more effective in the slope instability than the ground water table level. As the angles of the slopes increase, deformations encountered increase as well. On the light of the analysis deformations and spectral accelerations of the slopes have been obtained and the differences in the results are discussed.

Keywords: liquefaction, sand, slope, seismic loads

1. INTRODUCTION

When an earthquake occurs, ground shakings cause slopes to fail, soils to liquefy and damages to structures. One of the reasons that soils fails is the liquefaction of soils. When liquefaction occurs due to repeated shear stresses as a consequence of earthquakes, it results in a quick loss in shear strength of soils. In recent earthquakes slope failures due to earthquakes and liquefaction was observed. Especially in 1999 Kocaeli earthquake, liquefaction, loss of bearing capacity, differential settlements and slope failures were observed. In this paper, slopes with different relative densities, angles and ground water table levels, but with the same height are investigated with the 1999 Kocaeli earthquake acceleration data. On the light of the analysis deformations and spectral accelerations of the slopes have been obtained and the differences in the results are discussed.

2. NUMERICAL ANALYSIS

Newmark (1965) assumes that a limiting frictional angle exists between the model block and slope, and that certain amount of acceleration is needed for the slope to fail. In this study, Quake/W and Slope/W programs were used in the numerical analysis. Quake/W and Slope/W programs use Newmark model block analysis and in the dynamic analysis pore pressure values are given as well. In this study 0.50mx0.50m mesh system is used. In the static analysis part, at the bottom of the soil profile two of the freedoms in x and y direction are removed or it is fixed. With depth, only the movement in the x direction is not allowed. In the dynamic analysis, equivalent linear model is used to model the sand and the model can take into account the density of soil, shear modulus change with depth and the damping functions. In the dynamic analysis part of the program, at the bottom of the soil profile two of the freedoms in x and y direction are removed. In the analysis done, certain amount of deformation was applied to the supports at the base of the model so as to mimic the volumetric change that would occur after the earthquake. The deformation amount was determined according to

Tokimatsu and Seed (1987) where the volumetric change ratios are presented in saturated sands after liquefaction.

Input parameters given in Table 2.1 are used in the analysis. Each slope has a height of 8 m, the ground water table (GWT) level is either at the surface or half height of the slope. Slope angles changing between 10° to 25° with different relative densities varying between 35 to 85% sandy soil slopes were used in the analysis where the acceleration acquired at Sakarya station during the 1999 Kocaeli earthquake was used. Displacement values and liquefaction potential were used to determine whether density or slope angles affect the slope stability most during earthquakes.

Table 2.1. Parameters used in the analysis

Model No	Slope Angle(°)	Width of the slope	Place of GWT	D_r (%)	γ_d (kN/m^3)
1	10	45	surface	35	18
2	10	45	half height	35	18
3	10	45	surface	50	20
4	10	45	surface	85	25
5	15	30	surface	35	18
6	15	30	half height	35	18
7	15	30	surface	50	20
8	15	30	surface	85	25
9	20	22	surface	35	18
10	20	22	half height	35	18
11	20	22	surface	50	20
12	20	22	surface	85	25
13	25	17	surface	35	18
14	25	17	half height	35	18
15	25	17	surface	50	20
16	25	17	surface	85	25

Figure 2.1 shows the acceleration time graph for the Kocaeli earthquake recorded at Sakarya station. Kocaeli earthquake was a 7.4 magnitude earthquake which occurred in the Northern Anatolian Fault line with 0.42g acceleration. The earthquake effected Marmara region.

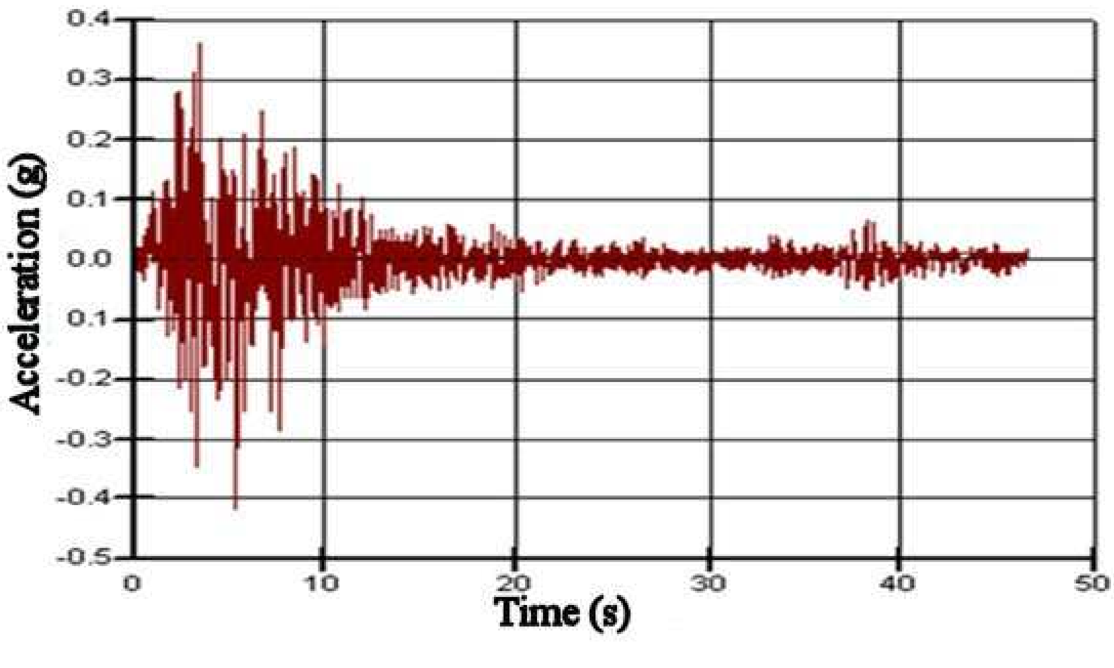

Figure 2.1. Acceleration-time graph for the Kocaeli earthquake recorded at Sakarya station.

2.1. Liquefaction analysis for slopes with 10° slope angle

Figure 2.2 shows the cross-sectional view of the slope model used in the numerical analysis. As seen on the figure the slope angle is 10° and the soil consists of sand with varying relative densities, unit weights and elasticity modulus. Sakarya station acceleration data was used as the earthquake input motion for all the analysis done.

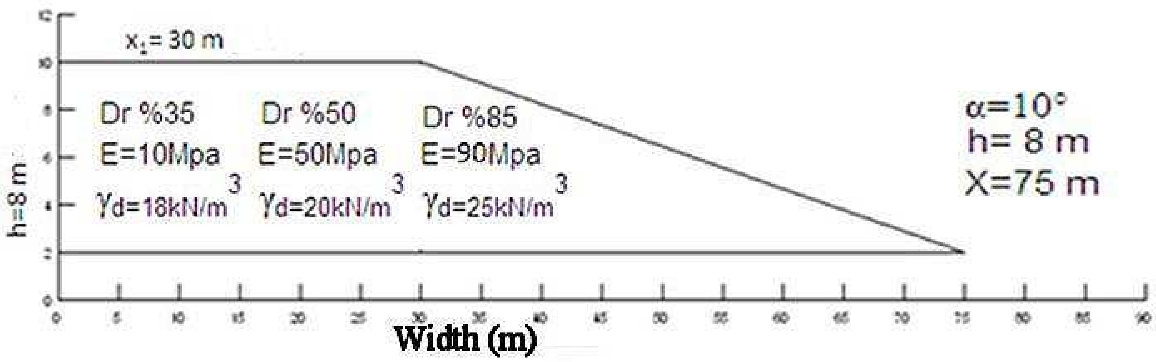

Figure 2.2. Slope geometry and material properties used in the analysis.

2.1.1. Liquefaction analysis of slope with relative density (35%) and GWT at the surface

Figure 2.3 shows the mesh used in the analysis and the ten nodes chosen to calculate the liquefaction potentials at various depths in the slope. The nodes were chosen with 5m apart in the x-direction and 2m apart in the y-direction. Table 2.2 shows the liquefaction potential analysis on the slope. As seen from the table, liquefaction occurs at the surface and with depth the potential decreases.

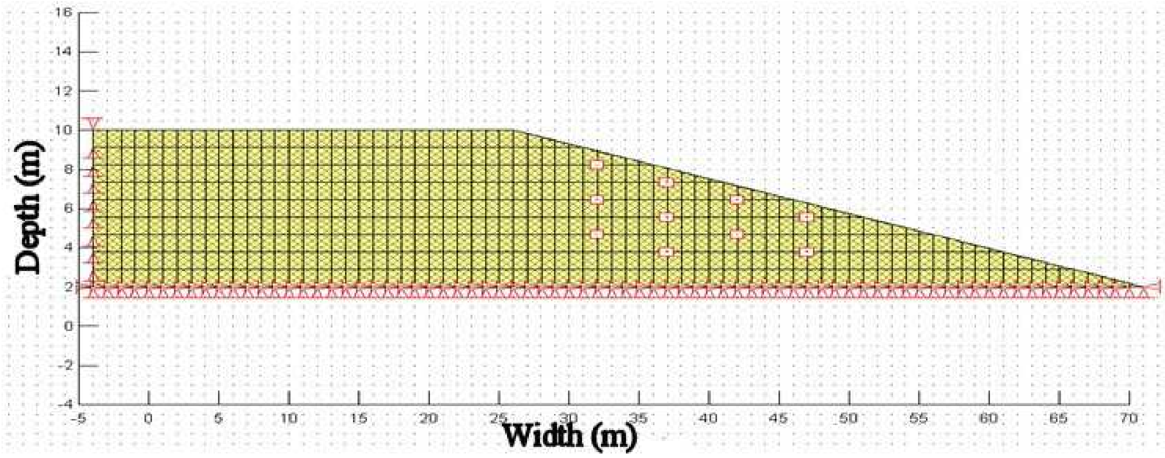

Figure 2.3. Mesh used in the analysis.

Table 2.2. Liquefaction analysis at some points on the slope

Point no.	x-coordinate	y-coordinate	Δu (kPa)	r_u
367	32	8.22	10.13	1
365	32	6.44	10.84	0.53
363	32	4.67	16.87	0.48
410	37	7.33	10.13	1
408	37	5.56	11.16	0.54
406	37	3.78	17.41	0.49
448	42	6.44	10.13	1
446	42	4.67	11.24	0.54
481	47	5.56	10.13	1
479	47	3.78	11.18	0.54

From the results of the analysis, slopes with 35% density and an angle of 10 °, total displacement value reached is 0.16 m.

2.1.2. Liquefaction analysis of slope with relative density (35%) and GWT at the half height of the slope

Table 2.3 shows the potential liquefaction at the chosen ten nodes in a slope with 10° slope angle with a relative density of 35% and GWT at the half height of the slope. As can be seen, ground water level is closely related to soil liquefaction potential; rise of underground water level triggers the possibility of ground liquefaction. The total displacement is 0.14m. When the relative density increases to 50% and the GWT is at the surface, total displacement decreases to 0.022m.

Table 2.3. Liquefaction analysis at some points on the slope with 10° slope angle, 35% relative density and the ground water table is at half height

Point no.	x-coordinate	y-coordinate	Δu (kPa)	r_u
367	32	8.22	0	0
365	32	6.44	11.6	0.26
363	32	4.67	30.41	0.47
410	37	7.33	0	0
408	37	5.56	20.6	0.51
406	37	3.78	27.04	0.49
448	42	6.44	5.99	0.45
446	42	4.67	16.77	0.52
481	47	5.56	10.13	1
479	47	3.78	12.71	0.52

2.1.3. Liquefaction analysis of slope with relative density (85%) and GWT at the surface

When the relative density increases to 85% and the GWT is at the surface, total displacement decreases to 0.012m.

2.2. Liquefaction analysis for slopes with 15°, 20° and 25° slope angles

When the slope analysis was conducted on the 15° angled slope with a relative density of 35% and where the ground water table was at the surface, 0.15m displacement was calculated. Then the ground water table was halved during the analysis and the displacement has decreased to 0.13m. As the relative density of the slope was increased to 50% and then to 85%, the total displacement values are 0.020m and 0.011 respectively. Displacement values are affected by the densities and the ground water table level. With 20° slope angle, 35% relative density with ground water at the surface total displacement was 0.14m when 85% density total displacement is 0.011m. When the slope angle is 25°, with a relative density of 35% GWT at surface, total displacement 0.136m where the GWT was at half-height 0.127m displacement was calculated. Therefore with depth the water table deformation has decreased. Figure 2.4 shows the displacements change with the angle of slope for 35% and 85% relative densities when ground water table is at the surface.

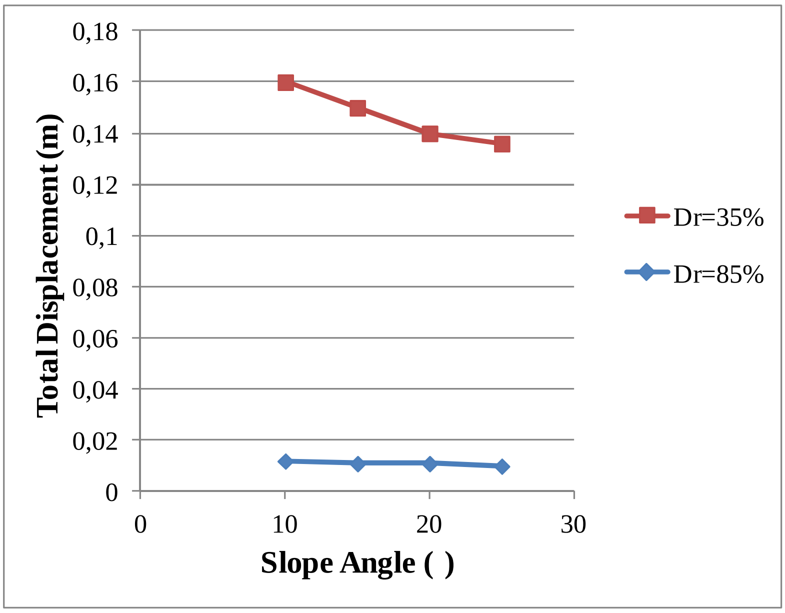

Figure 2.4. Total displacement change with the angle of the slope.

3. CONCLUSIONS

Displacement results achieved show that relative density of the soil is more effective in the slope instability than the ground water table level. As the angles of the slopes increase, deformations encountered increase as well. Table 3.1 shows the strains calculated in the slopes due to earthquakes where the ground water table was at the surface. The amount of strains decrease as the relative densities increase.

Table 3.1. Strains calculated in the slopes due to earthquakes with ground water table at the surface

Slope Angle	D_r=35%	D_r=50%	D_r=85%
10	0.35	0.05	0.03
15	0.50	0.07	0.04
20	0.64	0.10	0.05
25	0.80	0.11	0.06
30	0.97	0.15	0.07

Figure 3.1 shows the relationship between slope angle and the deformations. As can be seen from the figure, with the increment in the slope angle, deformations increase. Even though the relative density increases, as the angle of the slope increases, deformations rise as well.

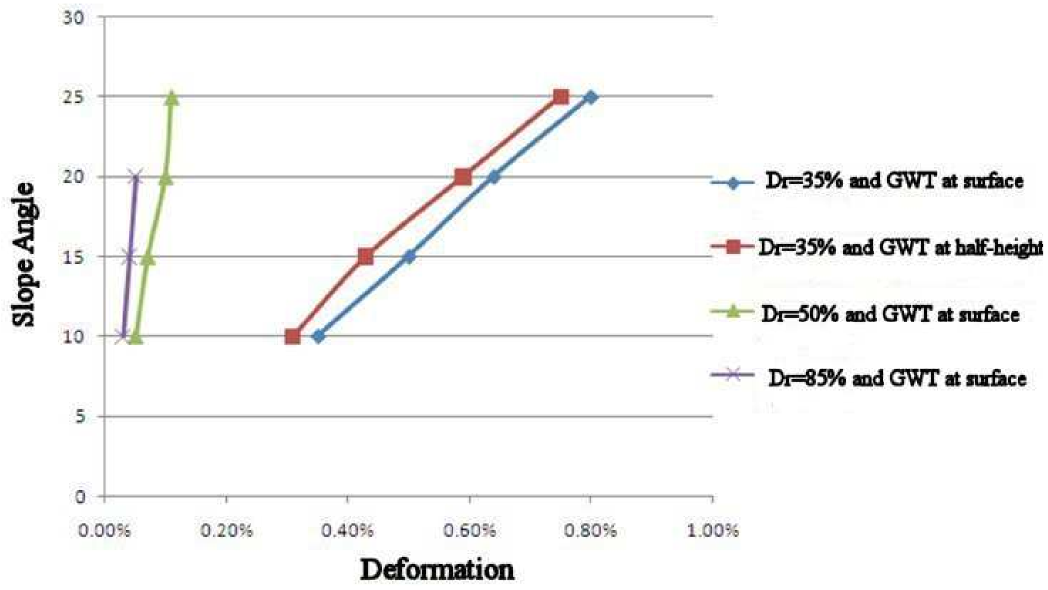

Figure 3.1. Deformation and slope angle relation

Figure 3.2 shows the response spectra of 35% relative density slope with different slope angles of 10°,15°,20° and 25° compared with Z4 soil in the TEC (2007) with 5% damping ratio. As seen increase in the angle of the sandy slope, response spectra of these exceed the response spectra of Z4 soil type between the periods of 0.3-0.5s.

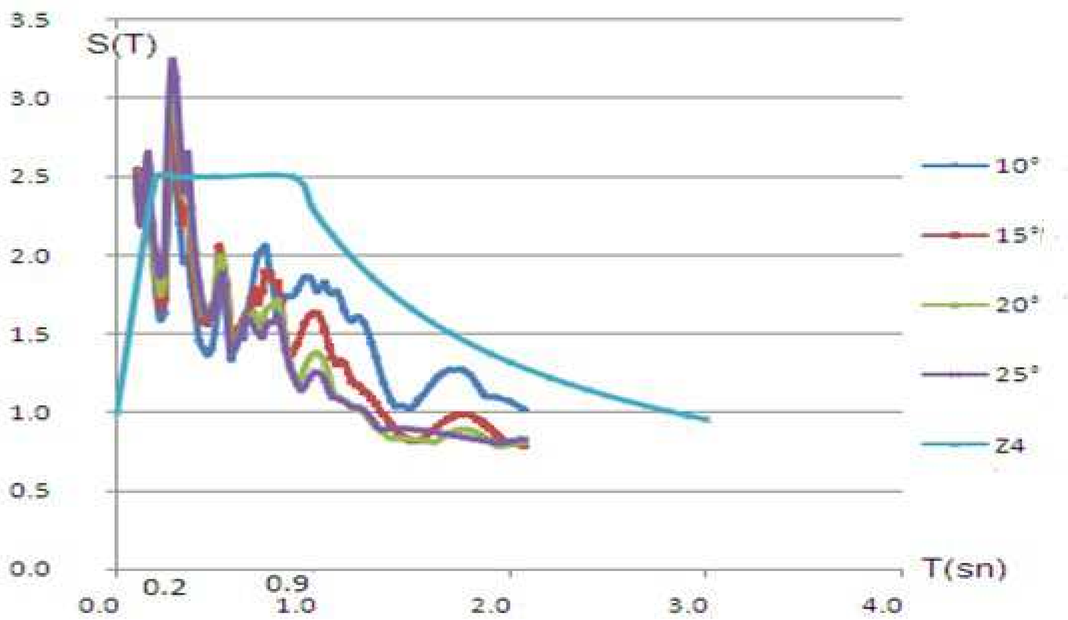

Figure 3.2. Response spectra of 35% relative density slope with different slope angles compared with Z4 soil in the TEC (2007) with 5% damping ratio

REFERENCES

Newmark, N.M. (1965). Effects of Earthquakes on Dams and Embankments. Geotechnique

Tokimatsu, K., and Seed, H.B. (1987). Evaluation And Settlement in Sand Due to Earthquake Shaking. *Journal of Geotechnical Engineering* **113:8**, 861-878.

TEC. (2007). Turkish Code for earthquake resistant design. Ministry of Public Works and settlement, Ankara.