SEISMIC ANALYSIS OF WEAKENED SLOPES REINFORCED WITH TIEBACK ANCHORS

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ABSTRACT

Over the past decades some slopes were created inadvertently without considering any analysis and design criteria. Consequently, such slopes faced sliding problem due to service and other probable loads. In order to revitalize their stability and prevent catastrophic events, especially in public gathering places such as parks, reinforcing those slopes was considered as an inevitable solution. Due to the fact that reinforcing by using tieback system could decrease the plastic displacement of a slope, this type of anchoring system was chosen to handle slope instability problem. However, an essential question is that whether reinforced slopes have proper safety factor during a severe earthquake or not?

In this paper, three slopes with different geometries in a park in Tehran are considered as case studies. After the slopes experienced sliding, they were reinforced with tieback anchors. Their stability situations have been examined by employing the finite element method.

INTRODUCTION

Earthquake ground motion exerts the most rigorous load to structures which are heavy and have a large amount of total weight. Geotechnical structures are heavy due to its geometry, e.g. slopes, embankments, retaining walls. Therefore, when designing such structures, it is of vital importance to consider the effect of possible earthquakes on the limit and service stability of them.

The three main approaches to investigate the seismic stability of slopes are pseudo static, stress deformation, and permanent displacement analysis (Kramer, 1996). The pseudo static method, based simply on adding an earthquake force to a static limit-equilibrium analysis, was formalized by Terzhagi (1950). Then, Finite-element modelling, a type of stress deformation analysis was developed and eventually would be applied to slopes (Clough and Chopra, 1966). Newmark (1965) proposed a method for estimating the displacement of slopes during earthquakes that addressed some of the assumptions of pseudo static analysis, and recently adopted by Trandafir et al. (2009), to study the earthquake-induced displacements of anchor-reinforced slopes.

In the present study, the seismic stability of three slopes which have a weak layer due to land slide and reinforced with tie-back system were examined numerically. Earthquake ground motion applied at the base of the model and a comparison between the displacements in the different monitoring points in the slope was performed. Two earthquake records with various time duration and frequency content were considered in the proposed SLE, DBE, and MCE intensity levels. In addition, a variety of anchors employed to reinforce the slopes.

PROBLEM STATEMENT AND METHODOLOGY

In the present study the stability of a weakened tied-back slope is investigated. Due to weakened zone in the soil slip surface the stability of slope depends upon the reinforcing system that is tie back (Figure 1). Considering the effect of frequency content, two different earthquakes are applied. Soil is assumed elastic-perfect plastic obeying Mohr-Coulomb criteria, while the soil properties are shown in Table 1.

At first, position of circular slip surface is obtained by means of Geo Slope software (Krahn 2004). Then, reinforcing of the slope with a weakened layer (above-mentioned slip surface with residual soil strength parameters) is simulated by Plaxis to gain an allowable safety factor in static loads (Brinkgreve 2002). Finally, the seismic stability of the reinforced slope was investigated for adopted horizontal component of two earthquake records at SLE, DBE and MCE intensity levels.

Two types of anchors were applied to reinforce the slope and their specifications were summarized in Table 2. The geometry and location of anchors were depicted in Figure 1 and the distance between the anchors is 4m and 2m in vertical and horizontal direction, respectively. Three different slopes (i.e. V = 13m, 9m, and 7m) and a constant slope inclination (i.e. V/H = 17/21) were analysed. It is worth mentioning that the number of anchors in the height of the slope affected the height of the slope, while the spaces between the anchors in horizontal and vertical directions and slope's toe keep constant. For each case the static safety factor was calculated, initial safety factor for the slope tied-back by A125 and A210 before sliding was about 1.15 and 1.69 respectively, while acceptable safety factor for global stability is greater than 1.5, corresponding to U.S. code, i.e. FHWA (Sabatini et al., 1999).

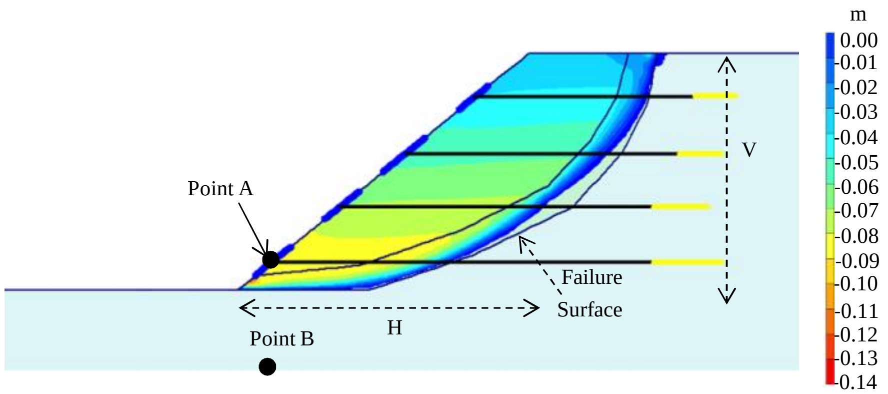


Figure 1. Horizontal displacement of reinforced slope with A125 at the end of dynamic analysis

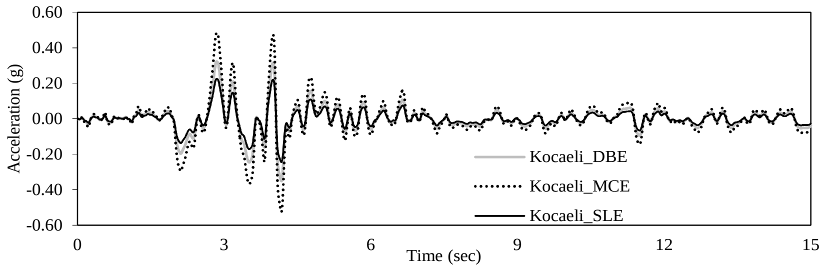
Table 1. The Soil Properties

Soil	γ(kN/m^3)	¨ (deg)	C (kN/m^2)
Intact soil	17	40	15
Weakened soil	17	20	3

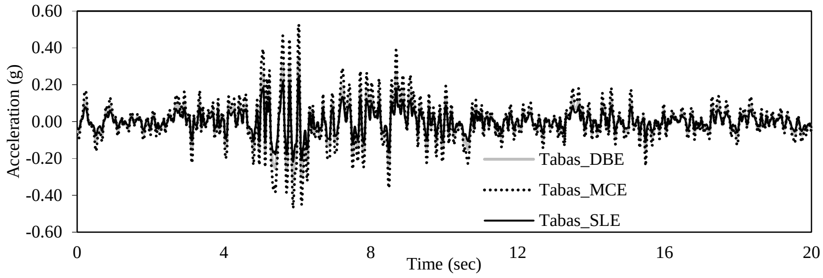
Table 2. The specification of two anchors were used to stabilize slopes

No.	Anchor	EA (kN)	Maximum Force (kN/m)	Pre-tensioned Force (kN/m)	Static S.F.
1	A125	1.03e5	125	90	1.15
2	A210	2.14e5	210	150	1.69

In order to study the seismic stability of tied-back slopes, the effective duration that are 15 sec and 20 seconds for horizontal component of Tabas and Kocaeli acceleration time-histories were used, respectively. The time-histories were scaled to the desired intensity levels (Figure 2).



a) Kocaeli

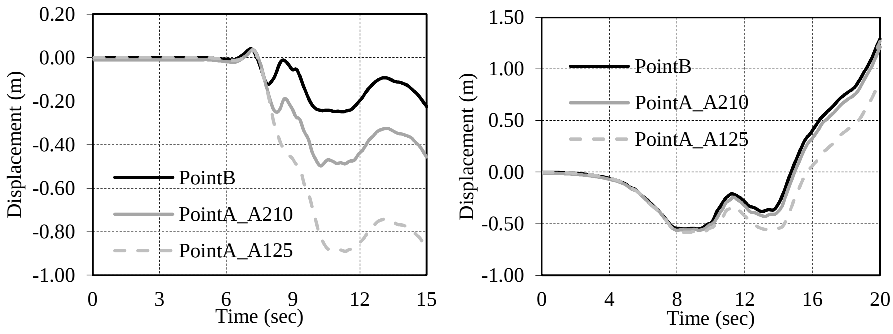


b) Tabas

Figure 2. The adopted earthquake records scaled to MCE, DBE, and SLE intensity levels

NUMERICAL RESULTS

The earthquake records in SLE level were applied to the slopes and the obtained results in the time-history analyses depicted in Figure (3-5). For the slopes tied-back by A125 anchors and subjected to Tabas earthquake at SLE level, A125 is just appropriate for V = 9m or V = 13m and is inappropriate for V = 17m slope, because there will be about 40cm plastic horizontal displacement in point A at the end of analysis, as shown in Figure 3b. On the other hand, using A210 anchors is appropriate for reinforcing slopes with all the above-mentioned heights subjected to Tabas at SLE level for slopes with V = 9m and V = 13m subjected to Kocaeli at SLE level. Because there are small differences between the horizontal displacements of point A and B, the amount of plastic displacement is negligible.

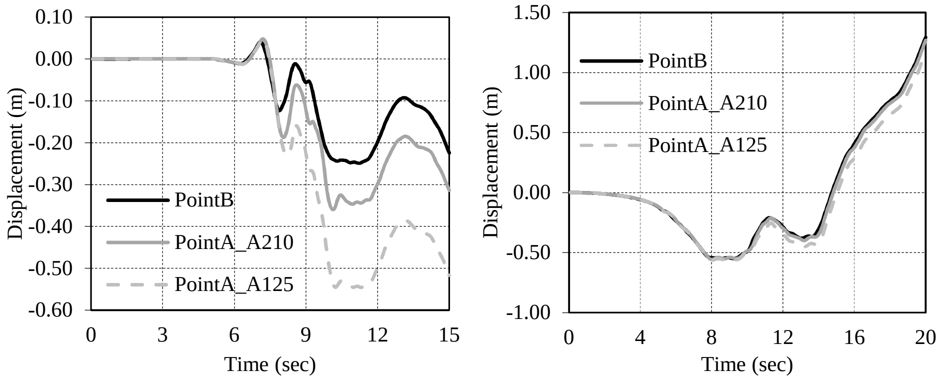


a) Kocaeli b) Tabas

Figure 3. Horizontal displacement of various points in the slope, V = 17m subjected to SLE intensity level

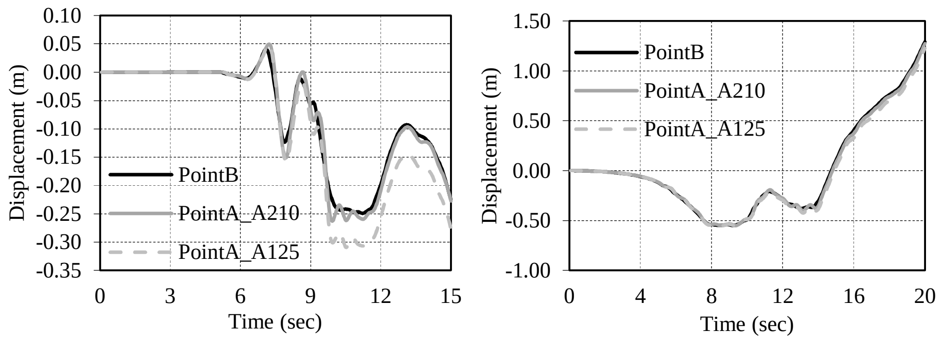
For the slopes tied-back by A210 and subjected to Tabas at DBE and MCE intensity levels, A210 is an appropriate choice just for slopes with different heights in DBE level, because, there is a difference between the horizontal displacement point A,B in MCE level (Figures 7b-9b). On the other hand, using A210 is appropriate for reinforcing varied heights of slopes subjected to Kocaeli at DBE level, in the case V = 9m.

Using A125 is not acceptable for reinforcing varied heights of slopes subjected to Kocaeli or Tabas in DBE and MCE intensity levels, because there is considerable plastic displacement in the toe of the slope, as depicted in Figures 10-12.



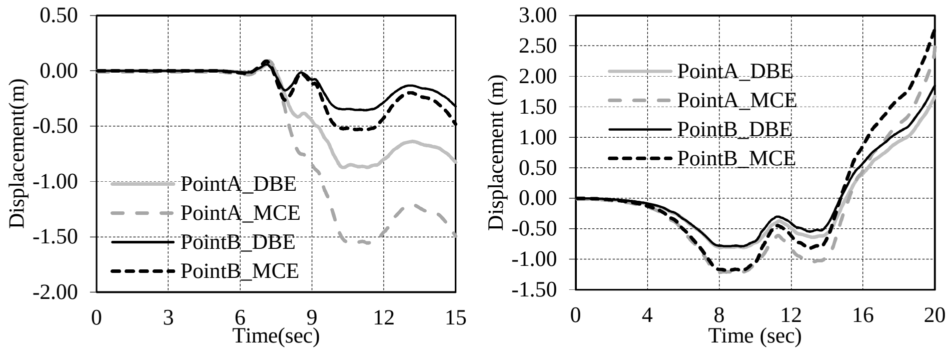
a) Kocaeli b) Tabas

Figure 4. Horizontal displacement of various points in the slope, V = 13m subjected to SLE intensity level



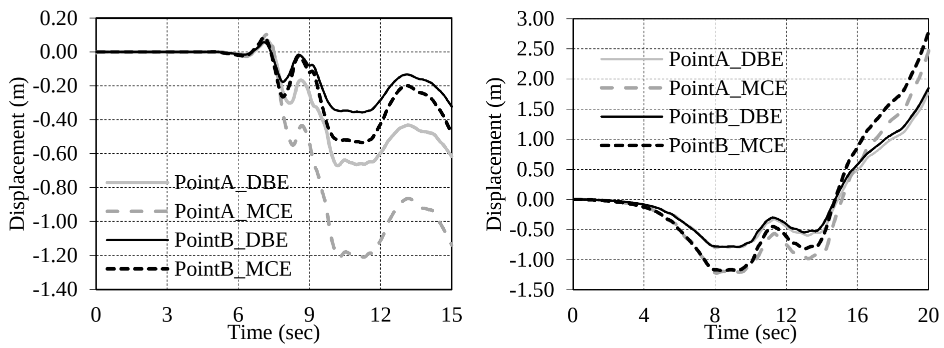
a) Kocaeli b) Tabas

Figure 5. Horizontal displacement of various points in the slope, V = 9m subjected to SLE intensity level



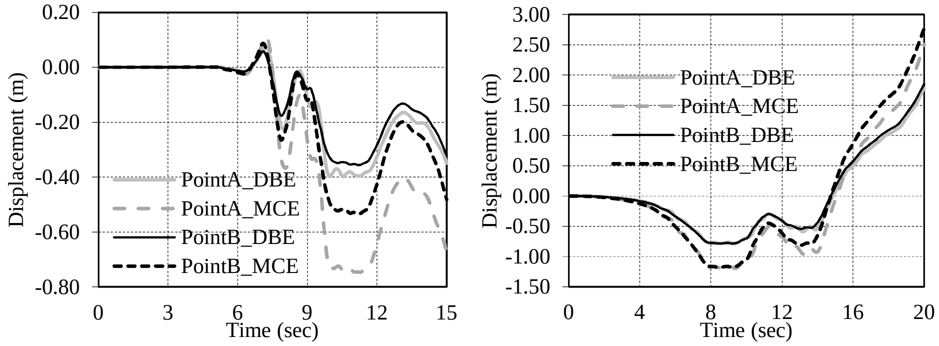
a) Kocaeli b) Tabas

Figure 6. Horizontal displacement of various points in the slope, V = 17m subjected to DBE and MCE intensity levels, reinforced with A210 anchors



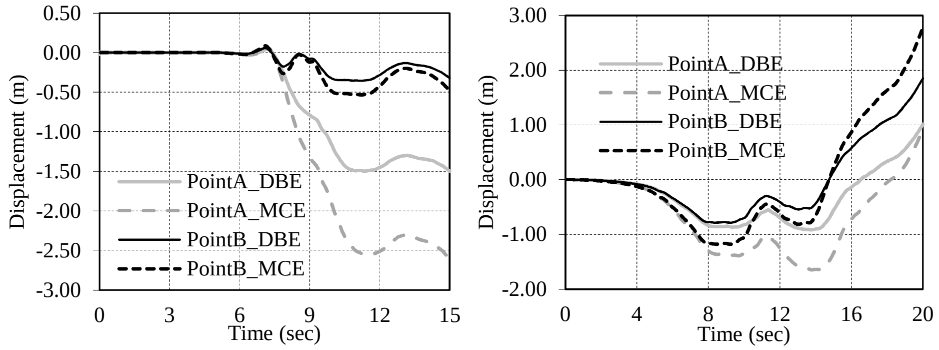
a) Kocaeli b) Tabas

Figure 7. Horizontal displacement of various points in the slope V = 13m subjected to DBE and MCE intensity levels, reinforced with A210 anchors



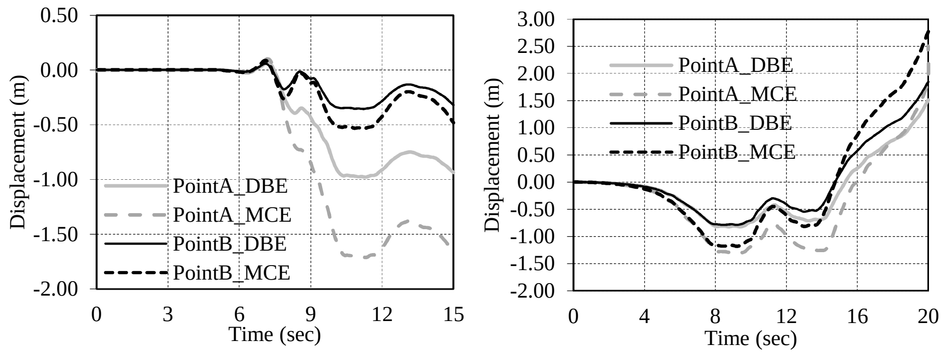
a) Kocaeli b) Tabas

Figure 8. Horizontal displacement of various points in the slope, V = 9m subjected to DBE and MCE intensity levels, reinforced with A210 anchors



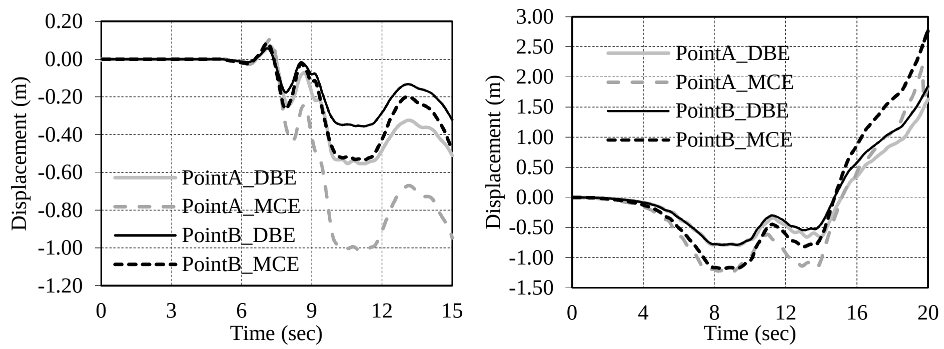
a) Kocaeli b) Tabas

Figure 9. Horizontal displacement of various points in the slope V = 17m subjected to DBE and MCE intensity levels, reinforced with A125 anchors



a) Kocaeli b) Tabas

Figure 10. Horizontal displacement of various points in the slope, V = 13m subjected to DBE and MCE intensity levels, reinforced with A125 anchors



a) Kocaeli b) Tabas

Figure 11. Horizontal displacement of various points in the slope, V = 9m subjected to DBE and MCE intensity levels, reinforced with A125 anchors

CONCLUSION

The seismic stability for three slopes with different geometries was investigated. Two earthquake records were chosen with different dynamic features in the SLE, DBE, and MCE intensity levels. Although, selecting and scaling an earthquake records is a comprehensive process, the purpose of this study is to demonstrate the significance of dynamic analysis on the stability of tied-back slopes, which is stable statically.

It was shown that a reinforced slope with small factor of safety about 1.15, which is not acceptable based on U.S code (FHWA), is unstable when subjecting to earthquake ground motion approximately in all levels of intensity. On the other hand, the slope with acceptable safety factor, i.e. 1.69, in static loading can be stable when subjected to an earthquake and unstable to another earthquake ground motion with the same PGA and scaling factor. Therefore, in designing reinforced slopes dynamic analysis is crucially important task that is proposed by relevant codes.

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