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EFFECTIVE STRESS BASED NUMERICAL ASSESSMENT OF LIQUEFACTION-INDUCED LANDSLIDE AT DEGIRMENDERE CAPE, IZMIT BAY DURING KOCAELI (IZMIT)-TURKEY EARTHQUAKE

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ABSTRACT

This paper presents the numerical assessment of seismically-induced slope instability observed at Degirmendere Cape, Izmit Bay during Kocaeli (Izmit)-Turkey earthquake. As is evident from the name of the site, Degirmendere Cape site is located at the north of Degirmendere, on a small intrusion into the Bay of Izmit. At Degirmendere Cape, there existed a municipality owned hotel and recreational areas. During the earthquake following slumping of the fill material, the site was unindated. All the recreational facilities as well as the municipality hotel were lost to Marmara Sea with its residents. Failure mechanism was attributed to fault rupture/seismically induced slope instability and/or liquefaction of underlying fill materials. The site was sloping at an angle of 10–15 degrees towards the bay. For understanding the true failure mechanism, 2-D finite difference analysis of the slope is performed by using modified UBCSAND effective stress liquefaction model. In the original model, effects of static effective confining shear stresses on cyclic pore pressure response of saturated cohesionless soils were not fully addressed. Thus, additional K_α and K_σ corrections are applied explicitly and conveniently on SPT input values as opposed to conventional application of corrections on CSR. As a conclusion, the observed large ground deformations are compared with model predictions. Close agreements among failure modes and large deformations strains are concluded to be mutually supportive of the adopted numerical scheme and the constitutive model. Estimated high pore pressure ratios revealed that the major cause of instability of the slope was triggered by seismic soil liquefaction, more specifically flow liquefaction.

INTRODUCTION

On the early morning of August 17, 1999, a devastating earthquake (Ms 7.4) occurred in Kocaeli-Turkey. More than 15,000 people were killed and more than 20,000 people were injured, mainly by the collapse of buildings. The earthquake caused extensive landslides, subsidences and liquefaction-induced ground deformations especially along the coast of Izmit Bay. At Degirmendere Cape, there existed a municipality owned hotel and recreational areas. During the earthquake following slumping of the fill material, the site was unindated. All the recreational facilities as well as the municipality hotel were lost to Marmara Sea with its residents. This paper presents a study on seismically induced landslide observed at Degirmendere Cape along the southern coast of Izmit Bay. For understanding the true failure mechanism, 2-D finite difference analysis of the slope is performed by using effective stress based liquefaction model.

SITE DESCRIPTION

The Bay of Izmit is located in an east–west trending active graben system which is dynamically affected by the interaction of the North Anatolian Fault Zone and the Marmara Graben System. It is covered by sandy deposits which gets finer (siltier and more clayey) as one moves towards north in to the depths of Izmit Bay. Degirmendere Cape site is located at the north of Degirmendere, on a small intrusion into the Bay of Izmit. Subsurface soil conditions across the site are represented by one interpreted cross-section as shown in Figure 1 included SPT and CPT measurements. This cross-section is selected to be largely perpendicular to the shoreline and parallel to the direction of lateral ground displacements. The site was sloping at an angle of 10–15 degrees towards the bay and failure mechanism was attributed

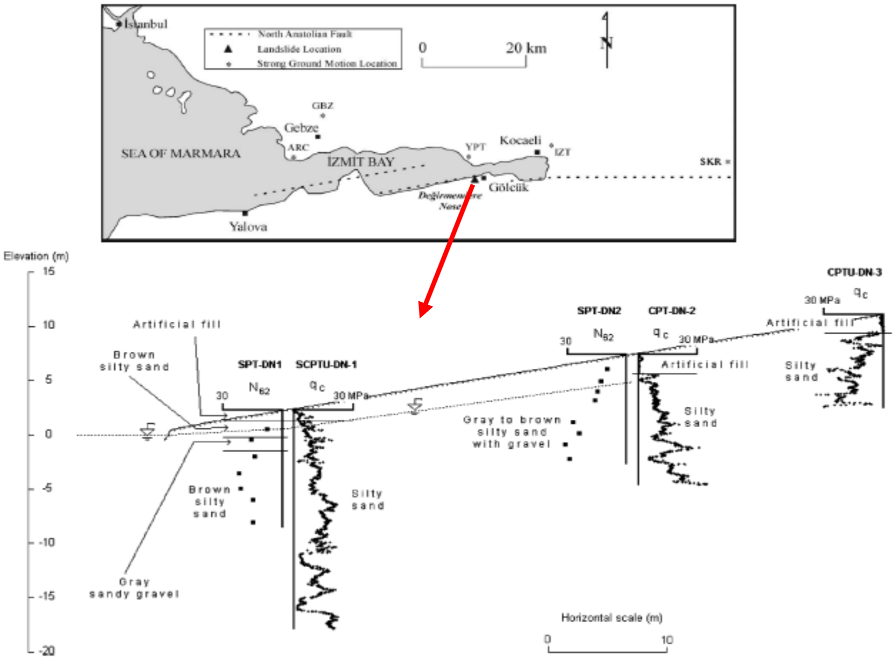


Fig. 1. Cross section of Degirmendere Nose included SPT and CPT measurements. (Cetin et al., 2004)

to fault rupture/seismically induced slope instability and/or liquefaction of underlying fill materials. The surface of the site consists of artificial fill of brown gravelly sand to red silty clay ranging in thickness from 0.5 to 1 m. This fill layer is underlain by thick silty sand layer of occasional gravelly sand and silty clay mixtures. (Cetin et al. 2004)

SEISMIC RESPONSE ANALYSES

Modelling Basics

Seismic response analysis of the Degirmendere Cape is performed by two-dimensional, explicit, finite difference software FLAC v4.0 (Fast Lagrangian Analysis of Continua) and representative soil cross-section shown in Figure 2. For the finite element analysis, a suitable material model is needed in order to model stress-strain behavior of the materials.

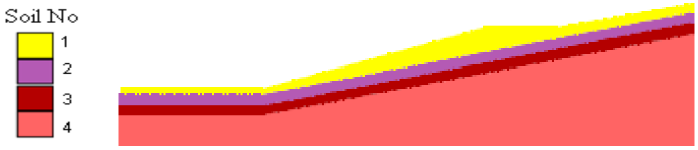


Fig. 2. Finite element model used in dynamic analysis.

Material model parameters in Table 1 were chosen based on the results of site investigation studies especially utilizing the correlations between shear strength parameters vs. CPT tip and skin friction measurements

Table 1. Material Properties

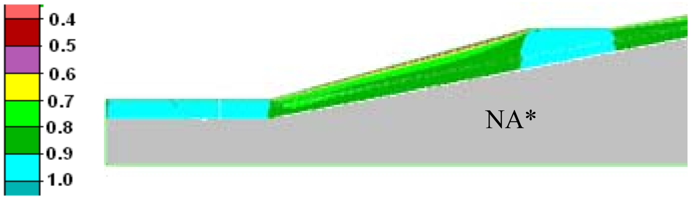
Soil No	Soil Type	Failure criteria	γ (kN/m3)	G (MPa)	c (kPa)	Φ (°)
1	Sand	UBCSAND	19	43.2	0	33
2	Sand	UBCSAND	19	76.8	0	35
3	Sand	UBCSAND	20	156.8	0	41
4	Rock	Mohr-Coulomb	22	204.8	50	47

2-D finite difference analysis of the slope is performed by using modified UBCSAND effective stress (Byrne et al., 2004) liquefaction model. No doubt that the finite element method has been one of the most powerful tools for evaluation the dynamic response of slopes under earthquake loading.

The UBCSAND modifies the Mohr-Coulomb model incorporated in FLAC v4.0 to incorporate the plastic strains that occur at all stages of loading. This model has been substantially improved to better model observed sand behavior and include the effects of effective overburden stress (σ_v') to the cyclic resistance of the slope. In the original model, changes in cyclic pore pressure response of saturated cohesionless soils due to changes in effective confining stresses, and presence of static shear stresses, were not fully captured. Thus a modification incorporating widely known K_σ and K_α issues was needed. So that, SPT based K_α and K_σ corrections are applied to the UBCSAND model and liquefaction triggering potential of the Degirmendere Cape is analyzed. The values of these K_α and K_σ correction factors are estimated by equations as recommended by Idriss and Boulanger (2003) and Harder and Boulanger (1997) respectively.

The application of K_α and K_σ corrections on $N_{1,60}$ is different than the conventional applications of them on CSR. However one can easily prove that, applying corrections on CSR or $N_{1,60}$ produce identical liquefaction triggering probabilities, based on Cetin et al. (2004) probabilistic liquefaction triggering methodology. It should be noted however that these modified $N_{1,60}$ values are only used in the excess pore pressure generation loops, but not in the estimation of modulus or failure envelope parameters. Different than the original UBCSAND model, input parameter, $N_{1,60}$ is modified through series of K_α and K_σ corrections as shown in Equation 1. The application of K_α and K_σ corrections on $N_{1,60}$ is presented in Figures 3 and 4.

$$N_{1,60_{(eqv)}} = N_{1,60} + 13.32\ln\left(K_\alpha\, K_\sigma\right) \qquad (1)$$



* NA (not applicable): The region is modeled with the mohr-coulomb failure criteria

Fig.3. K_α adjustment values through the cross section

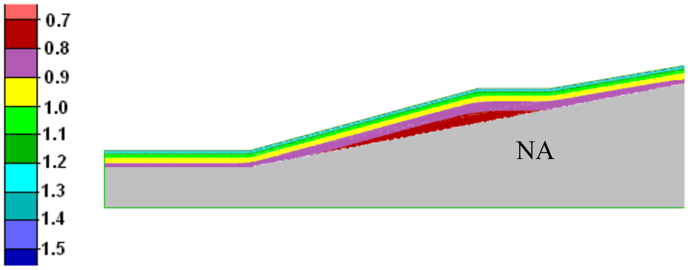
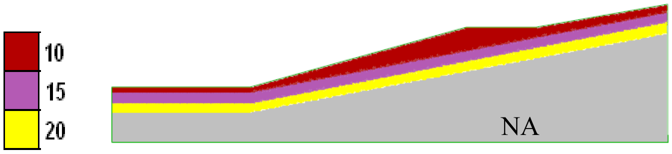
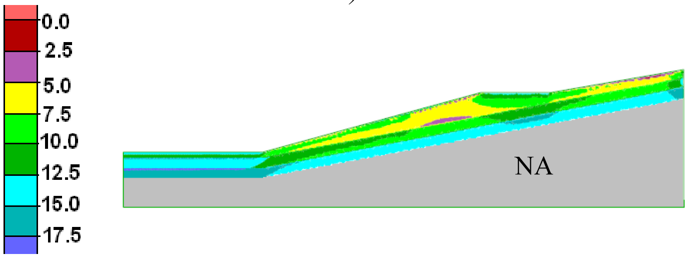


Fig.3. K_σ overburden correction values through the cross section

Static shear stress ratio, α, is stress dependent. So that, K_α adjustment value is unity through flat regions and decreasing through beneath the slopes. In contrast to K_α effects, overburden correction factor, K_σ is decreasing with increasing confining pressure. As discussed earlier, SPT based K_α and K_σ corrections are applied to the UBCSAND model and liquefaction triggering potential of the Degirmendere Cape is analyzed. The SPT-N values with and without K_α and K_σ corrections are shown in Figure 5. $(N_1)_{60}$ values significantly decreases beneath the sloped regions with the applications of K_α and K_σ corrections.



a) UBCSAND Model
b)

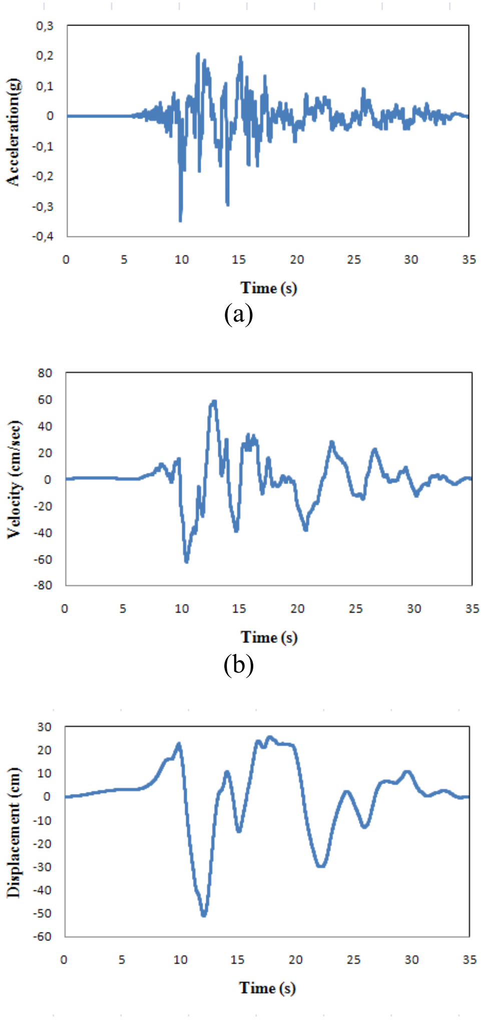


c) Modified UBCSAND Model

Fig.5. $N_{1,60}$ *values through the slope*

<u>Dynamic Response Analysis</u>

To better understand the mechanism of the slope instability, a finite difference dynamic analysis of the Degirmendere Cape was performed by using the software Flac. Strong ground motion adopted for these analyses were chosen as the Yarimca record (YPT) (Figure 6), which was recorded on a soft soil site, 4.4 km north of fault rupture, along the north shores of Izmit Bay. Event-specific attenuation relationships suggest that the peak horizontal ground acceleration on a hypothetical 'rock outcrop' and on soft soil at Degirmendere Cape, located within less than a kilometer from the fault rupture would have been about 0:3–0:45g: Most conventional attenuation relationships available prior to the event tend to over-predict the observed near-field levels of shaking. However, if the attenuation relationship proposed by Abrahamson and Silva is scaled, on an event-specific local basis, using the near-field Izmit, Yarimca and Gebze station recordings, then the soft soil site peak horizontal ground acceleration at a comparable fault distance is estimated approximately as 0:4g for Degirmendere Cape site.



(a)

(b)

(c)

Fig. 6. Earthquake record (a) acceleration, (b) velocity, (c) displacement time histories.

Mean effective stresses needed for the dynamic analyses were determined by performing static analyses with Mohr-Coulomb failure criteria. Before starting the dynamic analysis, displacements were reset to zero to estimate only seismically-induced deformations. Then, material properties and strong ground motions are given as input data to the program in order to obtain the acceleration time histories of the required points pore pressures and displacements are evaluated.

For illustration purposes, seismic response analysis results are presented in the form of i) seismically induced maximum horizontal displacements and ii) distribution of the excess pore pressure ratio, r_u , values throughout the cross section as shown in Figures 7-8.

The Figure 7 implies that finite difference analyses predicted large displacements and possible failure planes after the earthquake. Moreover, estimated high pore pressure ratios (r_u>0.8) of the soil layer below 10 m depth revealed that the major cause of instability of the slope was triggered by seismic soil liquefaction, more specifically flow liquefaction.

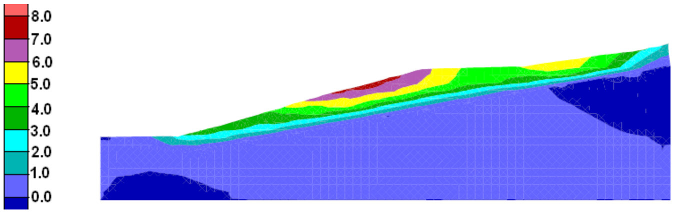


Fig7. Seismically-induced maximum horizontal displacements(m)

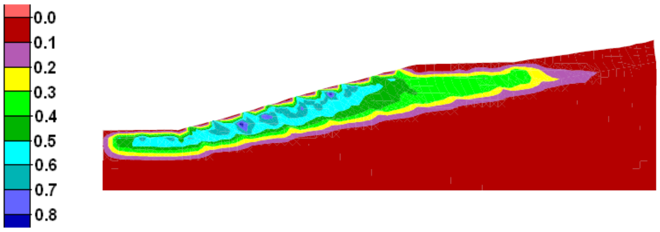


Fig 8. Seismically-induced excess pore pressure ratio, r_u

CONCLUSION

This study presents the numerical assessment of seismically-induced slope instability observed at Degirmendere Cape, Izmit Bay during Kocaeli (Izmit)-Turkey earthquake. Failure mechanism was attributed to fault rupture/seismically induced slope instability and/or liquefaction of underlying fill materials.

For understanding the true failure mechanism, 2-D finite difference analysis of the slope is performed by using modified UBCSAND effective stress liquefaction model. In the original model, effects of static effective confining shear stresses on cyclic pore pressure response of saturated cohesionless soils were not fully addressed. Thus, additional K_α and K_σ corrections are applied explicitly and conveniently on SPT input values as opposed to conventional application of corrections on CSR. As a summary, the modified version of the Byrne model powerfully captures effective stress based seismic response of saturated cohesionless soils. Close agreement with the predictions of field performance based methodology (e.g.: Cetin et al., 2004) and numerical simulations by FLAC software was found to be mutually supportive.

As a conclusion, the observed large ground deformations are compared with model predictions. Close agreements among failure modes and large deformations, strains are concluded to be supportive of the adopted numerical scheme and the constitutive model. Estimated high pore pressure ratios (r_u>0.8) of the soil layer below 10 m depth also revealed that the major cause of instability of the slope was triggered by seismic soil liquefaction, more specifically flow liquefaction.

Last but not least, the results of these studies revealed significant liquefaction risk for the soils at a depth range of 8–12 m. Thus, it is believed that liquefaction induced reduction in shear strength triggered the landslide observed at Degirmendere Cape causing more than a dozen casualties as well as major economical losses.

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