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Ahmed El-Nimr
professor of Geotechnical Engineering, Faculty of Engineering, Mansoura University

Adel Gabr
Association professor of Geotechnical Engineering, Faculty of Engineering, Mansoura University

Ahmed EL-Wakeel
B.Sc. of Civil Engineering, Faculty of Engineering, Mansoura University

Effect of Earthquakes on slope stability

تأثير الزلازل على ثبات الميول

El-Nimr.A.[1], Gabr.A.[2], & Wakeel.A.[3]

1 Prof.Dr. Ahmed El Amin El nimr, Professor of Geotechnical Engineering, Faculty of Engineering, Mansoura University.
2 Ass. Prof. Adel Gabr, Association Professor of Geotechnical Engineering, Faculty of Engineering, Mansoura University.
3 Eng. Ahmed Ossama EL Wakeel, B.sc. of Civil Engineering, Faculty of Engineering, Mansoura University.

المستخلص: تسبب انهيار الميول الترابية أو السدود فى كوارث انسانية وبيئية. على سبيل المثال فإن أنهيار سد ترابى أو ضفة نهر قد يتسبب فى محو القرى او المدن المجاورة له وذلك تبعا لحجم الأنهيار الحادث. تنتشر الزلازل فى صورة موجات تتسبب فى حدوث إزاحات أفقية ورأسية وتغيرات مفاجئة فى الأجهادات الرأسية والأفقية والرئيسية وكذلك زيادات متباينة فى ضغط المياه البينية مما قد يتبعه أنهيارات فى جسور المجارى المائية والسدود. وقد يتسبب الزلزال الواحد فى عشرات من الأنهيارات والأنزلاقات الأرضية شديدة الخطورة على الأنسان والمنشآت.
تم إجراء دراسة متغيرات للميول الترابية لتقييم رد فعل الميول المختلفة تحت تأثير زلازل مختلفة الشدة وذلك للعديد من القطاعات الهندسية للميول باستخدام برنامج Geo-slope 2007 فى تحليل الميول المختلفة و تعيين معامل الأختزال فى ثبات الميل للميول المختلفة. أظهرت النتائج أنه بمجرد التأثير على الميل بزلزال ولو منخفض الشدة يحدث إنخفاض واضح فى قيمة معامل أمان الميل. يقل معدل الإنخفاض تدريجيا بزيادة شدة الزلزال.

Abstract: Failure of slopes usually leads to human and/or environmental disasters. For example, the failure of an earth dam or a riverbank may eradicate villages or even towns, depending on the failure size. Earthquakes propagate from the source fault in the form of waves; these waves induce horizontal and vertical movements which are associated with sudden changes in the vertical, horizontal, principal stresses, and in the generation of excess pore water pressures, leading to failures in soil slopes and dams. Only one earthquake may cause tens of slope failures and landslide cases endangering human beings and structures.
A parametric study was performed on a soil embankment in order to assess the response of the slope under the effect of different earthquakes to the geometry of soil slopes, as well as the characteristics of input ground motions. An approach to get the siesmic reduction factor for the different slopes under the effect of different earthquakes was developed. The computer program Geo-slope (2007) is used in the analysis. Results showed that just applying the earthquake, even with minor magnitude, causes a significant reduction in the safety factor for the slope, and this reduction rate decreases gradually with increasing the earthquake magnitude.

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1. Introduction

Instability related issues in constructed as well as natural slopes are common challenges to both researchers and professionals. In construction areas, instability may result due to rainfall, increase in groundwater table and change in stress conditions. Similarly, natural slopes that have been stable for many years may suddenly fail due to changes in geometry, external forces and loss of shear strength (Abramson et al. 2002). Thielen et al. (2005) stated that, "The combination of intense rainfalls, steep topography and soil conditions are critical". Nepal has been facing challenges of large number of water induced disasters such as landslides or slope failures mainly along the Highways. Likewise, Tayler & Burns (2005) stated that, "Earthquakes are the greatest threat to the long term stability of slopes in earthquake active zones". In addition, the long term stability is also associated with the weathering and chemical influences that may decrease the shear strength and create tension cracks. In such circumstances, the evaluation of slope stability conditions becomes a primary concern everywhere.

The engineering solutions to slope instability problems require good understanding of analytical methods, investigative tools and stabilisation measures (Abramson et al. 2002). According to Nash (1987), a quantitative assessment of the safety factor is important when decisions are made. Likewise, Chowdhury (1978) stated that, "The primary aim of slope stability analyses is to contribute to the safe and economic design of excavation, embankment and earth dams". Development activities may face great challenges due to unstable grounds. Similarly, the slope failure may interrupt the established imperative services like traffic movement, drinking water supply, power production and similar infrastructures. In this way, the main motivation of stability analyses is to save human lives, reduce property damages and provide continuous services.

2. Scope of study

The scope of this study ,"Effect of dynamic loads on slope stability" is expected to address such instability problems. The Analytical solutions to instability problems are expected to contribute to improve the knowledge of these processes.

The Main aim of this study is to study the effect of different embankment parameters on the stability under the earthquake effect. This work is conserened with effect of different parameters on the side slope stability in case of occurrence of an expected dynamic loading introduced by an earthquake. The mathematical model used is reffered by "QUAKE/W" it is one of of the known Geo-slope Modelling set.

3.Numerical Analysis

3.1 Physical Model Description

3.1.1 Model Configuration

The model used in the study consisted of a homogeneous earth embankment of fixed height 5 m with variable slope angle (β), overlying a 10 m thick homogeneous soil foundation layer, as shown in Figure 3.1. The foundation layer was underlain by bedrock. The soil behavior is modeled in Goe-slope as a linear, perfectly plastic material with a Mohr-Coulomb yield condition and an associated flow rule. No water table was specified for the study and pore water pressures are assumed to be zero.

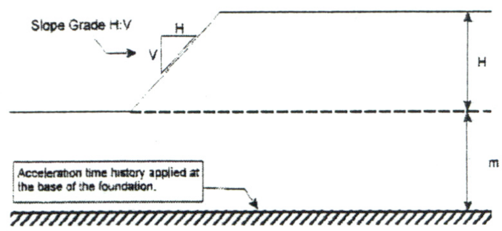

Figure 3.1 Embankment model used in the study

3.1.2 Soil Proprieties

The soil proprieties of the embankment and foundation layers are fixed during the analysis, the unit weight, Poission's ratio, damping ratio, and angle of internal friction are assigned in the analysis as shown in Table 3.1.

Table 3.1 Soil properties for embankment and foundation layers.

Layer	Foundation	Embankment
Unit weight (KN/m^3)	18	17
Poission's ratio	0.334	0.334
Damping ratio	0.1	0.1
angle of Internal friction (degree)	35	32

3.1.3 Gmax moduli

The small strain shear moduli Gmax are specified as function of effective stress. Figure 3.2 shows the function adopted for the embankment layer. The minimum value is 8000 kPa. Function for the Foundation material has a similar shape but with a higher minimum value.

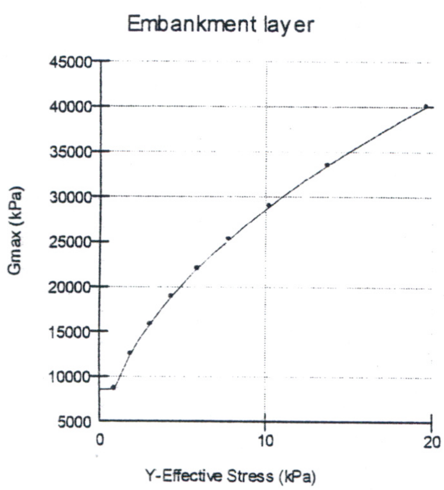

Figure 3.2 Gmax Function

3.2 Numerical Model Description

QUAKE/W is formulated for two-dimensional plane strain problems using small displacement, small strain theory. The governing motion equation for dynamic response of a system in finite element formulation can be expressed as:

$$[M]\{\ddot{a}\}+[D]\{\dot{a}\}+[K]\{a\}=\{F\}$$

Where:

[M] = Mass matrix,

[D] = Damping matrix,

[K] = Stiffness matrix,

{F} = Vector of loads,

$\ddot{a}$ = vector of nodal accelerations,

$\dot{a}$ = vector of nodal velocities, and

{a} = vector of nodal displacements.

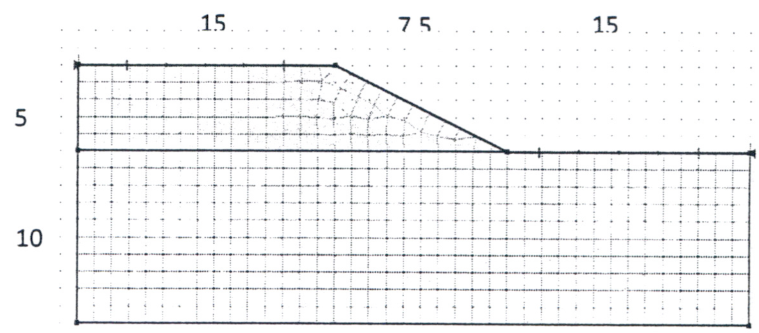

Figure 3.3 Finite element meshing of QUAKE/W model

3.3 Study Cases

This work studies the case of varying slope angle β under the effect of three different earthquakes with different Peak Ground Acceleration (PGA) ranged from 0.0 g to 1.0 g, for three values of slopes 1:1, 3:2, and 2:1 corresponds to ; 45°, 33°, and 26° respectivily. A number of 45 modeles have been analyzed in this work to achieve the aim of the study.

3.4 Strong Motion Records

Three records of strong motion records from earthquakes of moment magnitude from 6.4 to 7.4 are used in this analysis. Each record is scaled to differents peak ground acceleration(PGA). Starting with PGA value of 0.2g until reaching 1.0g with an increment of 0.2g. This variation of PGA is employed to investigate it's influence on the seismic response. The graphic representation of these records are shown in Figures 3.4.a, 3.4.b, and 3.4.c respectivily.

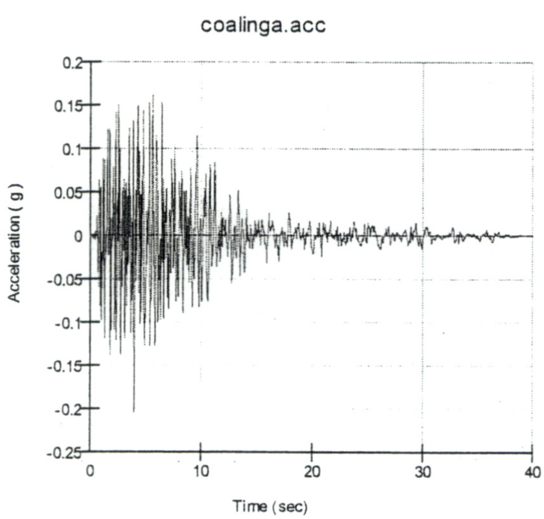

Figure 3.4.a Earthquake records for Coalinga earthquake

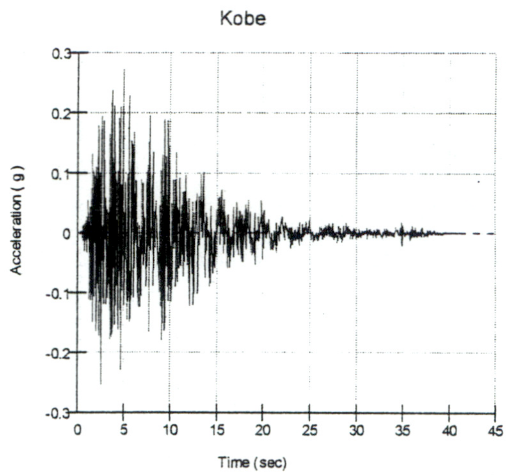

Figure 3.4.c Earthquake records for Kobe earthquake

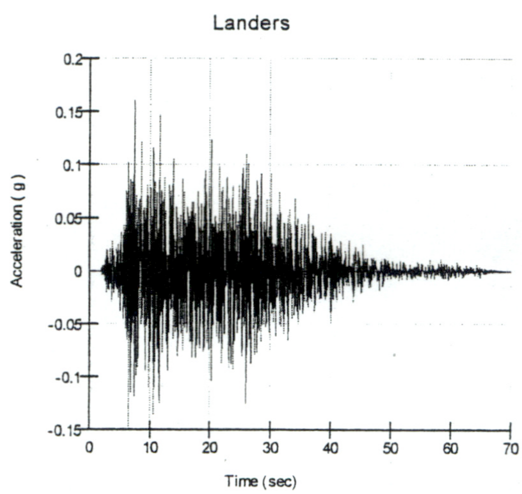

Figure 3.4.b Earthquake records for Landers earthquake

3.5 Analysis and results

Different embankments diemensions are first analyzed for static conditions to allow for the computation of static stresses along their respective critical failure surfaces once static equilibrium was reached. Then, the embankments were subjected to three different earthquake acceleration time histories to permit the computation of the dynamic stresses along their respective critical failure surfaces. The difference in stresses between dynamic and static conditions is then used to calculate seismic reduction factor of stability (Dynamic Factor of Safety / Static Factor of Safety).

The results illustrate the effect of the slope angle on seismic reduction factor of stability for PGA varied from 0.0g ,which represents the static state, to 1.0g. The Figures 3.5.a,3.5.b, and 3.5.c illustrate that by increasing the slope angle the dynamic factor of safety deacreses and the rate of reduction of the factor of safety deacrese by increasing PGA

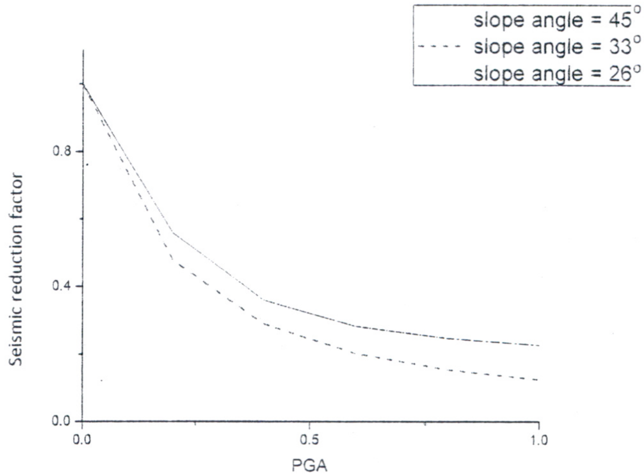

Figure 3.5.a Seismic reduction factor of stability for Coalinga earthquake

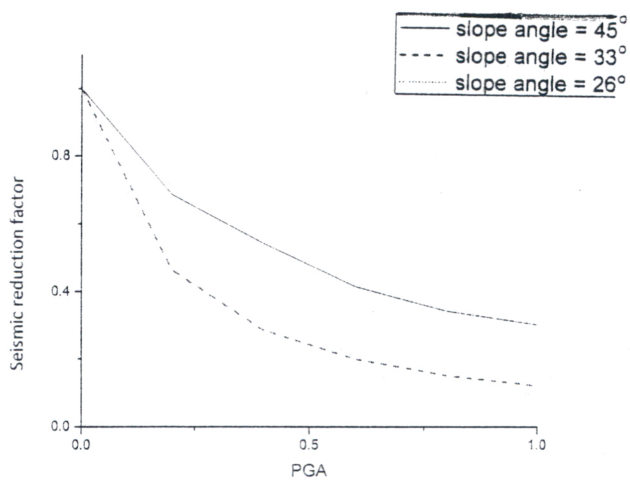

Figure 3.5.b Seismic reduction factor of stability for Kobe earthquake

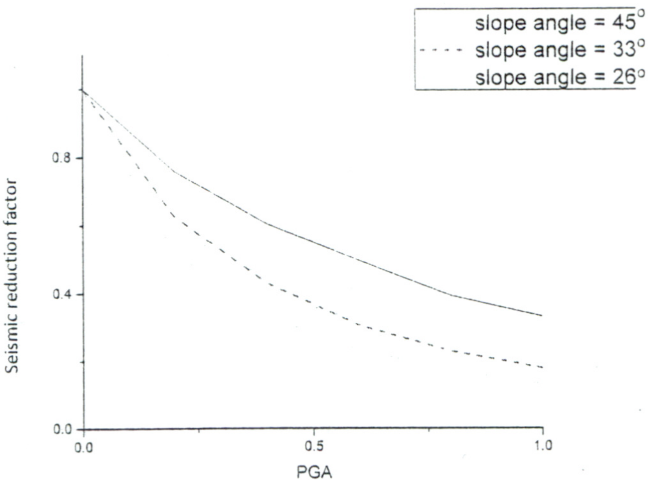

Figure 3.5.c Seismic reduction factor of stability for Landers earthquake

The figures illustrate that a reduction is introduced to the factor of safety of slopes by the presence of earthquake. This reduction factor icreases by increasing the slope angle β, e.g. in figure 5.56 at PGA equales 0.2 the reduction factors for slope angles 26°, 33°, and 45° are 0.4, 0.47, and 0.56 respectivily. Also the figures show that the rate of reduction factor is very high at small PGAs and the rate deacreses by incresing the PGA, e.g. in Figure 5.56 for slope angles of 26°, 33°, and 45° for PGA ranges 0.0g to 0.2g, the reduction is 0.44, 0.52, and 0.6, respectivily. However the reduction in factor of safety for PGA varies from 0.2g to 0.4g is founded 0.2, 0.18, and 0.6.

4. Conclusion

This work presents a study for the overall stability of a typical sandy slope under the effect of different earthquakes of different magnitudes. The most significant results are:

i. The earthquakes with its different magnitudes cause a reduction in slopes factor of safety.

ii. This effect varies according to the earthquake magnitude and the geometric shape of the slope.

iii. A marked decrease in the slope factor of safety occurs at earthquake of PGA 0.2, and 0.4. This rate decreases gradually by increasing the earthquake magnitude.

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