Australian Journal of Basic and Applied Sciences, 8(9) June 2014, Pages: 219-228

AENSI Journals

Australian Journal of Basic and Applied Sciences

ISSN:1991-8178

Journal home page: www.ajbasweb.com

Effects of temperature and suction on safety factor against pullout failure of mechanically stabilized earth under undrained condition

Anuchit Uchaipichat

Department of Civil Engineering, Vongchavalitkul University, Nakhon Ratchasima, 30000, Thailand.

ARTICLE INFO

Article history:
Received 2 March 2014
Received in revised form
13 May 2014
Accepted 28 May 2014
Available online 23 June 2014

Keywords:
Mechanically stabilized earth; Thermal effect; Suction; Factor of safety; Undrained condition.

ABSTRACT

Background: Mechanically stabilized earths can be encountered in construction projects located on the area affected by facilities generating heat. The compacted granular soils are usually selected as backfill materials to produce essentially free-draining paths. However, it is difficult in some areas to find granular soils which have to be hauled from other areas. In order to decrease construction costs, the fine-grained soils may be allowed to use in some projects and the short-term or undrained condition analysis must be performed to calculate factor of safety. However, the shear strength of soils, the essential parameter in safety factor calculation, can increase with increasing matric suction but decrease with increasing temperature. **Objective:** The main purpose of this study is to derive the expression of safety factor against pullout failure of mechanically stabilized earth including temperature and suction effects and simulate the variation in safety factor with temperature and suction under undrained condition. **Results:** The simulation results show that the safety factor against pullout failure under undrained condition decreased with increasing depth for all values of temperature. The results also show that the safety factor for all steel strip layers decreased with increasing matric suction for the suction ranging from 0-100 kPa but increased win increasing matric suction for suction greater than 100 kPa. Moreover, the factor of safety decreased with increasing temperature for all values of matric suction**. Conclusion:** The expression of safety factor against pullout failure of mechanically stabilized earth including temperature and suction effects was derived in this study. The simulation of variation in safety factor with temperature and suction under undrained condition was performed on a wall reinforced by ribbed galvanized steel strips. The simulation results show a decrease in safety factor against pullout failure under undrained condition with increasing depth and temperature. The safety factor for all steel strip layers decreased with increasing matric suction at low level of suction.

To Cite This Article: Anuchit Uchaipichat., Effects of temperature and suction on safety factor against pullout failure of mechanically stabilized earth under undrained condition. ***Aust. J. Basic & Appl. Sci.,*** *8(9): 219-228, 2014*

INTRODUCTION

Thermo-mechanical behaviors of soils surrounding underground facilities generating heat have been investigated for several decades (e.g. Sherif and Burrous 1969; Maruyama 1969; Lagurous 1969; Hueckel and Baldi 1990; Kuntiwattanakul *et al*. 1995; Tanaka *et al*. 1997; Cui *et al*. 2000; Graham *et al*. 2001; Uchaipichat 2010a, 2013). Typical examples of these types of facilities are underground nuclear waste repositories, buried high-voltage cables and buried hot pipes. The earthworks in construction projects, such as embankment and landfills, located on the area affected by these facilities can be encountered.

In the earthworks, mechanically stabilized earths have been used as retaining structures for several decades. The compacted granular soils are usually selected as backfill materials to produce essentially free-draining paths. However, it is difficult in some areas to find granular soils which have to be hauled from other areas. In order to decrease construction costs, the fine-grained soils may be allowed to use in some projects and the short-term or undrained condition analysis must be performed to calculate factor of safety.

However, the shear strength of soils, the essential parameter in safety factor calculation, can increase with increasing matric suction (e.g. Vanapalli *et al*. 1996; Khalili and Kahbbaz 1998; Uchaipichat 2010b, c; Uchaipichat and Man-koksung 2011) but decrease with increasing temperature (Sherif and Burrous 1969; Maruyama 1969; Lagurous 1969; Cui *et al*. 2000; Graham *et al*. 2001; Uchaipichat 2010a). Furthermore, Uchaipichat (2014) extended the expression for undrained shear strength of saturated porous media at particular ambient temperature based on critical state concept derived by Uchaipichat (2013) to simulate the variation of

Corresponding Author: Anuchit Uchaipichat, Department of Civil Engineering, Vongchavalitkul University, Nakhon Ratchasima, 30000, Thailand
E-mail: anuchitu@yahoo.com

undrained shear strength of unsaturated soils with temperature and suction. Thus, the safety factor of mechanically stabilized earth also varies with temperature and suction.

The main purpose of this study is to derive the expression of safety factor against pullout failure of mechanically stabilized earth including temperature and suction effects and simulate the variation in safety factor with temperature and suction under undrained condition. The simulation was performed on a wall reinforced by ribbed galvanized steel strips. The properties of backfill material were obtained from Uchaipichat (2005).

Safety Factor Against Pullout Failure Of Strip-Reinforced Earth Including Thermal And Suction Effects Under Undrained Condition:

Typically, the stability of mechanically stabilized earth depends on the friction between the reinforcement and the backfill material behind the wall. Figure 1 shows the general layout of the mechanically stabilized earth. A failure plane occurring behind the wall divides the backfill soils into two zones, namely active and resistant zones. The driving force acting on the wall occurred from the movement of the soil mass in the active zone towards the wall while the resistant force occurred from the friction force between the reinforcement surfaces and the soil mass in the resistant zone.

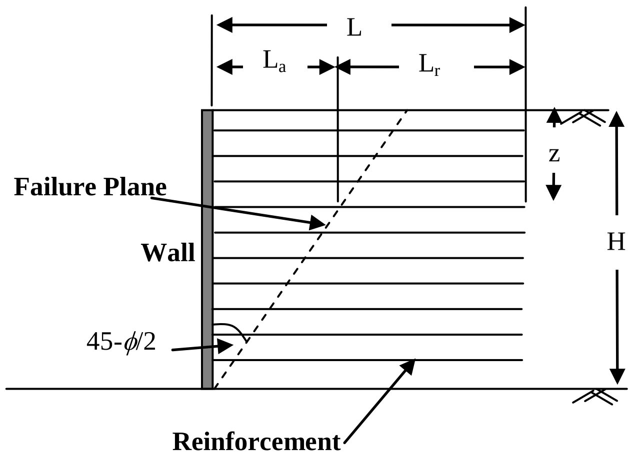

Fig. 1: Failure plane in reinforced earth

Juran and Christopher (1989) proposed the tie-back theory, in which the failure plane makes an angle of 45^o minutes a half angle of internal friction of backfill soils (ϕ) with the vertical. Therefore, the length of reinforcements can be expressed as,

$$L_r = L - L_a \quad (1)$$

$$L_a = (H - z)\tan\left(45^o - \phi/2\right) \quad (2)$$

in which L is the total length of reinforcement. L_a and L_r are the lengths of reinforcements in the active and resistant zones, respectively.

The resistant force against pullout force due to movement of soil mass in the active zone away from the resistant zone, depending on cohesion and friction between soil and reinforcement, can be expressed as,

$$P_r = (c_\alpha + \sigma'_v \tan\delta)A_s \quad (3)$$

where, P_r is the pullout resistant force, c_α and δ are cohesion and friction angle between soil and reinforcement and A_s is a surface area of reinforcement in the resistant zone. σ'_v is the vertical effective stress which can be expressed as,

$$\sigma'_v = (\sigma_v - u_a) + \chi s \quad (4)$$

where σ_v is the total vertical stress, u_a is the pore air pressure, s is the matric suction within the soils, defined as the difference between pore air pressure and pore water pressure, and χ is the effective stress parameter, which can be expressed as (Khalili and Khabbaz 1988),

$$\chi = \begin{cases} 1 & \text{for } \dfrac{s}{s_e} \le 1 \\ \left(\dfrac{s}{s_e}\right)^{-\Omega} & \text{for } \dfrac{s}{s_e} > 1 \end{cases} \tag{5}$$

in which, s_e is the air entry suction. Khalili and Khabbaz (1998) suggest that the values of Ω are assumed to be 0.55.

The lateral pressure acting on the wall is due to movement of soil mass in the active zone away from the resistant zone. The effective lateral earth pressure can be expressed as (Bell, 1915),

$$\sigma'_h = K_a \sigma'_v - 2c\sqrt{K_a} \tag{6}$$

in which, c is the cohesion of backfill soils, and K_a is the coefficient of active earth pressure, which can be expressed as,

$$K_a = \tan^2(45 - \phi/2) \tag{7}$$

Thus, the lateral forces acting on the wall equal to,

$$\sum P_h = K_a \sigma'_v A_{wall} - 2c\sqrt{K_a} A_{wall} \tag{8}$$

Considering the direction of forces, the pullout resistant force in Equation (3) and the term $2c\sqrt{K_a} A_{wall}$ in Equation (8) are the resistant forces while the term $K_a \sigma'_v A_{wall}$ in Equation (8) is the driving force. Thus, the safety factor (FS), the ratio between resistant forces and driving forces, can be expressed as,

$$FS = \frac{2c\sqrt{K_a} A_{wall} + (c_\alpha + \sigma'_v \tan\delta) A_s}{K_a \sigma'_v A_{wall}} \tag{9}$$

In case of undrained condition, the value of ϕ is equal to zero and the cohesion is equal to the undrained shear strength. Thus, the value of K_a becomes unity and the safety factor in Equation (9) becomes,

$$FS = \frac{2S_u A_{wall} + c_\alpha A_s}{\sigma'_v A_{wall}} \tag{10}$$

in which, S_u is the undrained shear strength of the backfill soil, which can vary with ambient temperature and suction. 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,

$$S_u = \frac{p'_o M}{2} \left(\frac{OCR}{r}\right)^{\frac{\lambda - k}{\lambda}} EXP\left[-\frac{nv}{k}(\alpha_f - \alpha_s)(T - T_o)\right] \tag{11}$$

where, 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 overconsolidation ratio, r is the pressure ratio 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.

The value of OCR can change with temperature and matric suction, and can be expressed as,

$$OCR = \frac{p'_T}{p'_c} \tag{12}$$

in which, p'_T is the mean effective stress at temperature T and can be expressed as

$$p'_T = p'_o \ EXP\left[-\frac{nv}{k}\left(\alpha_f - \alpha_s\right)\left(T - T_o\right)\right] \tag{13}$$

The value of p'_c can be expressed as,

$$p'_c = EXP\left(\frac{N - v}{\lambda}\right) \tag{14}$$

in which, N is the specific volume at the mean effective stress of 1 kPa and varies with temperature and matric suction. The values of N for different temperatures and matric suctions.

Simulation of Variation In Safety Factor With Temperature And Suction:

Material Properties:

The variation in safety factor against pullout resistance of mechanically stabilized earth was simulated. The backfill soils used in simulation was compacted silt with the unit weight of 15.3 kN/m^3. The soil properties reported by Uchaipichat (2005) are given in Table 1. Table 2 shows its values of N at different temperatures and matric suctions.

Table 1: Material parameters

Parameters	Values
s_e	18 kPa
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
OCR	2.0
r	2

Table 2: Values of N at different temperatures and matric suctions (Uchaipichat 2005)

Matric suction (kPa)	N		
	$T = 25^oC$	$T = 40^oC$	$T = 60^oC$
0	2.049	2.044	2.039
18	2.049	2.044	2.039
100	2.058	2.050	2.043
300	2.068	2.058	2.051

Simulations and Discussions:

The simulation in this study was performed on a wall with the height of 5 m reinforced by five layers of ribbed galvanized steel strips with 50 mm wide, 4 mm thick and 10 m long as shown in Figure 2. The layer 1 was installed at the depth of 0.5 m from the backfill surface. The spacing between the steel strips for both vertical and horizontal directions was 1 m. The cohesion between backfill soil and reinforcement was assumed to be two-third of the value of undrained shear strength obtained from Equation (11). The values of safety factor against pullout failure of mechanically stabilized earth at various temperatures and suctions were calculated using Equation (10).

Figures 3 to 5 show the variation in factor of safety against pullout failure with matric suction at temperatures of 25, 40 and 60^{o}C, respectively. It can be noticed that the safety factor against pullout failure under undrained condition decreased with increasing depth for all values of temperature. The simulation results also show that the safety factor for all steel strip layers decreased with increasing matric suction for the suction ranging from 0-100 kPa but increased with increasing matric suction for suction greater than 100 kPa as shown in Figures 6 to 10. Moreover, Figures 11 to 14 show a decrease in factor of safety with increasing temperature for all values of matric suction.

Unlike the results from simulations of safety factor against pullout failure of strip-reinforced earth using sand as backfill material at various suctions performed by Man-koksung and Uchaipichat (2011), with increasing matric suction, the area within the fine-grained soils such as silt affected by suction is much greater than that within the sands. Thus, the increase in effective stress and driving force acting on the wall with increasing matric suction within silts is also much greater than those within sands. As a result, the factor of safety decreased with increasing matric suction for the level of suction less than 100 kPa.

An engineer responsible for designing mechanically stabilized earths in the area affected by the facilities generating heat must take a serious attention, if using fine-grained soil as backfill materials, since the factor safety against pullout failure can decrease with changing temperature and matric suction. The simulation results for steel strip Layer 5 in Figure 10 show that the factor safety can decrease from 1.7 to the value less than 1.0 for the changes in temperature from 25 to 60^{o}C and suction from 0 to 100 kPa. It should be noted that failure occurs at the value of safety factor less than 1.0.

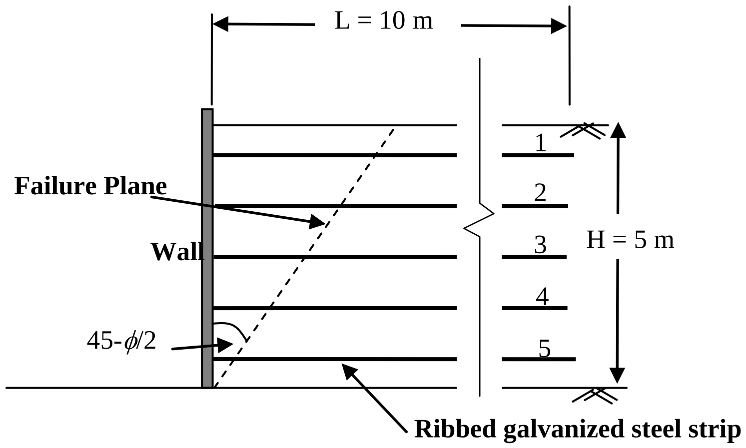

Fig. 2: Diagram of reinforced earth used in simulations

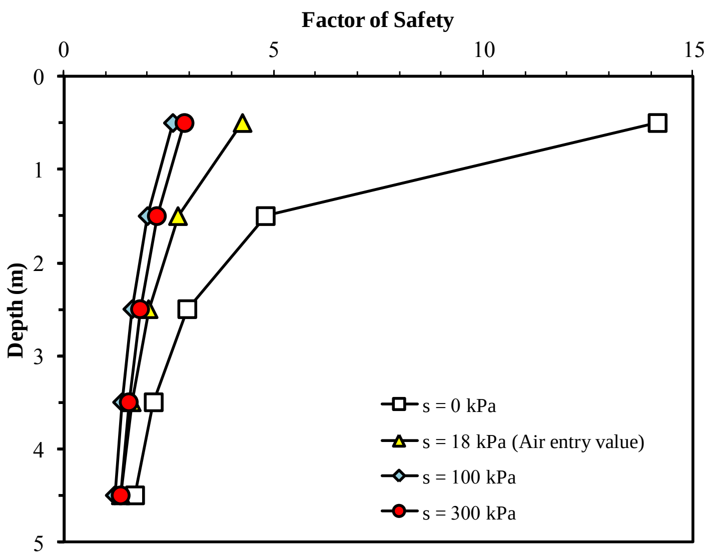

Figure 3: Variation in factor of safety against pullout failure with matric suction at temperature of 25^{o}C.

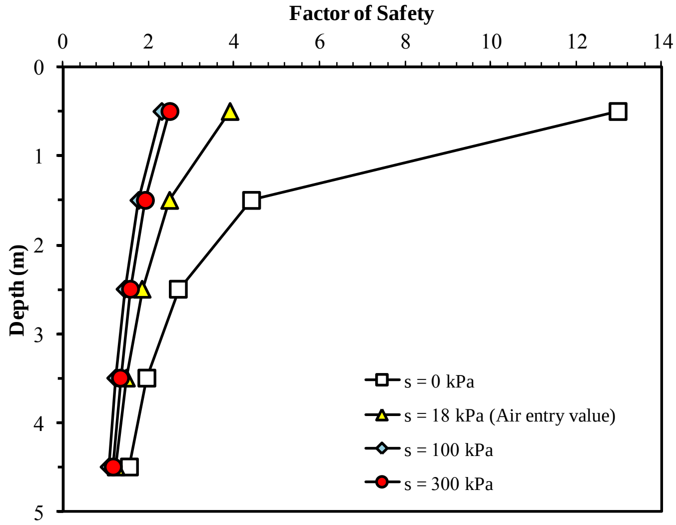

Fig. 4: Variation in factor of safety against pullout failure with matric suction at temperature of 40°C.

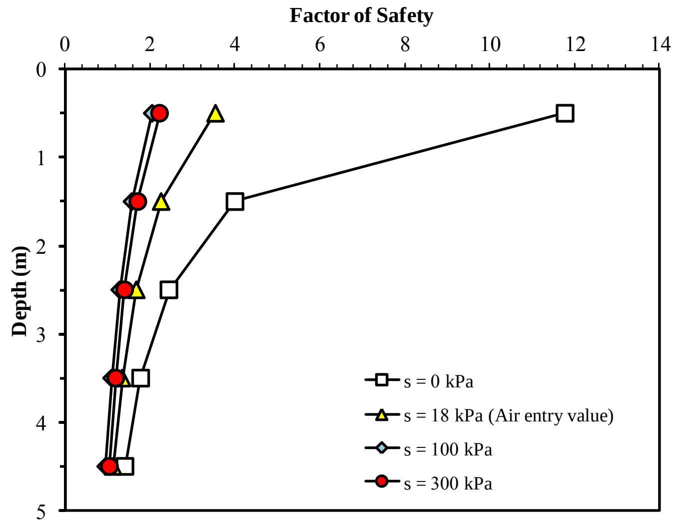

Fig. 5: Variation in factor of safety against pullout failure matric suction at temperature of 60°C.

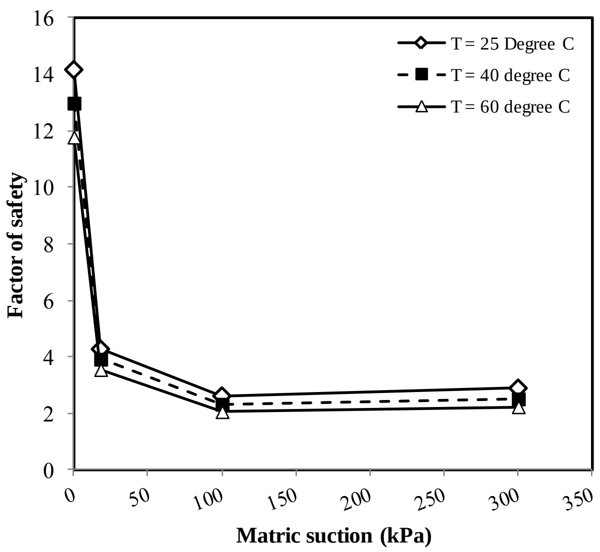

Fig. 6: Variation in factor of safety against pullout failure with matric suction at different temperature for steel strip Layer 1.

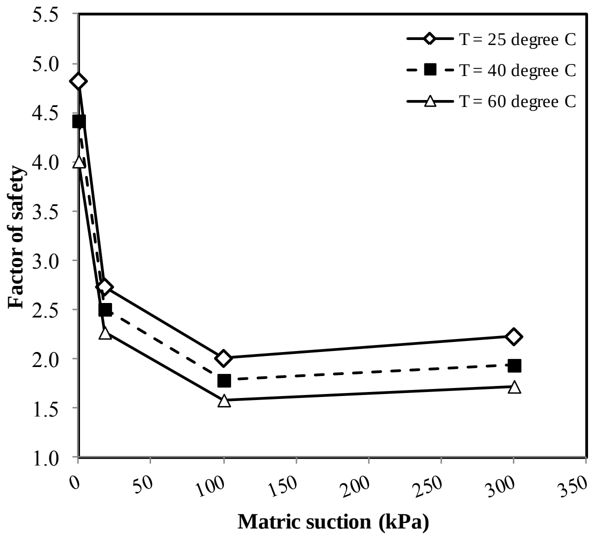

Fig. 7: Variation in factor of safety against pullout failure with matric suction at different temperature for steel strip Layer 2.

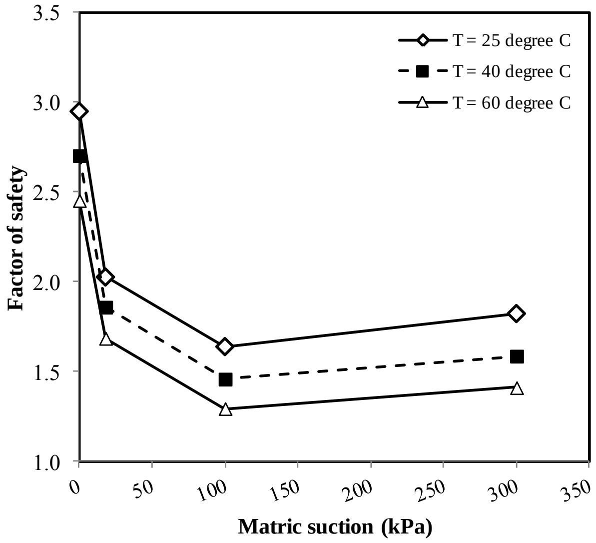

Fig. 8: Variation in factor of safety against pullout failure with matric suction at different temperature for steel strip Layer 3.

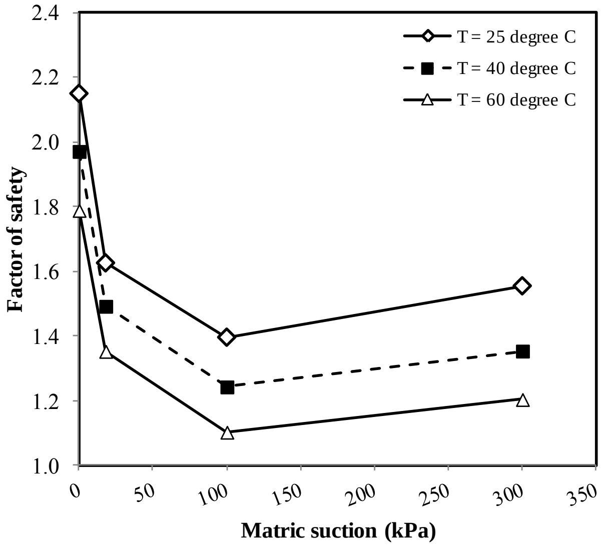

Fig. 9: Variation in factor of safety against pullout failure with matric suction at different temperature for steel strip Layer 4.

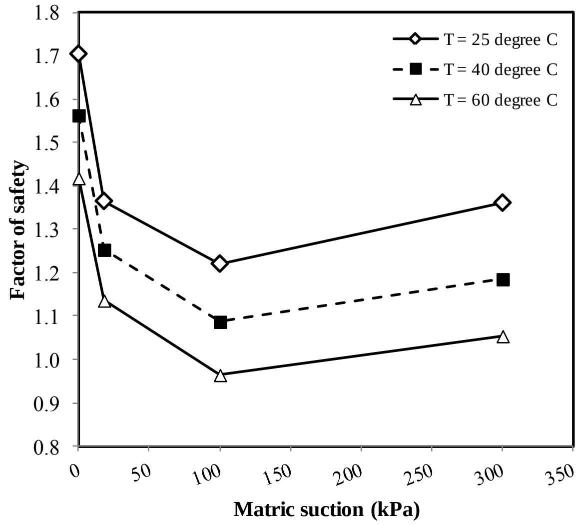

Fig. 10: Variation in factor of safety against pullout failure with matric suction at different temperature for steel strip Layer 5.

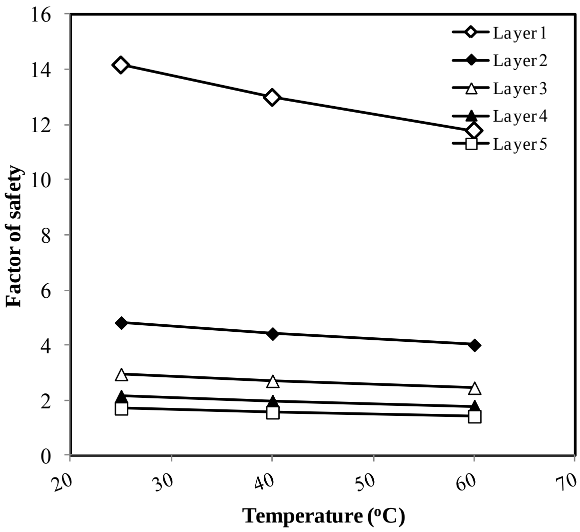

Fig. 11: Variation in factor of safety against pullout failure with temperature at matric suction = 0 kPa

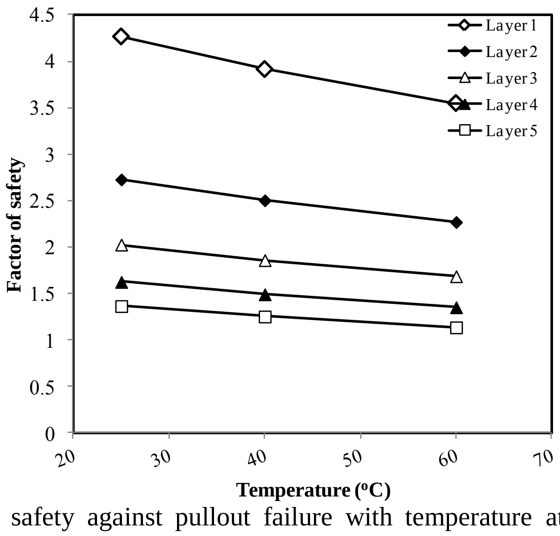

Fig. 12: Variation in factor of safety against pullout failure with temperature at matric suction = 18 kPa (Air entry value)

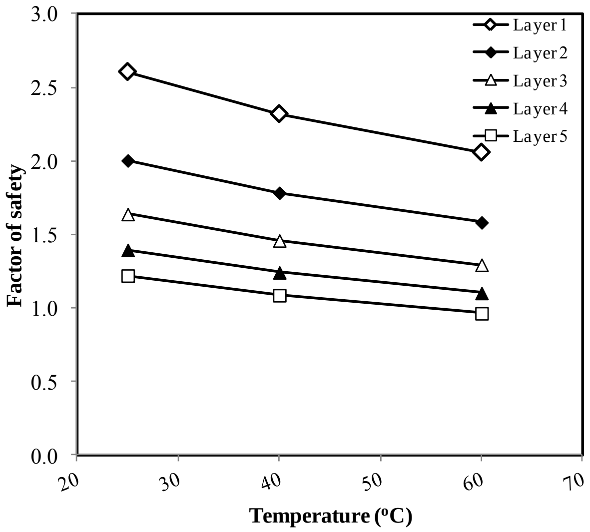

Fig. 13: Variation in factor of safety against pullout failure with temperature at matric suction = 100 kPa

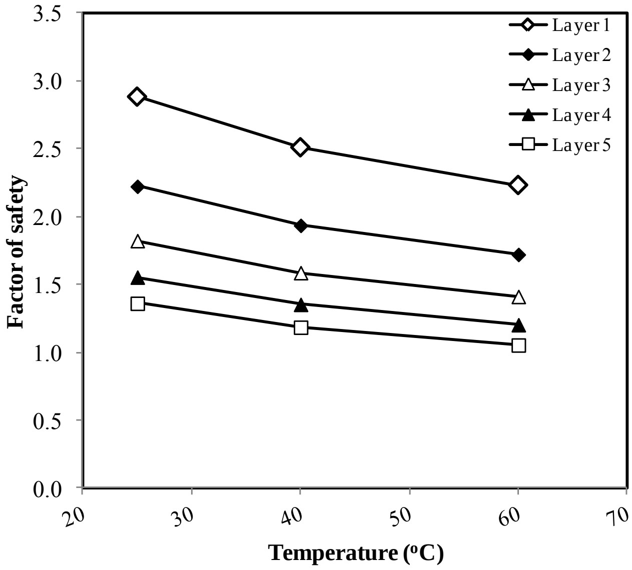

Fig. 14: Variation in factor of safety against pullout failure with temperature at matric suction = 300 kPa

Conclusions:

The expression of safety factor against pullout failure of mechanically stabilized earth including temperature suction effects was derived in this study. The simulation of variation in safety factor with temperature and suction under undrained condition was performed on a wall reinforced by ribbed galvanized steel strips. The properties of backfill material were obtained from Uchaipichat (2005). The simulation results show that the safety factor against pullout failure under undrained condition decreased with increasing depth for all values of temperature. The results also show that the safety factor for all steel strip layers decreased with increasing matric suction for the suction ranging from 0-100 kPa but increased with increasing matric suction for suction greater than 100 kPa. Moreover, the factor of safety decreased with increasing temperature for all values of matric suction.

ACKNOWLEDGEMENT

This work was supported of by Vongchavalitkul University.

REFERENCES

Bell, A.L., 1915. The Lateral Pressure and Resistance of Clay and the Supporting Power of Clay Foundations. A Century of Soil Mechanics, ICE, London, pp: 93-134.

Cui, J.U., N. Sultan and P. Delage, 2000. A Thermomechanical Model for Saturated Clays. Canadian Geotechnical Journal, 37: 607-620.

Graham, J., N. Tanaka, T. Crilly and M. Alfaro, 2001. Modified Cam-Clay Modelling of Temperature Effects in Clays. Canadian Geotechnical Journal, 38: 608-621.

Hueckel, T., G. Baldi, 1990. Thermoplasticity of Saturated Clays: Experimental Constitutive Study. Journal of Geotechnical Engineering, 116(12): 1778-1796.

Juran, I. and B.R. Christopher, 1989. Laboratory Model Study on Geosynthetic Reinforced Soils Retaining Wall. Journal of Geotechnical Engineering, 115(7): 905-926.

Khalili, N., and M.H. Khabbaz, 1998. A unique Relationship for the Determination of the Shear Strength of Unsaturated Soils. Geotechnique, 48(5): 681-687.

Kuntiwattanakul, P., I. Towhata, K. Ohishi, and I. Seko, 1995. Temperature Effects on Undrained Shear Characteristics on Clay. Soils and Foundations, 35(1): 427-441.

Lagurous, J.G., 1969. Effects of Temperature on Some Engineering Properties of Clay Soils. Proceedings of an International Conference on Effects of Temperature and Heat on Engineering Behavior of Soils, Highway Research Board, Special Report, 103: 189-193.

Man-koksung, E. and A. Uchaipichat, 2011. Simulations of Safety Factor against Pullout Failure of Strip-Reinforced Earth at Various Suctions. Electronic Journal of Geotechnical Engineering, 16(J): 1055-1066.

Maruyama, S., 1969. Effect of Temperature in Elastic of Clays. Proceedings of an International Conference on Effects of Temperature and Heat on Engineering Behavior of Soils, Highway Research Board, Special Report., 103: 194-203.

Sherif, M.A. and C.M. Burrous, 1969. Temperature Effects on The Confined Shear Strength of Saturated, Cohesive Soil. Proceedings of an International Conference on Effects of Temperature and Heat on Engineering Behavior of Soils, Highway Research Board, Special Report., 103: 267-272.

Tanaka, N., J. Graham and T. Crilly, 1997. Stress-Strain Behaviour of Reconstituted Illitic Clay at Different Temperature. Engineering Geology, 47: 339-350.

Uchaipichat, A., 2005. Experimental Investigation and Constitutive Modelling of Thermo-Hydro-Mechanical Coupling in Unsaturated Soils, University of New South Wales, Sydney, NSW, Australia.

Uchaipichat, A., 2010a. Laboratory Investigation of Thermal Effect on Compressive Strength of Cement Admixed Clay. Electronic Journal of Geotechnical Engineering, 15(M): 1277-1284.

Uchaipichat A., 2010b. Prediction of Shear Strength for Unsaturated Soils under Drying and Wetting Processes. Electronic Journal of Geotechnical Engineering, 15(K): 1087-102.

Uchaipichat, A., 2010c. Experimental Investigation on Loading Collapse Curve of Unsaturated Soils under Wetting and Drying Processes. Geomechanics and Engineering., 2(3): 203-11.

Uchaipichat, A., 2013. Simulation of Thermal Effect on Undrained Shear Strength of Saturated Porous Media. European Journal of Scientific Research, 113(1): 106-111.

Uchaipichat, A., 2014. Variation of Undrained Shear Strength of Unsaturated Porous Media with Temperature and Suction. ARPN Journal of Engineering and Applied Sciences, 9(3): 326-328.

Uchaipichat, A. and E. Man-koksung, 2011. Bearing Capacity Characteristic of Unsaturated Granular Soils. Advanced Material Research, 261-263: 989-993.

Vanapalli, S.K., D.G. Fredlund, D.E. Pufahl and A.W. Clifton, 1996. Model for the Prediction of Shear Strength with Respect to Soil Suction. Canadian Geotechnical Journal, 33: 379-392.