Seismic Performance of Existing Bakacak Landslide After 1999 Duzce (Turkey) Earthquake

L'Exécution sismique de Glissement de terrain de Bakacak Existant Après 1999 Duzce (Turquie) le Tremblement de terre

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ABSTRACT

Within the confines of this study, seismic performance of the existing Bakacak landslide during November 12, 1999 Duzce, Turkey, earthquake of M_w= 7.2 is assessed. For the purpose, two cross sections of the creeping soil slope were numerically modeled and shaken by Bolu acceleration time history record scaled down to 0.6 g, consistent with the level of excitation expected at the site during the earthquake. The inclinometers installed revealed that the amount of lateral displacements at these cross sections were 28 and 2 cm, respectively. Based on the yield acceleration values, estimated as 0.07 and 0.14g by pseudo-static slope stability analyses, Newmark seismic displacements were found to be 26 and 3 cm, which are in close agreement with the actual measured values. Both the close agreement in the magnitudes of permanent seismic displacements and the similarities of the actual and numerically-estimated shear zones are found to be encouraging for the use of numerical seismic response analyses techniques in the assessment of permanent seismic slope displacements.

RÉSUMÉ

Dans les limites de l'étude, cette exécution sismique du glissement de terrain de Bakacak existant pendant le 12 novembre, 1999 Duzce, Turquie, le tremblement de terre de Mw = 7,2 sont évalués. Pour le but, deux coupes transversales de la pente de sol de ramper ont été numériquement modelées et ont été secouées par le rapport d'histoire de temps d'accélération de Bolu a réduit la l'échelle d'à 0,6 g, conforme au niveau d'excitation prévue au site pendant le tremblement de terre. Le inclinometrés a installé a révélé que la quantité de déplacements latéraux à ceux-ci traverse des sections étaient 28 et 2 cm, respectivement. A basé les valeurs d'accélération de rendement, a estimé comme 0,07 et 0.14g par la stabilité de pente pseudo-statique analyse, déplacements sismiques de Newmark ont été trouvés pour être 26 et 3 cm, qui sont dans l'accord proche avec les véritables valeurs mesurées. Les deux l'accord proche dans les magnitudes de déplacements sismiques permanents et les similarités des véritable et numériquement-estimé zones de cisailles sont trouvées encourager pour l'usage de réponse sismique numérique analyse des techniques dans l'évaluation de déplacements de pente sismiques permanents.

Keywords: Slope stability, Duzce earthquake, Newmark displacement analysis, seismic response analysis.

1 INTRODUCTION

Within the confines of this study, seismic performance of the existing Bakacak landslide during November 12, 1999 Duzce, Turkey earthquake of M_w= 7.2 will be assessed. Bakacak landslides extend through Ankara-Istanbul E5 highway and have jeopardized the stability of the highway at various locations. This specific landslide region was defined by station kilometers of 212+920 and 214+000. Nearby slides were also studied by Aydan and Ulusay, 2004, Bakir and Akis, 2005. Deformations evidenced by cracks where lateral and vertical offsets amounting to as much as 15 and 10 cm, respectively, were observed on the highway pavement before the earthquake. A plan view of the landslide was shown in Figure 1. A retaining wall system consisting of 2 m diameter bored tangent piles extending to a depth of 30 m, supported by five rows 2 m x 2 m spaced anchors was constructed to stabilize the landslide. Inclinometer measurements indicated that the failure surface of the landslide is about 20 m deep from the pavement elevation. The landslide supported by the piled wall system was shaken by two successive earthquakes: August 17, 1999 Kocaeli earthquake of moment magnitude, $M_w = 7.4$ and November 12, 1999 Duzce earthquake of $M_w = 7.2$. Kocaeli earthquake, closest distance to the fault rupture of which was more than 50 km, caused only 6 mm lateral movement of the soil slope. After the earthquake, previously 20 m deep shear zone has shifted to 26 m depths. Duzce earthquake, whose fault rupture was located approximately 2 km north of the site, caused 280 and 20 mm permanent horizontal displacements at cross-sections I-I and IV-IV, respectively. Figure 2 and 3 show soil profiles along the cross sections I-I and IV-IV. Detailed documentation of the soil characteristics as well as displacement measurements are presented in Erol et al. (1997) and Horoz et al. (2000).

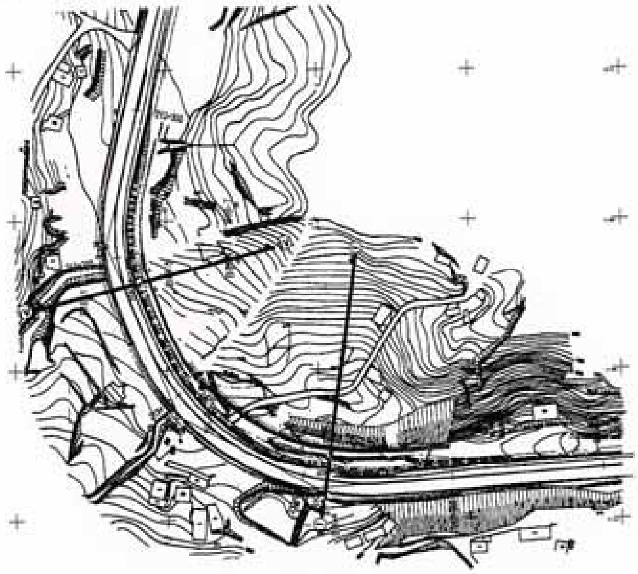

Figure 1. Plan view of the landslide

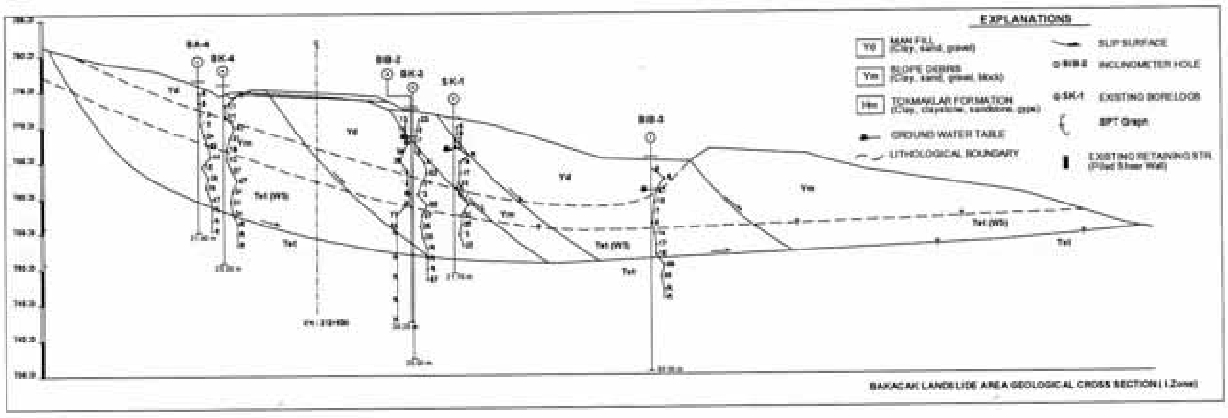

Figure 2. Cross Section I – I

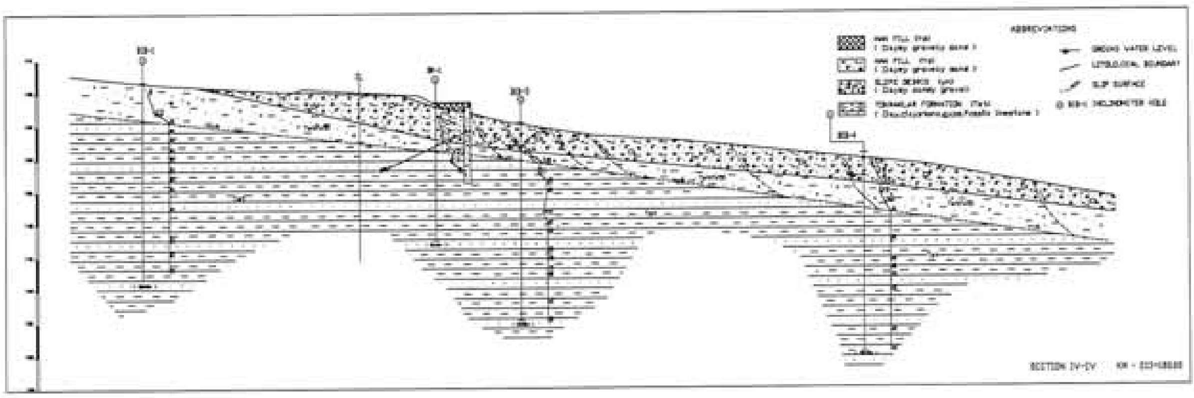

Figure 3. Cross Section IV – IV

As both of the figures illustrate, the slope is composed of 1.0 to 11.0 meter thick highway fill of gravelly, clayey sand, represented by an SPT blowcount, $N_{60} = 10$ blows/30 cm. This fill layer is followed by 4.0 meter thick residual soil, also characterized as silty, clayey sand of $N_{60} = 18$

blows/30 cm. Underlying the residual soil layer, there exist a highly weathered mudstone layer of 5.0 m thickness with N_{60} = 30 blows/30 cm, which is followed by moderately weathered mudstone, with N_{60} = 40+ blows/30 cm. Water table was monitored to be at approximately 4 m depth, parallel with the surface trace of the slope. Table 1 presents a summary of soil characteristics as well as parameters adopted throughout our assessments. For dynamic response assessments, degradation and damping curves were adopted as recommended by Vucetic and Dobry (1991) for the corresponding plasticity index, PI values. Due to creeping (drained) nature of the slope movements, shear strength of the weathered mudstone was modeled as frictional and the ultimate angle of friction was estimated as 13 degrees from back analyses leading to a factor of safety 1.1. This ultimate friction angle is also found to be consistent with the recommendations available in the literature. (e.g.:Gibson, 1953)

Table 1. Soil Characteristics

Soil Type	SPT-N_{60}	Class	ϕ (°)	c (kPa)	PI	ν	G_{max} (MPa)
Yd	10	SM	30	0	–	0.3	40
Ym	18	SM	32	0	–	0.3	80
Tet (W)	30	CL-MH	13	5	20	0.5	125
Tet	40	CL-MH	13	15	30	0.5	250

2 SEISMIC PERFORMANCE AFTER THE EARTHQUAKE

Existing Bakacak landslide, continuing to accumulate creep deformations with a rate of 4.5 mm to 15 mm/month was shaken by moment magnitude, M_w, 7.2, November 12, 1999 Duzce earthquake. The site was located at approximately 2 km away from the surface rupture of North Anatolian Fault. After the earthquake, by simply studying the available inclinometer readings before and after the earthquake, it was concluded that, i) the existing shear zone was extended to 26 meter depths as compared to initial 20 meter deep static shear zone, either due to seismic loading or newly installed 30 meter long piled retaining wall, ii) post earthquake lateral displacements were estimated as 250 mm at I-I and 50 mm at IV-IV cross sections, iii) lateral displacements have slowed down to pre-earthquake creeping magnitudes of 15 – 45 mm/month within a week after the earthquake.

3 DYNAMIC RESPONSE ASSESSMENTS

For the purpose of assessing the seismic performance of landslide through finite element-based seismic response analyses, mesh models shown in Figures 4 and 5 were developed.

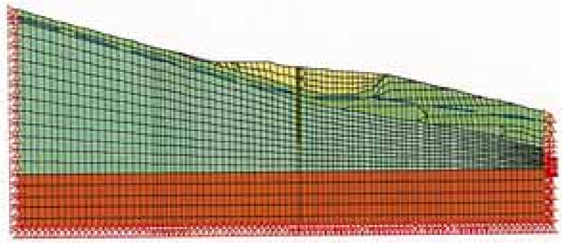

Figure 4. Finite Element Mesh for Section I – I

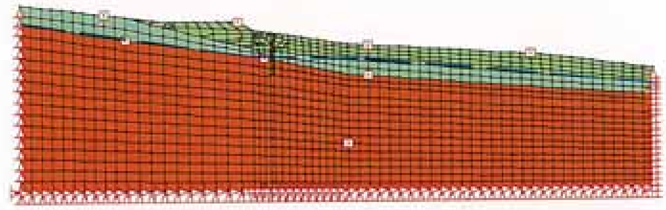

Figure 5. Finite Element Mesh for Section IV – IV

Adopting the model parameters presented in Table 1, series of equivalent linear seismic response analyses were performed by using Quake-W software. Level of excitation needed for assessing seismic displacements was estimated as 0.6 g for a M_w = 7.2 earthquake at a distance of 2 kms, through currently available attenuation models (e.g.: Abrahamson and Silva, 1997) calibrated by peak ground acceleration levels specific to the earthquake. The closest available strong motion station to the site was identified at the city of Bolu. The stronger of the two horizontal Bolu acceleration time histories, which has a peak ground acceleration value of 0.82 g was concluded to be the best alternative. Bolu record, scaled down to 0.6 g and deconvolved to mudstone "bedrock" level was used as the "within" motion, as shown in Figure 6, to shake the soil slope.

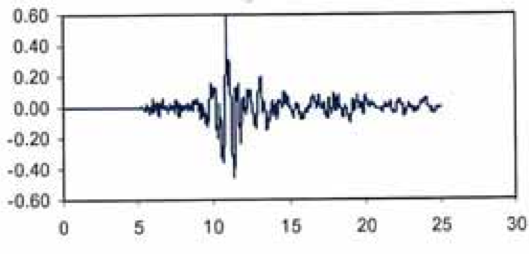

Figure 6. Input "within" motion

The resulting outcropping acceleration time histories were shown in Figures 7 through 8 for the cross sections I-I and IV-IV. Yield acceleration values, as the input to Newmark seismic displacement analyses, were estimated as 0.07 and 0.14 g by pseudo-static slope stability analyses for the cross sections I-I and IV-IV, respectively. These values are shown by dash lines on Figure 7 and 8. Double integrating the acceleration time history regions above and below yield acceleration values, Newmark displacements were estimated as 26 and 3 cm, respectively.

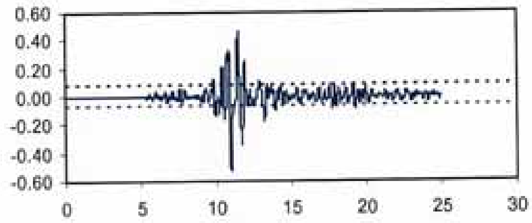

Figure 7. Output Time History for Section I – I, Newmark Displacement = 26 cm

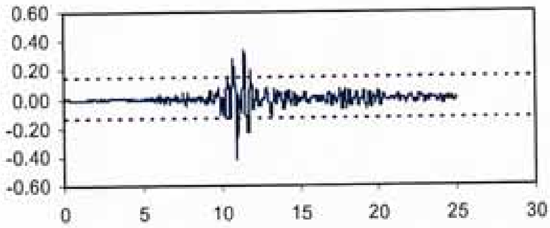

Figure 8. Output Time History for Section IV – IV, Newmark Displacement = 3 cm

On Figures 9 and 10, maximum seismic shear strain contours were shown along with post earthquake net lateral displacements. As the figure implies, the actual landslide shear zone obtained from inclinometer measurements consistently coincides with the shear zone predictions of seismic response analyses. As also shown on the same figures, post earthquake lateral displacements were monitored through inclinometers as 28 and 2 cm. These values are found to be surprisingly consistent with the predictions by Newmark analyses. Due to equivalent linear nature of the seismic response analyses, it was not possible to fairly compare the actual measured permanent displacements with the predictions of the seismic response analyses.

4 SUMMARY AND CONCLUSIONS

Within the confines of this study, seismic performance of the existing Bakacak landslide was investigated. For the purpose two cross sections of the creeping soil slope was numerically modeled and was shaken by Bolu acceleration time history record scaled down to 0.6 g, consistent with the level of excitation expected at the site after November 12, 1999 Duzce earthquake of M_w=7.2. The inclinometers installed at the site revealed that the amount of lateral displacements at cross sections I-I and IV-IV were 28 and 2 cm, respectively. Based on the yield acceleration values estimated as 0.07 and 0.14 g by pseudo-static slope stability analyses, Newmark permanent seismic displacements were found to be 26 and 3 cm, respectively for the cross sections of I-I and IV-IV. The close agreements between the actual measured lateral displacements by inclinometers and the Newmark method, as well as the similarity of the actual and numerically-estimated shear zones are found to be mutually supportive.

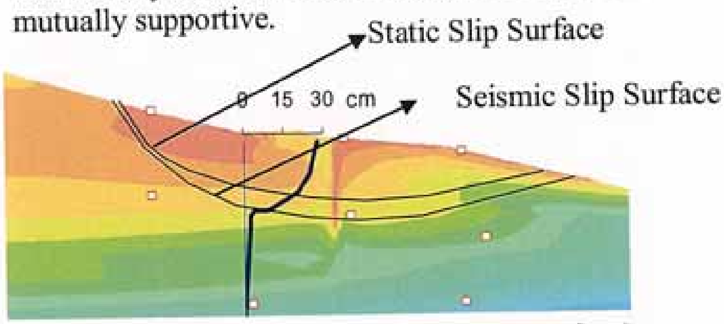

Figure 9. Shear Strain and Displacements for Section I – I

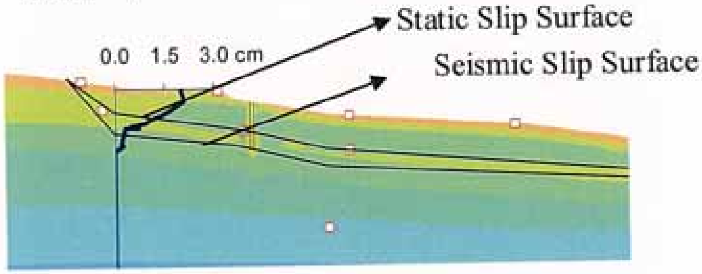

Figure 10. Shear Strain and Displacements for Section IV – IV

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