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A Study About Effect Of Soil Model On Slope Under Vibration Load

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ABSTRACT

This paper presents the effect of soil material model on slope under vibration loading. A hard consistency clay is assumed within an example slope profile with the height of 10m and angle 25^{o} for the evaluations. The linear elastic, Mohr-Coulomb and hardening soil models are considered using 2D finite element method by dynamic analysis. The results indicate that the velocities evaluated by the soil models are within the safety limits and accepted for the design. The soil models almost perform same values for factor of safety (not for linear elastic) and velocities. This study is believed to be beneficial for the applications in practice.
Key words: Slope, dynamic analysis, material model, finite element method

INTRODUCTION

Due to urbanization, a particular infrastructure works on which vibrations are generated by such as railways are often subjected to follow a near or top of slope structures, thus the vibrations effects from them will need to be rigorously assessed from a construction viewpoint and stability of slope in both. For slope stability analysis, the conventional limit equilibrium methods are usually applied in geotechnical practice investigating the equilibrium of a soil mass tending to move downslope under the influence of gravity. In limit equilibrium analyses, the available shear strength and shear stress of soil mass is calculated along the slip surface and then a factor of safety (FS) that is ratio of shear strength to stress resistance is greater than 1 is aimed for the slopes to be stable. For the details of the analysis the readers are referred to the past surveying [1-3]. Alternately, the pseudostatic method is an enhancement of conventional limit equilibrium analyses evaluating the seismic stability of an earth slope by applying a horizontal acceleration [4]. Although this analysis has some value, it is an only rough approximation of the physical mechanism acting in the field and thus should be applied only with engineering judgment seriously [5].

One of the efficient skills performing the slopes analysis is the finite element method (FEM) that may also work as supplementary to the other methods for both static and dynamic analysis. Low frequency vibrations can be calculated with a pseudostatic analysis. However, when the frequency of dynamic load is equal or higher than the natural frequency of soil, the vibration effects have to be calculated with a dynamic analysis. The vibration effects using FEM depend on many factors and the soil modeling is the important one among them. Apart from the linear elastic model, any available soil model offered from the literature can be used for vibration effects in dynamic analysis [6].

Under vibration loading peak particle velocity observed could be a good indicator of damage to structures and the structures that can readily tolerate a peak particle velocity of 50mm/sec can be considered in good condition without any risk of damage. However, due to amplification effects between the ground and structure, 25mm/sec particle velocity can be set to prevent damage to buildings or geotechnical structures such as slopes [7].

In this paper, a dynamic analysis is done for an example slope profile subjected to a vibration loading coming from a typical train travelling on a railway on the top and toe of slope separately using 2D FEM. For the accuracy of solution, the effects of soil models are investigated. The material models regarded for soil are the linear elastic, Mohr-Coulomb and hardening soil.

MATERIAL AND METHOD

Material

An example of a typical slope profile as shown in Fig.1 is considered for the investigation of effect of soil models under vibration loading. The slope profile has the height of 10 m, the slope angle of 25^o and the unit weight of 20 kN/m^3. The ground water is well below toe of slope. The soil is considered as a cohesive soil (clay) representing a hard to very hard consistency with the assumed shear strength parameters of cohesion c=30 kPa and angle of internal friction ϕ=35^o. For an overconsolidated clay, the cohesion has a value not usually exceeding 30 kPa. The angle of internal friction generally lies between 20^o and 35^o. The elasticity modulus of the soil is taken as at least 60000 kPa regarding the soil consistency [8-9]. The basic material properties of the soil are given in Table 1. The source of vibration loading is assumed coming from a train travelling on a railway. The railway is taken into consideration with a concrete footing (the width of 2 m, the thickness of 0.50 m), on which rails are mounted. The footing is assumed to be elastic. The footing properties are given in Table 2. In addition to the weight of footing, the weight of train is taken as 50 kPa modeled as a uniformly distributed load. Vibrations caused by the train are transmitted through the footing into the soil of slope. These vibrations are simulated as a uniform harmonic loading with a frequency of 80 Hz [10]. A 40kPa amplitude induced by the train is thought from the considerations of [11]. Additionally, 0.5 sec period of harmonic motion from the train is regarded for the analysis.

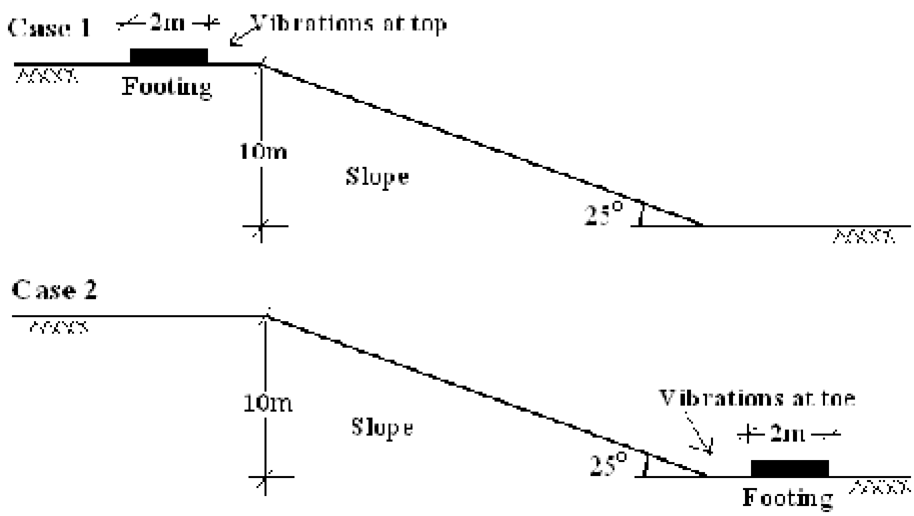

Figure 1 Slope profile of the worked example

Table 1 Material properties of soil

Parameter	Value
Material Model	Linear Elastic, Mohr Coulomb, Hardening,
Type of material behavior	Drained
Cohesion (c, kPa)	30
Angle of internal friction (ϕ)	35^o
Unit weight (γ, kN/m^3)	20
Young's modulus (E, kPa)	60000
Poisson's ratio (ν)	0.3

Table 2 Material properties of footing (a railway adopted in this study)

Parameter	Value
Normal stiffness (EA, kN/m)	$40x10^6$
Flexural ridity (EI, kNm^2/m)	$0.84x10^6$
Weight (kN/m/m)	24
Poisson's ratio (ν)	0.0

Method

The method for studying soil models on the slopes under vibration load is 2D FEM via PLAXIS dynamics analysis module. The basic equation of a soil mass under the influence of a dynamic load is given by:

$$M\ddot{u}+c\dot{u}+Ku=F \quad (1)$$

where*M* is the mass matrix, *u* is the displacement matrix, *c* is the damping matrix, *K* is the stiffness matrix and *F* is the load vector. The theory here is described on the bases of linear elasticity. Both the drained and undrained soil behaviors can be considered for the evaluations. The details of theory can be found in [12-13]. The vibrations within the soil mass are evaluated at various degrees of accuracy depending on the material behavior of soil mass. The material models that are taken to characterize the slope profile are [6]:

i) Linear elastic (LE): The soil mass is considered to behave fully elastic with constant stiffness properties of *E*and *ν*.

ii) Mohr-Coulomb (MC): The MC model involves five basic parameters by the consideration of elastic-plastic. For soil elasticity *E* and *ν*, for soil plasticity c, ϕ, and an angle of dilatancy are employed. Apart from those parameters, initial conditions are important for the deformations. Initial stresses are generating by adopting proper K_O-values.

ii) Hardening-Soil (HS): As compared to the MC, the soil stiffness is described much more accurately using the elasticity modulus from triaxial loading (E_{50}), triaxial unloading (E_{ur}) and oedometer loading (E_{oed}). HS model also accounts for stress-dependency of stiffness moduli as compared with the MC. In other words, all stiffnesses increase with pressure in the HS modeling.

As for the factor of safety (FS) by 2D FEM through PLAXIS, it is executing by reducing the strength parameters of the soil (*Phi-c reduction*). In the Phi-c reduction approach the strength parameters (ϕ, c) are successively reduced until failure of the structure occurs. The total multiplier$\Sigma Msf$is used to define the value of the soil strength parameters at a given stage in the analysis given by the equation:

$$\Sigma Msf = \frac{\tan \phi_{input}}{\tan \phi_{reduced}} = \frac{c_{input}}{c_{reduced}} \tag{2}$$

ΣMsf is set to 1.0 at the start of a calculation to set all material strengths to their unreduced values. Until failure occurs, the strength parameters are successively reduced automatically.

RESULT AND DISCUSSION

A dynamic analysis via FEM method is applied by a plane strain model with 15-noded elements. The model boundaries are done by absorbent boundaries as well as standard fixities. The FEM mesh is generated with a global coarseness. The initial stresses are generated using K_O=0.5. The calculations are composed of three phases: i) before vibration (stage construction), ii) under vibration (dynamic analysis), iii) after vibration (The vibration is turned off). By applying the method and following the procedure, the FS and the total responses of displacement, velocity and acceleration are obtained for each three phases of loading regarding three material models in the two cases. The FS is considered for only after phases (i) and (ii). The results of FEM models under vibrations are shown in Fig.2 for the cases 1 and 2. The responses before, under and after vibration are given in Table 3.

It is observed from the Table 3 that the displacements induced vibration is evaluated considerably smaller than the static case. This is referring the fact that overconsolidated soils under increasing load usually present a trend of expansion in volume due to particle reorientation. It can be seen from the table that the material models under vibration calculate different displacements. However, the HS model estimates relatively larger displacements than the others.

It is found from the results that the entire material models evaluate the velocities smaller than 50 mm/s [7], which can be tolerated for the design. In the case 1 under vibration, while the LE and MC models result the velocities nearly same with each other, the HS model are producing greater than them. On the other hand, the entire models nearly yield same velocities in the case 2 under vibration. Additionally, the case 2 slightly induces greater velocities than those of the case 1 in particular with the LE and MC models. This imply that the location of vibration load (toe or top) may generate different velocities within the slope and that toe of the slope may slightly more prone to vibration than top of the slope under the worked conditions in this study.

As for the FS values, the LE model is not able to produce reasonable FS values (that are not presented in Table 1). The similar inability is obtained for the HS only for the case 1 at the static calculation. It is observed from Table 1 that the FS values after vibrations are estimated same as the before ones. This is probably coming from the hard consistency of soil. As can be seen from the table, the FS values are evaluated nearly same by the models MC and HS. This may be due to the reason that both the MC and HS models utilize the same FS equation (Eq.2) by using same shear strength parameters. It is appeared from the results that the models generate slightly greater FS values in the case 2 than the ones of case 1. The case with the lower FS (case 1) can be said as critical that needs a conservative design, but as indicated above the case 1 under vibration at top are objected slightly lower velocities than the case 2 under vibration at toe.

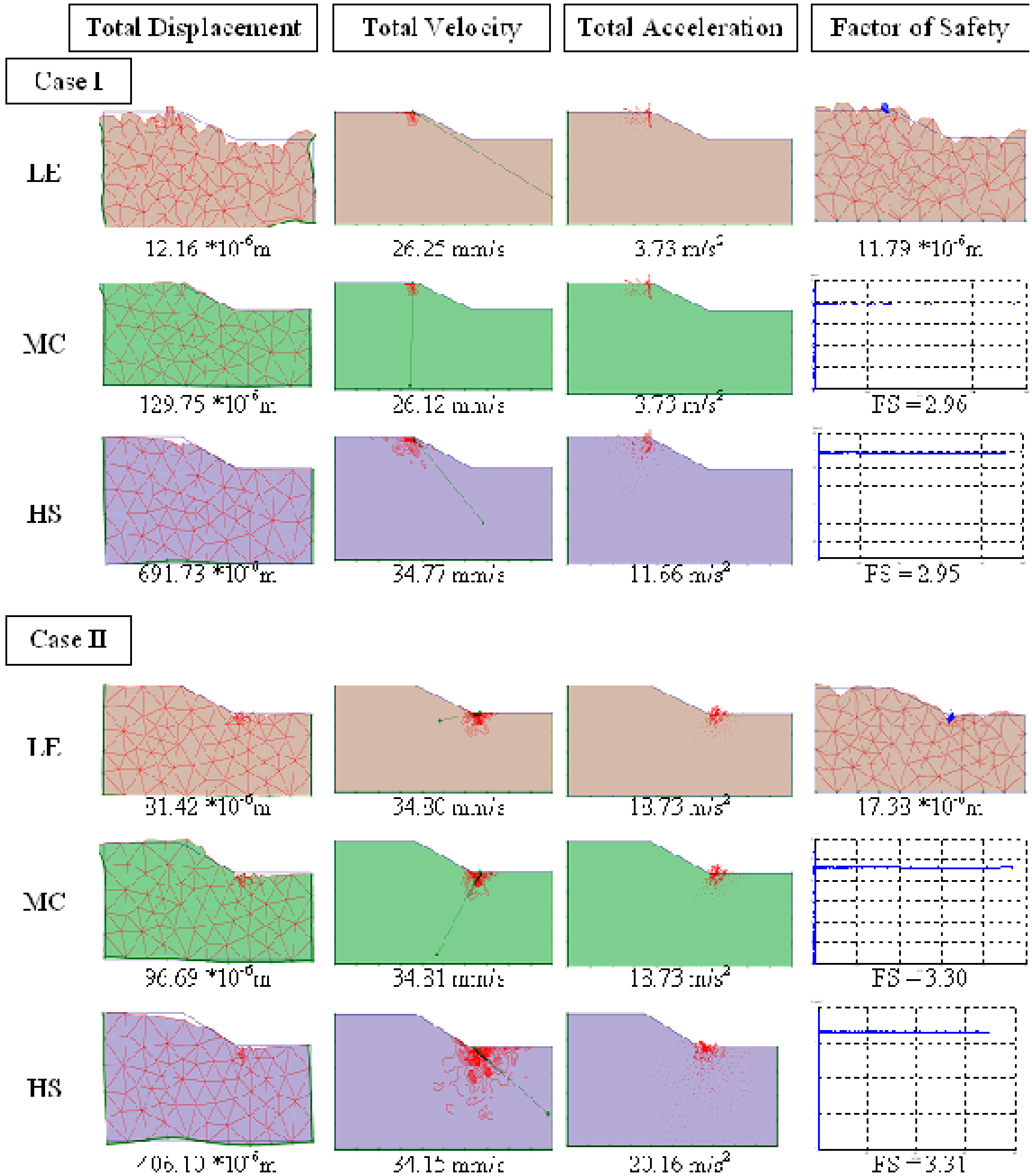

Figure 2 FEM models of soils under vibration (FS values are shown for after vibration. LE is shown by the total displacement from the Phi-c reduction approach for FS)

In consequence of the results and discussions, it can be said that the material models performed almost same FS values (unreasonable for LE) and velocities. As emphasized from the surveying, the velocities are a good indicator of damage to structures. For this study all velocities calculated by the material models can be tolerated for the design. Additionally, the location of vibration load (top or toe of slope) is slightly affecting the velocity response. As a preliminary study the dynamic analysis done via 2D FEM here can be beneficial for the applications in practice. A further study can be recommended for verification of the results by analytical methods and model tests.

Table 3 Results of soil models

Case 1				
Model	Parameter	Before Vibration	Under Vibration	After Vibration
LE	Total Displacement (mm)	21.51	$12.16 *10^{-3}$	$11.99 *10^{-3}$
	Total Velocity (mm/s)	-	26.25	$652.1 *10^{-3}$
	Total Acceleration (m/s^2)	-	3.73	$88.51 *10^{-3}$
	Factor of Safety	-	-	-
MC	Total Displacement (mm)	22.05	$129.8 *10^{-3}$	$203.6 *10^{-3}$
	Total Velocity (mm/s)	-	26.12	$727.3*10^{-3}$
	Total Acceleration (m/s^2)	-	3.73	$86.54 *10^{-3}$
	Factor of Safety	2.95	-	2.93
HS	Total Displacement (mm)	12.90	$691.7 *10^{-3}$	$662.2 *10^{-3}$
	Total Velocity (mm/s)	-	34.77	$436.0 *10^{-3}$
	Total Acceleration (m/s^2)	-	11.66	$68.60 *10^{-3}$
	Factor of Safety	-	-	2.95
Case 2				
Model	Parameter	Before Vibration	Under Vibration	After Vibration
LE	Total Displacement (mm)	21.22	$81.42 *10^{-3}$	$17.41*10^{-3}$
	Total Velocity (mm/s)	-	34.80	$867.7*10^{-3}$
	Total Acceleration (m/s^2)	-	18.73	$84.61*10^{-3}$
	Factor of Safety	-	-	-
MC	Total Displacement (mm)	21.97	$96.69*10^{-3}$	$120.3*10^{-3}$
	Total Velocity (mm/s)	-	34.81	$839.4*10^{-3}$
	Total Acceleration (m/s^2)	-	18.73	$83.76*10^{-3}$
	Factor of Safety	3.307	-	3.314
HS	Total Displacement (mm)	11.75	$406.1*10^{-3}$	$468.1*10^{-3}$
	Total Velocity (mm/s)	-	34.15	$633.3*10^{-3}$
	Total Acceleration (m/s^2)	-	20.16	$136.1*10^{-3}$
	Factor of Safety	3.312	-	3.307

CONCLUSION

A dynamic analysis is done for an example slope under vibration using 2D FEM in order to perform the soil material models (linear elastic, Mohr-Coulomb and hardening soil). The results indicate that the FS (not for LE) and the velocity known as a good indicator of damage to structuresare calculated almost same by the soil models. The location of vibration (induced at toe or top of slope) produces different velocity responses in particular for the LE and MC models. All velocities calculated can be tolerated and accepted for the design. This study is believed to be beneficial for the applications in practice. A further study can be recommended for verification of the results by analytical methods and model tests.

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