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Influence of Temperature on Infinite Soil Slope Stability

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ABSTRACT

The variation of safety factor of infinite soil slope with temperature was simulated in this paper. The safety factor of infinite slope with the thickness of failure mass ranging from 1 to 5 m and the overconsolidation ratio (OCR) ranging from 1 to 8 was simulated. The simulation results show that the safety factor of infinite slope decreases with increasing temperature for all values of OCR and thickness of failure mass. The results also show an increase in safety factor with increasing thickness of failure mass and values of OCR.

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INTRODUCTION

In construction projects above underground facilities generating heat, earthworks, such as landfills and embankments, are generally conducted for construction buildings, roads and other structures above these areas. The examples of facilities generating heat are underground nuclear waste repositories, buried high-voltage cables and buried hot pipes. The safety factor of earthwork slope must be checked to ensure that they are stable during the period of lifetime. The important parameter in the slope stability analysis is shear strength of soil.

It has been known for several decades that shear strength can be affected by temperature changes (e.g. Sherif and Burrous 1969; Maruyama 1969; Lagurous 1969; Hueckel and Baldi 1990; Kuntiwattanukul *et al.* 1995; Tanaka *et al.* 1997; Cui *et al.* 2000; Graham *et al.* 2001). Moreover, Uchaipichat (2013) recently derived the expression of the undrained shear strength including thermal effect and simulated the variation of undrained shear strength of porous media with temperature at different values of overconsolidation ratio. Thus, the safety factor of soil slope, which depends on the shear strength of soil, can vary with temperature changes.

The main purpose of this paper is to simulate the variation of safety factor of soil slope with temperature. The infinite slope stability analysis, in which the failure plane parallels to the slope surface, was used in simulation. Several conditions of values of overconsolidation ratio (OCR) of soil and failure mass thickness were assumed. The simulation results are carefully presented and discussed.

2. Infinite Slope Stability Analysis:

The infinite slope stability analysis is typically used for the case of failure plane parallels to the slope surface. The analysis can be conducted by considering the soil slice with the width of 1 unit in the failure mass as shown in Figure 1. The shear stress can be obtained by considering equilibrium of shear forces along the slip plane and can be expressed as,

$$\tau = \gamma z \sin \beta \cos \beta \quad (1)$$

in which, τ is the shear stress along the slip plane, γ is the unit weight of soil, z is the thickness of failure mass, β is the elevation angle of soil slope.

In case of undrained condition, the safety factor, a ration of undrained shear strength of soil to shear stress, can be expressed as,

$$FS = \frac{S_u}{\gamma z \sin \beta \cos \beta} \quad (2)$$

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in which, S_u is the undrained shear strength of soil.

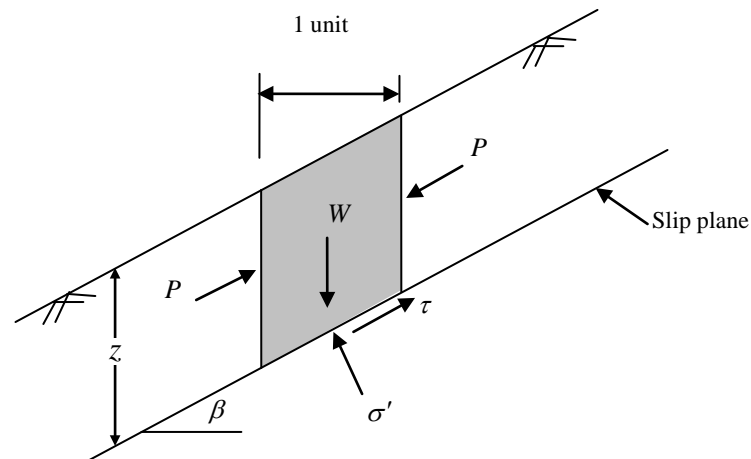


Fig. 1: Analysis of infinite slope stability.

3. Thermal Effect on Undrained Shear Strength of Porous Media:

The shear strength of porous media in geotechnical engineering field, such as rocks, sands, silts and clays, can vary with temperature. Uchaipichat (2013) derived the expression of undrained shear strength of porous media including thermal effect at particular ambient temperature T , which can be written as,

$$S_u = \frac{p'_o M}{2} \left(\frac{OCR}{r} \right)^{\frac{\lambda-k}{\lambda}} \text{EXP} \left[-\frac{nv}{k} (\alpha_f - \alpha_s) (T - T_o) \right] \quad (3)$$

where, S_u is the undrained shear strength of porous media, p'_o is the initial mean effective stress at temperature T_o , M is the slope of the critical state line on the mean and deviator stresses plane, OCR is the over consolidation ratio, r is the pressure ration on any particular unloading-reloading line between the normal compression and critical state lines, n is the porosity of soil, v is the specific volume, k is the slope of the unloading-reloading line in the semi-logarithmic compression, α_f and α_s are the coefficients of thermal expansion of fluid and solid phases, respectively. λ and k are the slopes on the plane between specific volume and logarithm of mean stress of the normal loading and reloading lines, respectively.

4. Simulation of Variation in Safety Factor of Infinite Slope with Temperature:

4.1. Material Properties:

In this study, the simulation was performed on silty soils used in the experiments conducted by Uchaipichat (2005). The material parameters are shown in Table 1.

Table 1: Material parameters.

Parameters	Values
κ	0.006
λ	0.09
n	0.36
M	1.17
α_s	3.4×10^{-5}
α_f	4.0×10^{-4}
n	0.36
r	2

4.2. Variation in Safety Factor with Temperature:

The variation in safety factor of infinite slope with temperature was performed on silt with OCR ranging from 1 to 8 and the thickness of failure mass (z) ranging from 1 to 5 m. The safety factor and the undrained shear strength were calculated using Equations (2) and (3), respectively. The elevation angle of soil slope was assumed to be 30° .

Figures 2 to 6 shows the variation in the safety factor with temperature of soil slope with different values of OCR at various values of thickness of failure mass. It is obvious that the safety factor of infinite slope decreases with increasing temperature for all vales of OCR and thickness of failure mass. It can also be noticed from the results that the safety factor decreases with increasing OCR for all values of thickness of failure mass. This corresponds to the simulation results of variation in undrained shear strength of soil with temperature and OCR presented by Uchaipichat (2013)

Figures 7 to 10 shows the variation in safety factor with temperature of soil slope with different values of failure mass thickness at various values of OCR. The simulation results show that the safety factor of infinite slope decreases with increasing thickness of failure mass. The results are similar to those of Uchaipichat (2012).

From the results, the infinite slope of high values of failure mass thickness (5 m) and high values of OCR is unstable at temperature greater than $60^\circ C$. In this case, the elevation angle of the slope must be reduced to maintain the stability of slope.

5. Conclusions:

Simulation of variation in safety factor of infinite slope with temperature was performed using the material parameters reported by Uchaipichat (2005). The safety factor of infinite slope with the thickness of failure mass ranging from 1 to 5 m and the overconsolidation ratio (OCR) ranging from 1 to 8 was simulated. The simulation results show that the safety factor of infinite slope decreases with increasing temperature for all vales of OCR and thickness of failure mass. The results also show an increase in safety factor with increasing thickness of failure mass and values of OCR.

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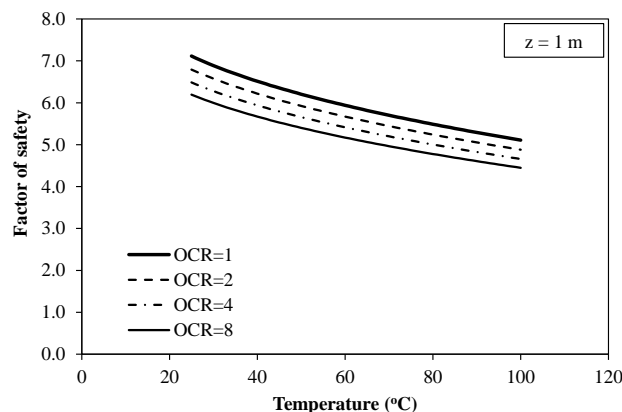


Fig. 2: Variation in safety factor of infinite slope with temperature at different values of OCR for $z = 1$ m.

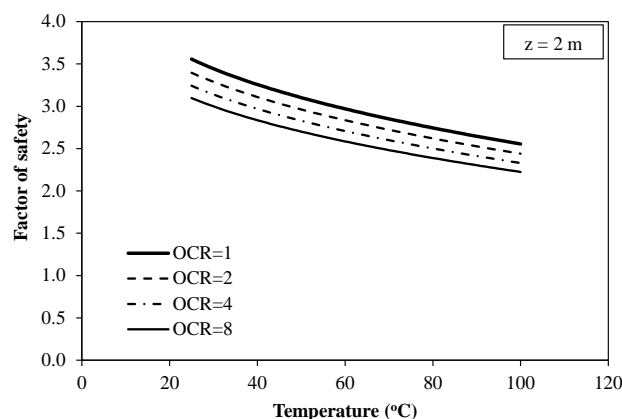


Fig. 3: Variation in safety factor of infinite slope with temperature at different values of OCR for $z = 2$ m.

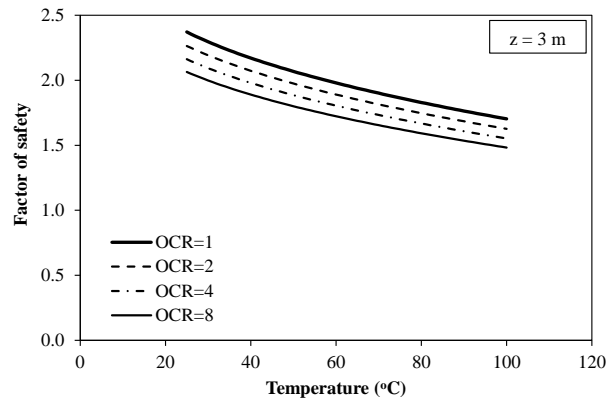


Fig. 4: Variation in safety factor of infinite slope with temperature at different values of OCR for z = 3 m.

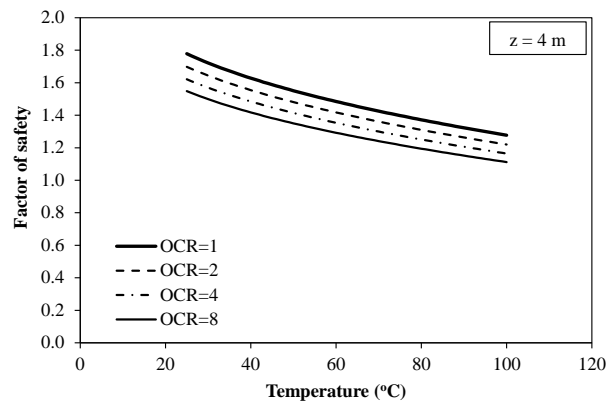


Fig. 5: Variation in safety factor of infinite slope with temperature at different values of OCR for z = 4 m.

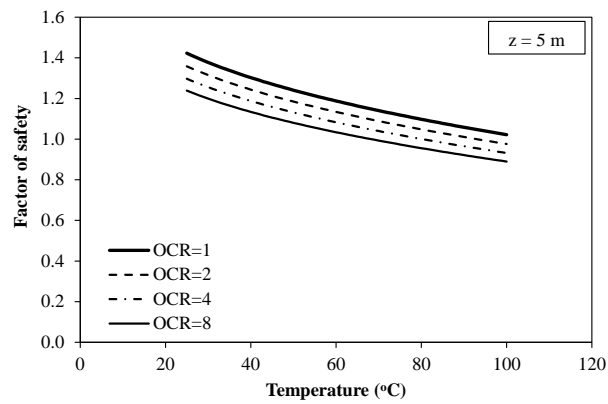


Fig. 6: Variation in safety factor of infinite slope with temperature at different values of OCR for z = 5 m.

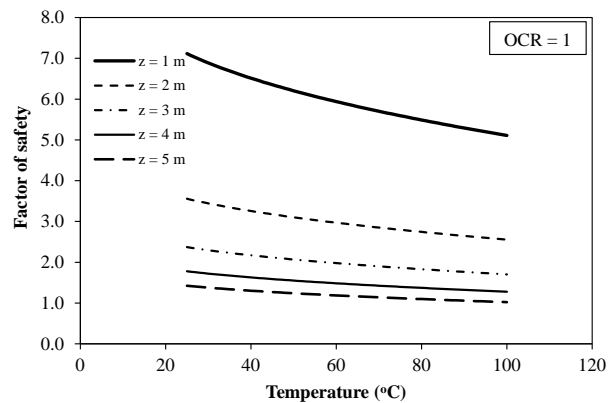


Fig. 7: Variation in safety factor of infinite slope with temperature at different values of failure mass thickness for OCR = 1.

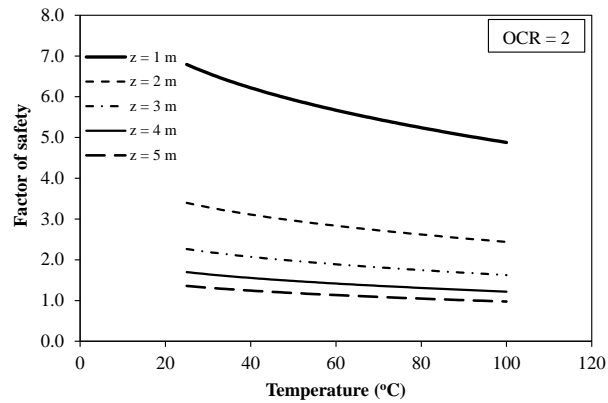


Fig. 8: Variation in safety factor of infinite slope with temperature at different values of failure mass thickness for OCR = 2.

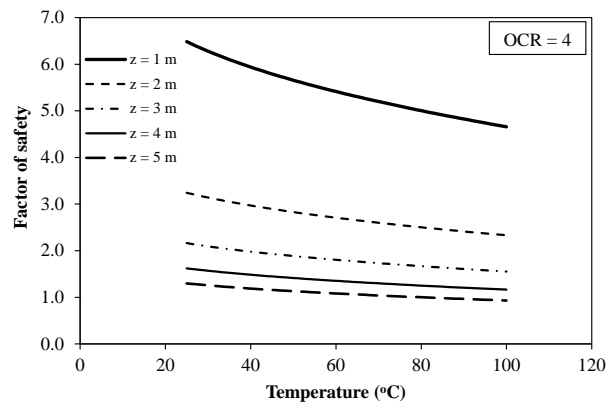


Fig. 9: Variation in safety factor of infinite slope with temperature at different values of failure mass thickness for OCR = 4.

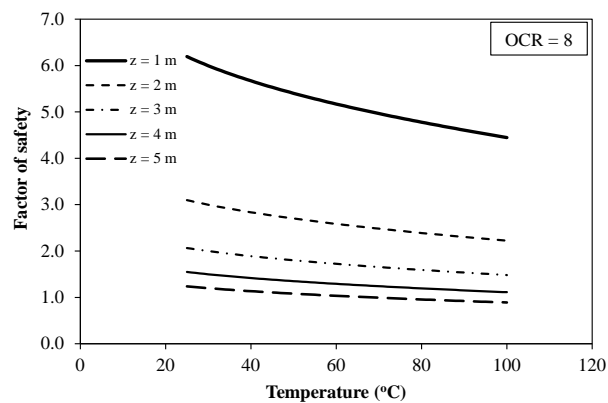


Fig. 10: Variation in safety factor of infinite slope with temperature at different values of failure mass thickness for OCR = 8.

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