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Some Applications of Unsaturated Soil Mechanics in Thailand: an Appropriate Technology Approach

W. Mairaing[1], A. Jotisankasa[2] and S. Soralump[3]
[1]*Geotechnical Engineering Research and Development Center (GERD),*
[2]*Department of Civil Engineering, Faculty of Engineering, Kasetsart University, Bangkok, Thailand*
E-mail: mairaing@yahoo.com; fengatj@ku.ac.th; soralump_s@yahoo.com

ABSTRACT: This paper is involved with some applications of unsaturated soil mechanics on several problems in Thailand, namely rainfall-induced landslide, dam engineering as well as other volume change problems. In particular, the concept of appropriate technology has been considered in applying unsaturated soil mechanics for these problems. Utilization of the in-house-built miniature tensiometer and relative humidity sensors with conventional standard apparatus has been proposed as an appropriate technology in the country for testing of unsaturated shear strength, volume change as well as other unsaturated hydraulic properties (Soil-Water Characteristic Curve and permeability function). Regarding rainfall-induced landslide, unsaturated soil mechanics has been used in correlating rainfall intensity with slope instability and developing a critical rainfall criteria which has been used in Geographic Information System (GIS) to create dynamic hazard map as well as providing a real-time early warning of landslide based on soil moisture and rain-fall. A case of leakage detection technique as well as volume change analysis for embankment dam are briefly explained. Finally, some aspects of unsaturated soil mechanics education in Thailand is discussed.

1. INTRODUCTION

1.1 Problem statement

Many geotechnical and geo-environmental challenges in Thailand are related to unsaturated soils, for example landslide, construction and maintenance of dams, landfills as well as shallow foundations and pavements located in areas of problematic soils such as shrink-swell clay and collapsible loess, etc. There are also needs to ensure infrastructure serviceability and integrity in the future especially with the apparent adverse effect of climate change that results in more intense rainfall and a longer period of drought. The importance of unsaturated soil mechanics thus cannot be overemphasized.

1.2 Appropriate technology concept

Despite a very impressive research & development of unsaturated soil mechanics in the recent decades, the subject still lack somehow in attracting practicing engineers to adopt such new approach in practice. Blight (2008) argued that this is often the case, due to the lack of complete process of advancing new technology and concepts, together with lab & field validation, practical application and evaluation.

Fredlund (2009) also recognized this problem and proposed that some paradigm shifts are needed to facilitate the practice of unsaturated soil mechanics. Some of the important ones are paradigm shift with respect to methodologies for obtaining unsaturated soil property function and methodologies for numerical modeling. He also emphasized on the practical use of Soil-Water Characteristic Curve (SWCC) for determining the other unsaturated soil property functions such as shear strength, permeability etc.

Considering such pressing needs for innovative solution of emerging geotechnical and geo-environmental problems stated earlier, unsaturated soil mechanics is in a good position to offer its expertise. However, such geotechnical problems commonly take place in developing countries where the level of industrialization is not so advanced and budget is often limited. For example, the geotechnical laboratories in those countries might only be equipped with some basic conventional apparatus used only for teaching.

It is for this situation that the paper will explore the possibility of applying the appropriate technology concept on unsaturated soil engineering. Hazeltine & Bull (2003) has described appropriate technology as being "small scale, energy efficient, environmentally sound, labor intensive, controlled by the local community and additionally it must be simple enough to be maintained by the people using it". Well known since 1970's, this concept nevertheless has lost its strength in recent years due to marketing complication (Polak, 2010). However, now there are a number of integral concepts such as "sustainable development" and especially in Thailand, the concept of "Sufficiency economy" as initiated by HM King Bhumibol regains much popularity.

This paper makes no claim that all the aspects of appropriate technology have been fulfilled in all the case histories explained here, and the cases presented here would all be related to works by the Geotechnical group of Kasetsart University and arguably not covering all other works in Thailand.

2. RAINFALL-INDUCED LANDSLIDE

2.1 General mechanism

Slope failures in Thailand are generally triggered by heavy rainfall (in excess of 100-300 mm/day) as shown in Figure 1. The failures are of various modes, such as shallow slide (about 0.5-2 m), deep-seated slide, rock fall and slides along rock discontinuities. Destructive debris flow and flash flood also often took place together with thousands of shallow slides in a very wide area, especially in the cases of extremely heavy rainfall, e.g. ADPC (2006) and Soralump (2010).

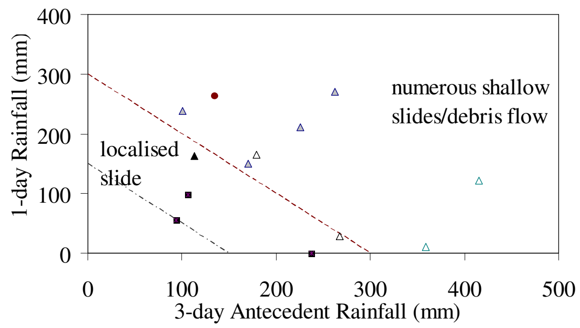

Figure 1 Rainfall patterns for past landslide events in Thailand

Various factors such as deforestation, oversteepening of the slopes, and population settlement in landslide-prone areas also contribute to increasing landslide risk. Yet, the major triggering factor is the increase in pore water pressure (decrease of soil suction) due to rain infiltration, which gives rise to decrease in shear strength and instability. For many slopes in Thailand, the soil profile at shallow depth is of negative pore water pressure and normally unsaturated during most times of the year (e.g. Jotisankasa et al., 2009). This soil suction gives rise to additional strength of the soil which helps stabilize the slope. Slopes become unstable after prolonged and heavy rainfall takes place, infiltrates the ground, and reduces the soil suction to zero, or even causes positive pore water pressure or a perched water table to rise. In particular, some slopes with a steep gradient (say greater that 45 deg) might fail even when the pore water pressure approaches zero (without necessarily becoming positive) as evidenced by Godt et al. (2009).

Nevertheless, ultimate failure of many slopes (especially those with smaller gradients) are triggered when pore water pressure goes positive (evidenced by assuming Factor of Safety of 1 and back-calculate the value of pore water pressure at failure). It is still the unsaturated flow that controls infiltration in the slope and thus the duration of rainfall prior to failure (which is so vital in designing an early warning system for landslide). Therefore, it is still important to have some understanding of unsaturated soil mechanics to realize a better solution for rainfall-induced landslide. In addition, alternating dry & wet cycle has been shown to cause reduction in shear strength of some weathered argillaceous rock in Northern part of Thailand (Jotisankasa & Tapparnich, 2010).

2.2 Required unsaturated soil properties

Since engineers want to identify the variation of slope stability (i.e. factor of safety) in different seasons, it is necessary to characterize the shear strength of soils at different moisture states. Early attempts at Kasetsart University to characterize unsaturated soil strength have been to use the total stress approach where the additional shear strength due to suction (capillary cohesion) was only related to the degree of saturation, S_r (Kunsuwan, 2005, and Mairaing & Thaiyuenwong, 2010). Hence the shear strength, τ_f equation is:

$$\tau_f = c + b \cdot (\ln S_r) + \sigma_n \tan\phi \tag{1}$$

where σ_n is the total normal stress (assuming u_a = 0), and c, b, $\tan\phi$, the material constants.

It is noted that if the soil is fully saturated, (S_r =1, lnS_r = 0), Eq (1) will be the same as the conventional Mohr-Coulumb equation. Therefore, there is an implicit assumption in Eq. (1) that there will be no additional capillary cohesion if the soil is fully saturated. This assumption might not be valid for clayey soils that have high air-entry suction because clays can have high suction (high capillary cohesion) even if fully saturated.

One of the most spatially extensive characterizations of unsaturated shear strength for Thai soils has been reported by Soralump (2007), Soralump et al.(2007), Soralump and Torwiwat (2009, 2010) for 307 undisturbed soils from the villages regarded as landslide-prone areas in Thailand and cover over 8 rock groups which sensitive to landslide in Thailand. Figure 2 shows some characteristics of the unsaturated shear strength obtained using direct shear tests with multi-stage shearing on samples having different degrees of saturation. This approach has been used to provide the criteria for early warning system for large area landslide based on GIS system as will be shown in the Section 2.4.

Furthermore, Soralump et al. (2007), Torwiwat and Soralump (2009) and Soralump (2010) has used the unsaturated shear strength to calculate the critical Antecedent Precipitation Index values (API_{cr}) of each rock group in Thailand. The values have been used for landslide warning in Thailand by comparing with API_t value which was calculated from the rainfall data. It has been proved that using API value instead of 3 days accumulated rainfall in the critical rainfall envelope gives a better warning time and accuracy (Fig 3).

Jotisankasa & Mairaing (2010) later elaborated the testing technique further in direct shear apparatus by incorporating a miniature tensiometer through the top cap to monitor soil matric suction during shearing as shown in Figure 4. The miniature tensiometer was manufactured at Kasetsart University using MEMs pressure sensor as described by Jotisankasa et al. (2007). The development was following the appropriate technology concept in the sense the device was simple enough to be used by practical engineers and readily applicable to the commonly used apparatus in the country.

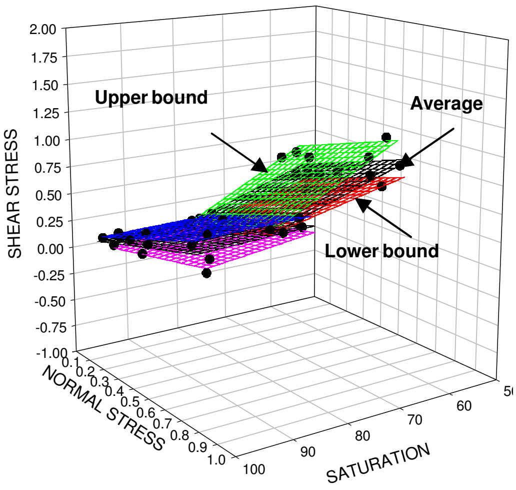

Figure 2 Strength reduction characteristic of sample with increasing soil moisture content (Soralump and Torwiwat, 2009)

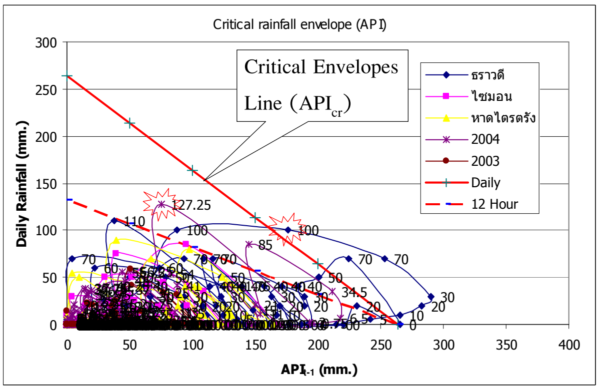

Figure 3 API envelop (Soralump, 2010)

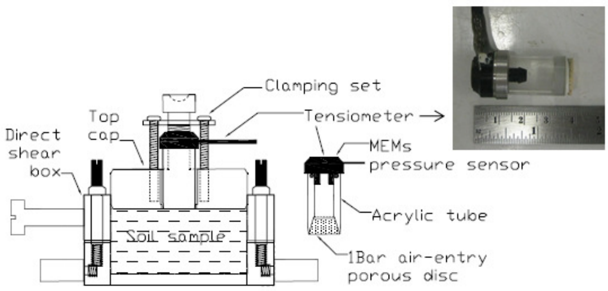

Figure 4 Suction-monitored direct shear apparatus

With such device, the relationship between unsaturated shear strength and suction as a variable could be realized. The Equation for unsaturated shear strength used by the authors is to consider the contribution of suction to shear strength as the capillary cohesion, c^s.

$$\tau_f = c' + (\sigma_n - u_a)\tan\phi' + c^s \tag{2}$$

$$c^s = (u_a - u_w)\chi\tan\phi' = \sigma^s \tan\phi' = (u_a - u_w)\tan\phi^b \tag{3}$$

Equations for the capillary cohesion variation with suction can be any of those proposed by Bishop (1959), Fredlund & Rahardjo (1993) or Lu & Likos (2006), where all parameters χ, σ^s, ϕ^b are functions of suction and degree of saturation and would show non-linear variation. Any choice of these equations does not seem to make much difference in the calculation results for practical purpose. It is not critical to estimate very accurately the factor of safety for slopes at a very high suction (and low S_r) since their factor of safety will be much greater than the value required for stability in design anyway. Some typical results are shown in Figure 5.

The Soil-Water Characteristic Curve (SWCC) of "undisturbed" sample from landslide site is normally determined using tensiometer and relative humidity sensors as well as pressure plate. Two testing methods are employed by the authors. The first one is the point-wise measurement method, by which the sample is gradually wetted (or dried) and suction monitored incrementally during each stage. A minimum curing period of several days between each increment was allowed for suction equilibration throughout the sample.

The second method is called continuous measurement, which is also used to determine permeability function based on simplified instantaneous profile principle (e.g. Hillel, 1998, Benson & Gribb, 1997). For the drying SWCC, the top surface of soil sample was left exposed to ambient air, and the soil suction was monitored continuously at three locations on sample's side as shown in Figure 6. The sample's weight was also continuously measured using an electric balance connected to a datalogger. For wetting SWCC tests, the top surface of sample is continuously wetted by way of water dripping from burette as shown in Figure 6.

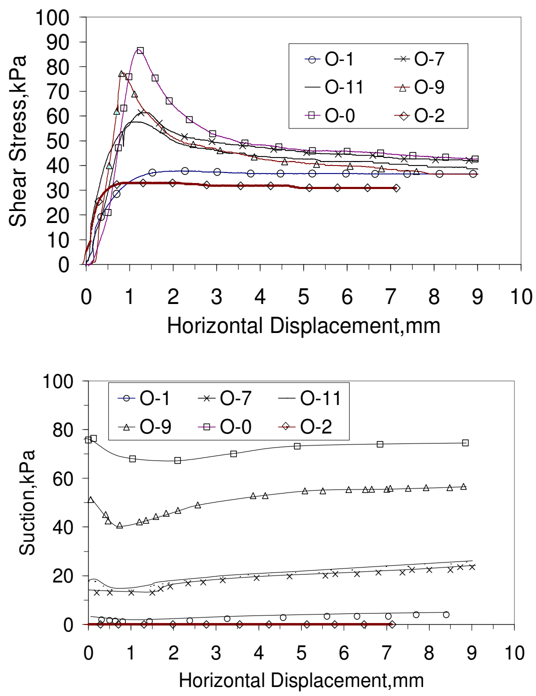

Figure 5 ypical results during constant water content shearing in the suction-monitored direct shear apparatus
(Jotisankasa and Mairaing, 2010)

The main advantage of the continuous SWCC measurement is the shorter test duration which is only a few days per one path (from suction of 90 to zero kPa). The permeability function is calculated using Darcy's law as shown in Eq (4).

$$k = \frac{v}{i} = \frac{\dfrac{dV_w}{A \cdot dt}}{\dfrac{d(z - s/\gamma_w)}{dz}} \qquad (4)$$

where dV_w is the change of volume of water in soil sample calculated from change in soil mass during test; A is the cross section area of sample; t is the elapse time; z is the elevation head of each tensiometer relative to the base of sample, s is matric suction, and γ_w the unit weight of water. Linear regression over about 30 data points was used in calculating the values of flux, v. For the drying test, the value of hydraulic gradient, i, is calculated using linear regression over the three tensiometer measurements.

There is nevertheless a difficulty in using this technique for wetting tests due to non-linearity of the pore water pressure distribution. This method is still not very accurate for wetting path. Yet, if the gradient, i, was calculated over only the upper and middle pore pressure measurement, the method tend to give a better results.

Typical results of the continuous drying tests on silty residual soil of sedimentary rock (mudstone/siltstone) from landslide area of Laplae, Uttaradit province (Jotisankasa & Tapparnich, 2010) are shown in Figure 7. During drying, the suction across the sample did not differ by more than 20%. As shown in Figure 7c, the drying SWCCs from both methods are in a good agreement.

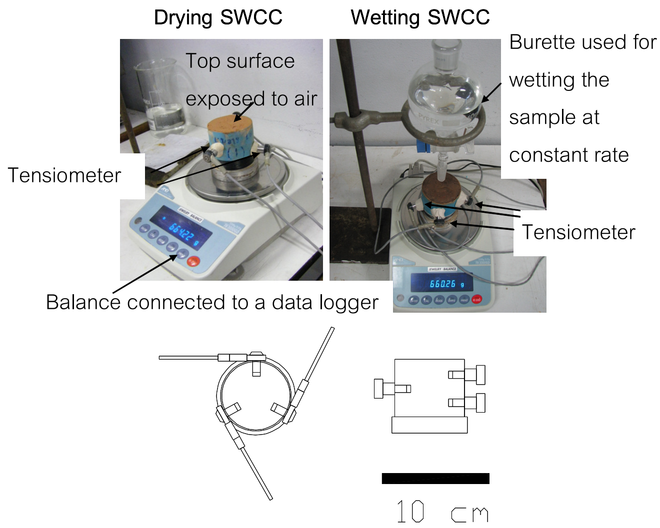

Figure 6 Experiment setup for the continuous measurement of SWCC

Some numerical analysis has also been performed to validate the permeability function results by simulating the drying test using Finite Element analysis (SEEP/W). A good agreement is obtained between the numerical analysis and experimental results as shown in Figure 8.

2.3 Field monitoring experience

The locations of instrumented slope sites where pore water pressure and suction are monitored by GERD are shown in Figure 9. An early device used for monitoring suction was the conventional tensiometer for irrigation purpose. Mairaing et al. (2006) used this type of tensiometer to study landslide behavior on hilly area around Kamala bay, an important tourist point in Phuket, southern Thailand. It was the first study in Thailand whereby the rain gauge and agricultural tensiometer were installed in the observation pit for change in water content as related to rainfall (Figure 10). Variation of soil suction was monitored from year 2003 to 2004 as shown in Figure 11. Rainfall intensity was measured by automatic rain gauge and record by data logger. Water content was determined by field sampling and laboratory testing. Matric suction was measured by agricultural tensiometer manually. From this study we found that water content and matric suction were changed according to the amount of rainfall. The upper soil layer appeared more sensitive to rainfall than the lower layer. There were however some questions regarding improper de-airing of the tensiometer during the second year of monitoring which might result in insensitivity of the matric suction reading to rainfall in the second year.

Jotisankasa et al., (2007, 2010) later applied the KU tensiometer (MEMs type) for monitoring the pore water pressure in the field as shown in Figure 10. It is well known that conventional tensiometers need periodic water saturation and water refilling of the reservoir during dry season to get rid of air bubbles forming within the reservoir of tensiometer. This is very important so that the tensile stress within soil water is always effectively transferred to the sensor. Based on the authors' experience in Thailand, for the installation depth greater than 1 metre, the frequency of tensiometer water-refilling needed is only once a year. The common practice is

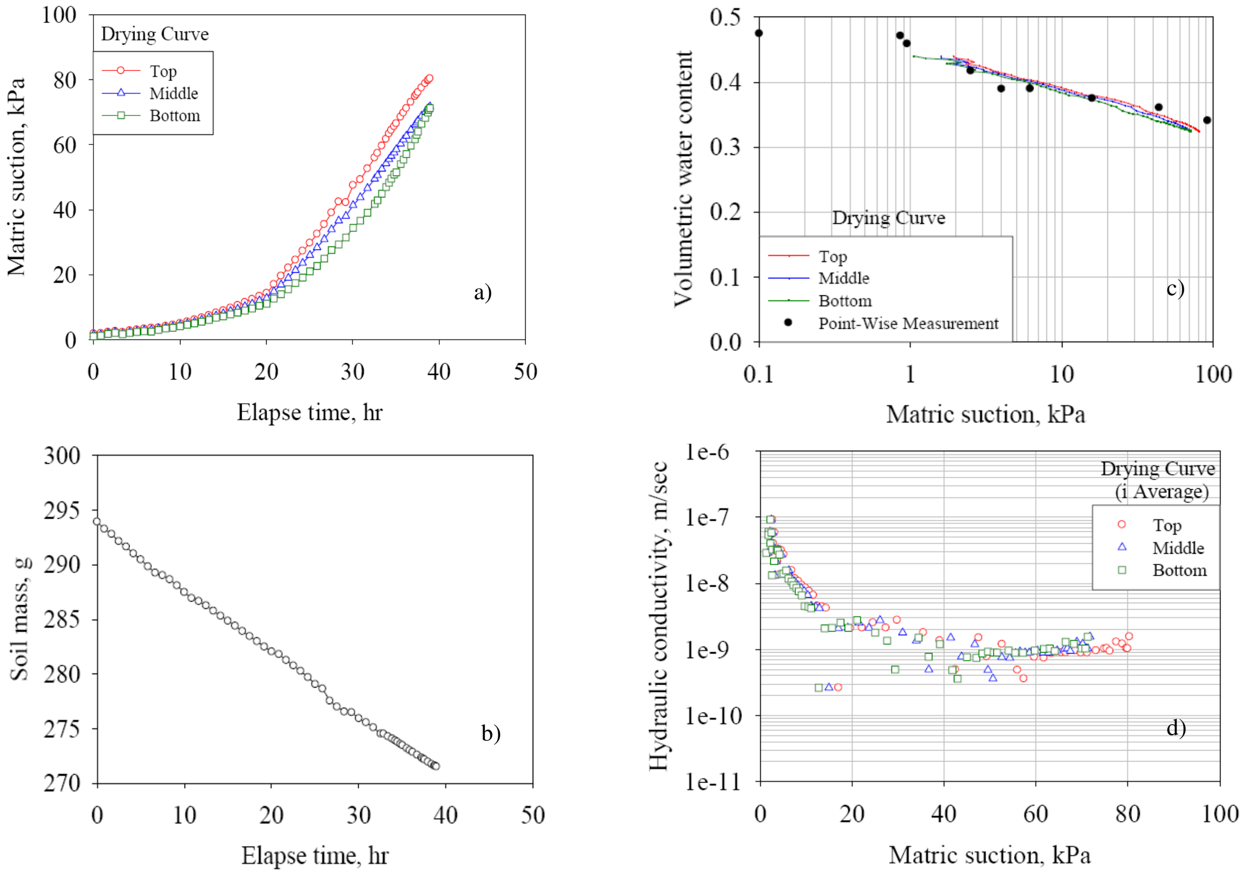

Figure 7 Typical results of continuous drying test for SWCC and k-function for argillaceous residual soil (Tapparnich, 2010) (a) matric suction during drying, (b) soil mass during drying, (c) SWCC and (d) permeability function

to refill and saturate the tensiometer with water after a dry season, just at the start of rainy season and the tensiometers usually work well for the rest of the rainy season.

The investigation of the slopes sites has been for several purposes; namely, validation of numerical analysis, investigation of stabilization performance as well as for safety evaluation. An example of long term monitoring results at a research slope of Thadan site, Nakhonnayok province is also shown in Figure 12.

The studied slope in Nakornnayok had failed in 2004 and then regraded to a slope of about 1:2 (V:H) before installation of instruments. The slope failure of soil mantle down to the bedrock in 2004 was triggered by an intense rainstorm of about 300mm in three days. The soil mantle on the slope is about 2-3 metre thick, of a volcanic rock parent material and classified as medium plasticity silts (MH/ML).

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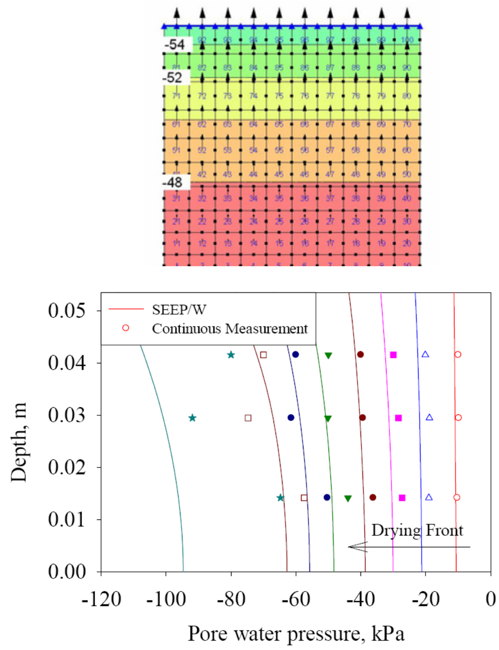

Figure 8 Finite element mesh for seepage analysis of a drying soil sample and comparison between the numerical analysis and experimental results of drying test (Tapparnich, 2010)

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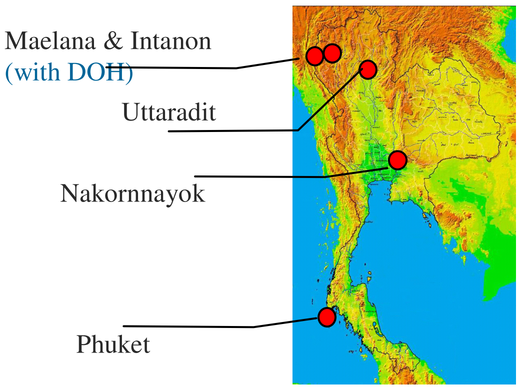


Figure 9 Locations of long-term instrumented slope sites by Geotechnical Engineering Research and Development, KU

In generally, the pore water pressure was negative and remained close to zero in rainy season. Only when the rainfall exceed about 100 mm/day that the pore water pressure coefficient ($r_u = u/(\gamma H)$) becomes about 0.17-0.20. Relationship between rainfall and pore water pressure variation has been studied using a variety of approach such as Finite element seepage analysis, Hydrological Tank model (Ohtsu et al., 2009) and Artificial Neural Network.

2.4 GIS application for hazard mapping and warning system

Landslide susceptibility mapping in Thailand has been developed by many government organization and universities in Thailand. Generally the Weighted Factor method and Logistic Regression techniques were used. The attempt at introducing the Geotechnical parameters such as strength reduction index of soil and factor of safety of infinite slope were done by Soralump (2007a,b) and Soralump et al.(2008 a,b). Precipitation with various return periods were also used for Weighted Factor method to obtain the series of landslide susceptibility and hazard maps based on the amount of precipitation (Figure 13).

However, recently the advancement in precipitation prediction and measurement together with the needs of semi-real time landslide warning system drives the anticipation of unsaturated soil mechanics to play a significant role in developing the dynamic landslide susceptibility map through the GIS system. Kunsuwan (2005) was the first in Thailand to perform the dynamic landslide hazard map based on the change of slope factor of safety from the induced precipitation. Soralump et al. (2008) insist in their concept of using API value for landslide warning by producing APIcr map (Figure 14) in the study area and used it to compare with APIt map for Rainfall Triggered Landslide values (RTL). The APIt values were obtained by using the result of volumetric water content calculated from the infiltration model proposed by Green and Ampt (1911). The scale of RTL was calibrated with the actual events to obtain the reliable scale of hazard levels.

The development of RTL's approach was done in two folds by Soralump et al (2010). First the prediction of precipitation contour map was done by using the satellite data to solve the problem of the lack of precipitation data in the remote area (Figure 15). Secondly, the calculation of slope factor of safety was done instead of RTL value. The slope stability analysis is done by the infinite slope concept in which the changing in shear strength is calculated based on the changing in volumetric water content from the precipitation through the modified Green-Ampt model (Chen and Young, 2006). All of the processes were embedded into the GIS application. With the appropriate speed of computer machine, all the processes including the acquiring the data can be used to produce the landslide susceptibility map of every 1-2 hours. Further development are planned to improve the warning system in the near future such as calculation of the probability of slope failure and so on.

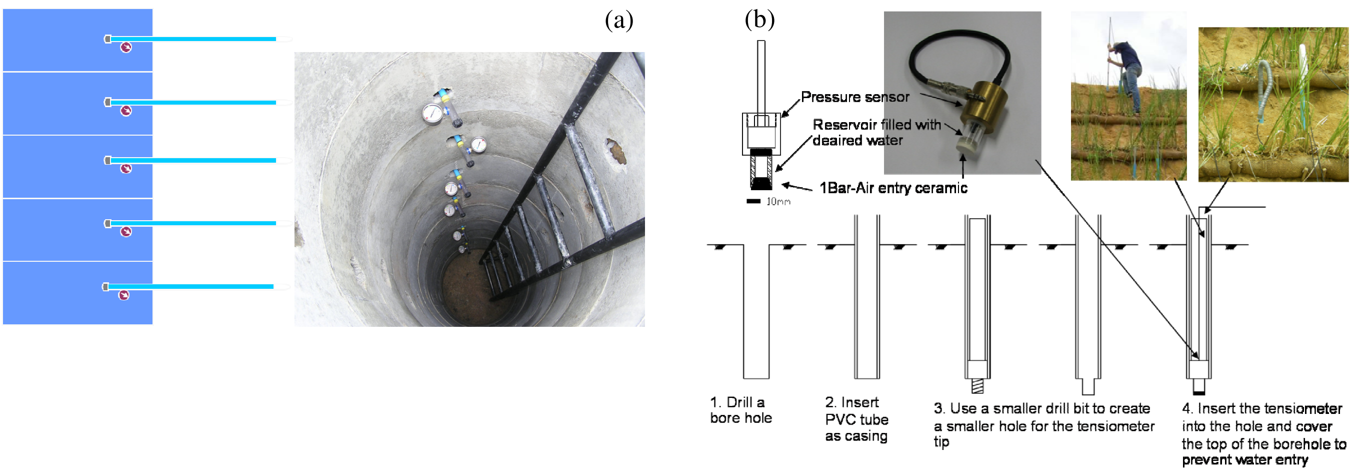
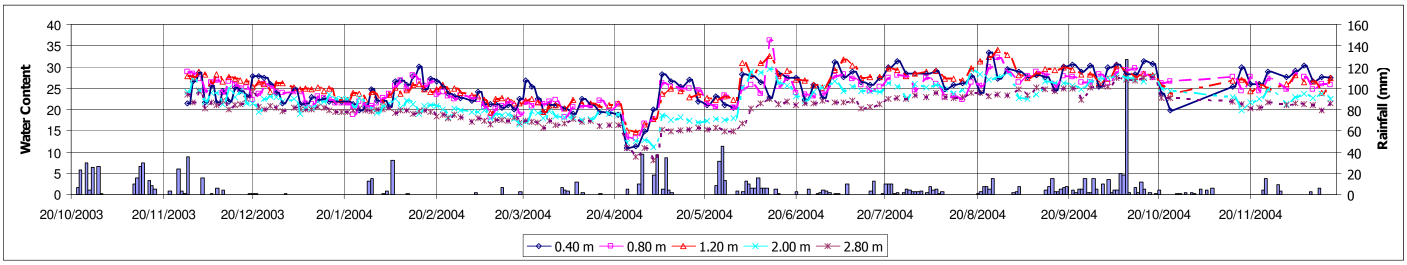
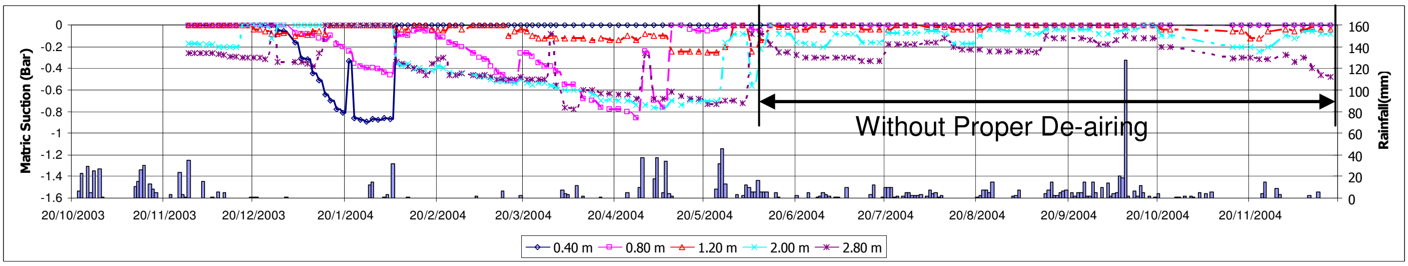


Figure 10. Two methods of tensiometer installation (a) at Phuket in 2003 to 2004. (Mairaing *et al*., 2006) (b) KU-Tensiometer and installation in the field (Jotisankasa *et al*., 2010)



a. Change in water content



b. Change in matric suction

Figure 11 Records of water content and matric suction related to rainfall at Phuket site (Mairaing *et al*., 2006)

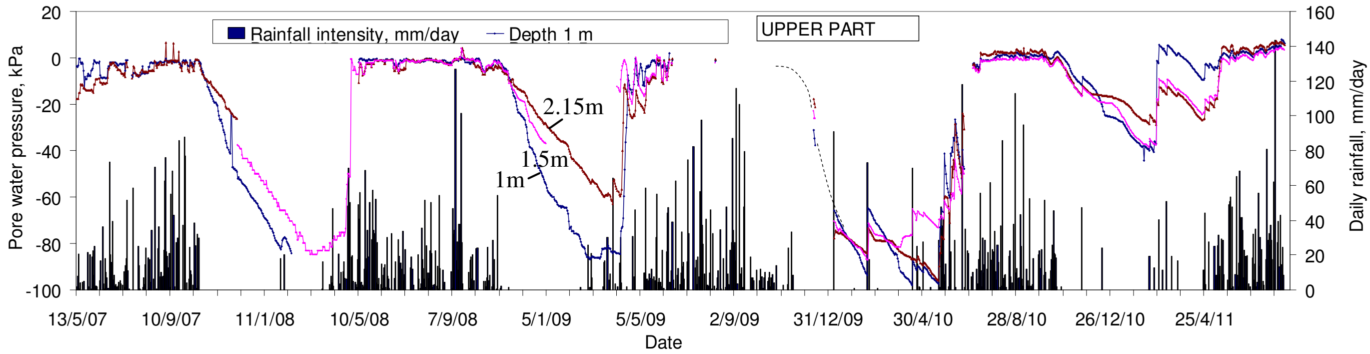


Figure 12 Variation of pore water pressure with daily rainfall at Nakornnayok (Thadan) site from 2007 until 2011

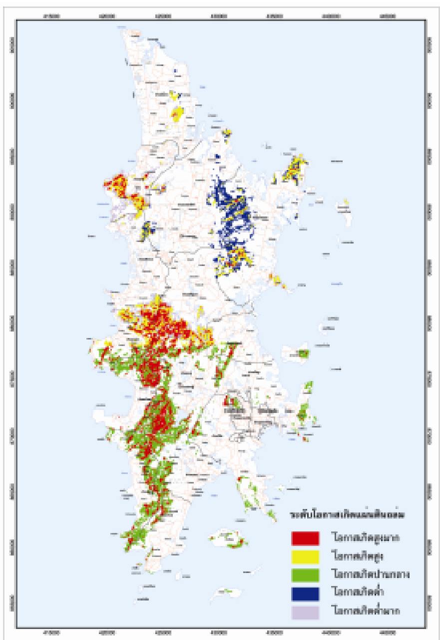


Figure 13 Landslide hazard map using different level of rain-fall intensity (Soralump, 2010)

3. DAM ENGINEERING

Embankment dams are normally built from geomaterials which are initially unsaturated in the as-compacted state. Subsequent field conditions involve wetting of the material during reservoir filling and possible drying during drawdown or drought could alter the material properties significantly. Rain infiltration can also influence the shear strength and volume change of the material on downstream slope of the dam. In this section, some selected case studies that the authors have direct experience in Thailand and Laos which involved possible applications of unsaturated soil mechanics and future technology will be briefly discussed.

3.1 Dam safety analysis

Unsaturated soil mechanics play an important role in dam safety management of the existing dams. Since the evaluation of dam behavior need to be done from time to time in order to assess the safety performance of the dam and also to set up the new criteria for instrumentations. After the first filling of the dam, transient seepage analysis is required for adjusting the unsaturated parameters by comparing with the pore pressure readings from instruments. Further analysis will be done to predict the pore pressure variations when unfavorable situation such as the piping has come. Soralump et al. (2009) has acquired the 30 years instrumentation data of Srinagarind dam, the largest dam in Thailand, in order to investigate the future of safety performance of this dam. Figure 16 shows the piezometric readings right after the reservoir has been filled and 12 years after that. The data has shown the presence of excess pore pressure from the compaction during construction. The excess pore pressure has disappeared in a few years after the seepage flow became steady. The modeling of transient flow state leads to the evaluation of many safety measures such as the hydraulic fracturing and the potential of developing of crack propagation.

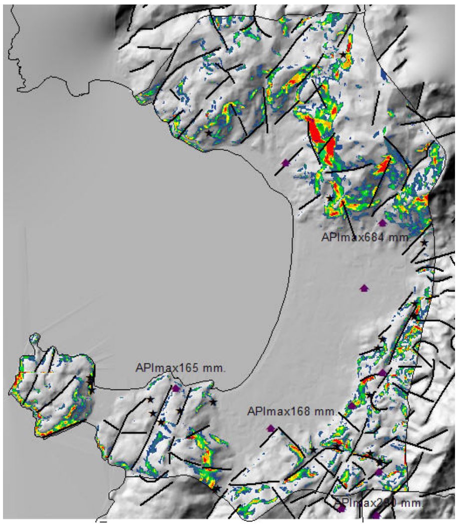


Figure 14 Critical API contour in Patong city, Phuket (ADPC, GERD and DMR, 2008, Soralump, 2009)

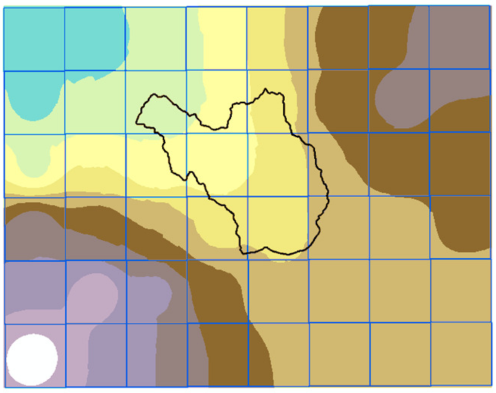


Figure 15 Precipitation contour predicted from satellite image data.

Furthermore, the modeling during the unsaturated stage of dam is also important for the safety analysis of dam subjected to earthquake forces. Even though Thailand is located in the low to moderate seismic region, however recent study found many new active faults that could have significant effect to the dam. One of the most important parts of seismic evaluation of dam is to determine the existing stress condition of the embankment. This is how unsaturated soil mechanics is required. Soralump and Tansupo (2009) have performed the seismic safety analysis of Srinagarind dam using dynamic response analysis. It is found that the critical response of the dam to the seismic force is found to be in the unsaturated region of the embankment as shown in Figure 17.

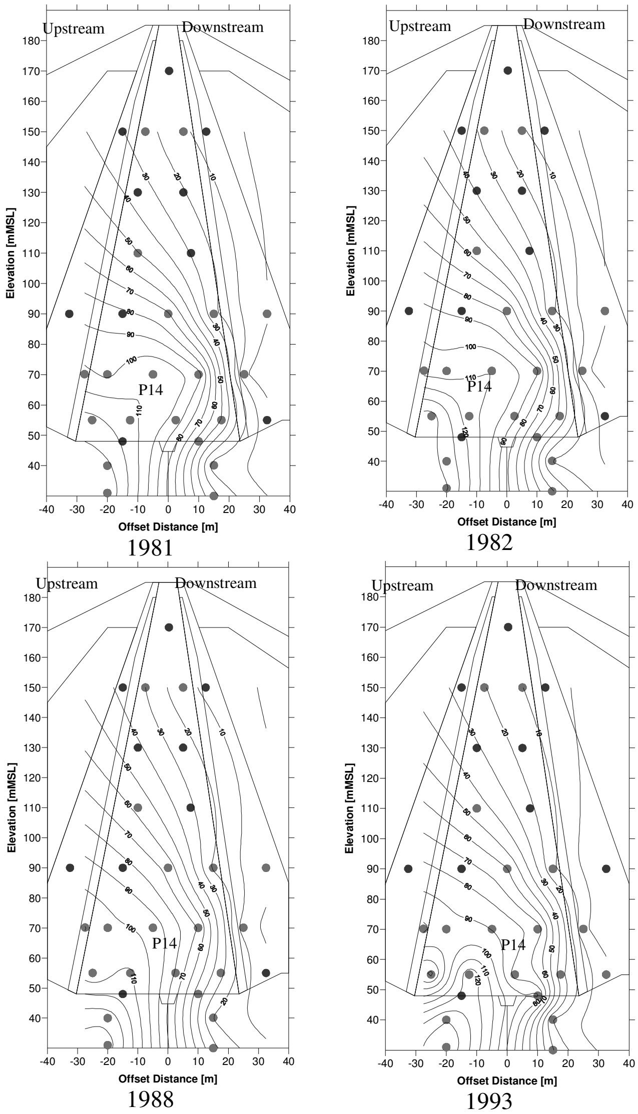


Figure 16 Distribution of pore water pressure in clay core (Soralump et al. 2009)

3.2 Leakage detection in CFRD dam

Nam Ngum 2 Dam (NN2), in PDR. Laos is a Concrete Faced Rockfill Dam (CFRD) of 182 m height and 512 m in crest length with a storage capacity of 4700 MCM. The typical section consisted of several compacted rockfill zones (generally in unsaturated condition) and the impervious concrete face slab on the upstream slope as shown in Figure 18. The leakage through the perimetric joint at the upstream toe was considered critical for dam operation and thus monitored by the DFOT - Distributed Fiber Optic Temperature technique. The DFOT is essentially the temperature sensor using optical impulse along the cable. The system can deliver the temperature values with a minimum spacing of 0.25 m. and the accuracy of better than +/- 0.2 °C. The cable alignment on NN2 is along the perimetric joint as shown Figure 18.

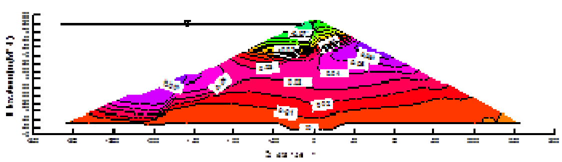


Figure 17 Relative horizontal displacement of Srinagarind dam in case of San Fernando 1971 earthquake induced at the dam base. (Unit:m) (Soralump and Tansupo, 2009)

The normal testing procedure is that the upper cable is unheated while the lower one is the heated cable. If the passive method is applied, when the temperature difference between heated cable is compared to the unheated one at any distance along the plinth station. The constant temperature difference is generally expected when no leakage through the perimetric joint. If leakage occurs, the seepage water will carry the heat from the heated cable away, thus the temperature difference significantly decreased. The results of the temperature differences observed between 10th October and 20th November 2010 are plotted for distance along perimetric joint as shown in Figure 19. This graph represented the no leakage pattern.

This technique is useful for practical purpose of detecting leakage through the concrete face slab. There is also a possibility for its use in determining the quantity of unsaturated seepage. In such case (when advanced analysis is needed) the active heating method (heat pulse method) need to be applied. The concept is as shown on Figure 20. In principle, the standard heating and relaxation temperature patterns for no leakage shall be established first. When leakage occurs, the flow will not permit the temperature rising to the standard temperature and after turn off the heating the relaxation time will be much faster. Relation between the quantity of flow versus the differences patterns of heating and relaxation curves shall be established in laboratory experiment or numerical modeling. For NN2 Dam, the FEM simulation on saturated and unsaturated soils behind the face slab will be established for future leakage detection through perimetric joint.

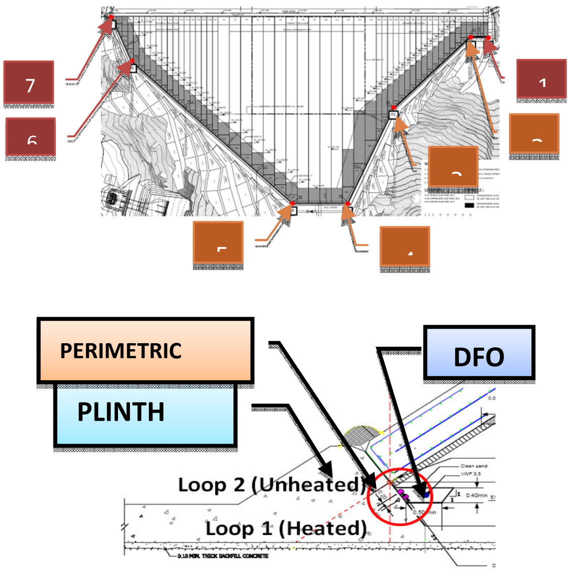


Figure 18 Locations of DFOT Cables

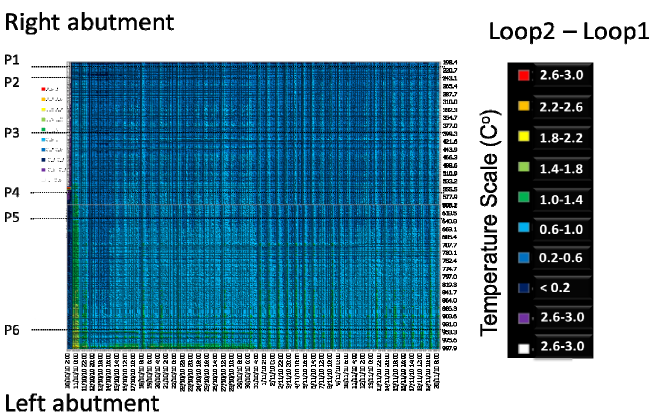


Figure 19 Temperature difference along the NN2 dam perimetric joint

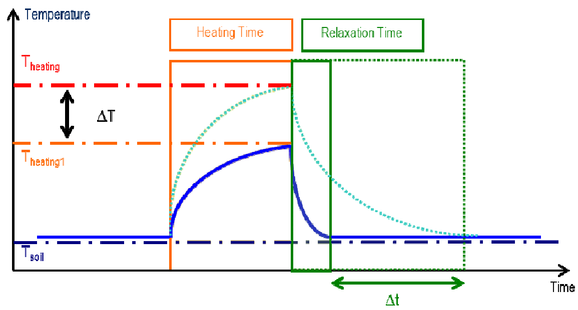


Figure 20 Heating and Relaxation Temperature Pattern for DFOT heat pulse method (Roctest/Smartec, 2010)

3.3 Volume change problem

Some embankments and dams in Thailand are constructed of compacted argillaceous fills, which were derived from mudstone, clays tone or siltstone. These materials disintegrate and their strength reduces considerably upon contact with water. Collapse-on-wetting induced by rain infiltration and seepage is also one of the main mechanisms affecting deformation of such dams. Recently there has been an attempt to employ the Barcelona-type constitutive model (Alonso et al., 1987) to characterize volume change behaviour of such material behaviour for an earth dam in Thailand. Suction-monitored oedometer tests similar to those used by Jotisankasa et al. (2007) were carried out. The constitutive formulations are as shown in the following.

The value of specific volume, ($v = 1 + e$), along the yield surface (series of normal compression lines at different suction) can be calculated using Equation (5).

$$v = v_s + v_c \tag{5}$$

where v_s is the function for specific volume variation with total vertical stress (σ_v) at zero suction (Equation 6)

$$v_s = v_{so} - \lambda_s \ln \sigma_v \tag{6}$$

v_c is the potential collapse calculated using Equations (7)-(9)

$$\frac{v_c}{v_{c1}} = 1 - \beta \ln \sigma_v \tag{7}$$

$$v_{c1} = m_1 \ln(s+1) \tag{8}$$

$$\beta = m_2 \ln(s+1) \tag{9}$$

where s is suction and v_{so}, λ_s, m_1, m_2 are fitting parameters. The elastic behaviour is defined using Equation (10)

$$dv = -\kappa \cdot \frac{d\sigma_v}{\sigma_v} - \kappa_s \cdot \frac{ds}{s+1} \tag{10}$$

Figure 21 shows some curve fitting using this formulation for oedometer test results on compacted argillaceous fill from an embankment dam in Thailand. The Loading-Collapse curve and some prediction of wetting behaviour is also shown in Figure 22. Based on this formulation, the magnitude of settlement (or expansion) induced by wetting a hypothetical embankment having various heights and initial suction of about 100 kPa is estimated as shown in Figure 23. This kind of plot is useful in providing practical engineers the feel for magnitude of collapse-on-wetting of an embankment.

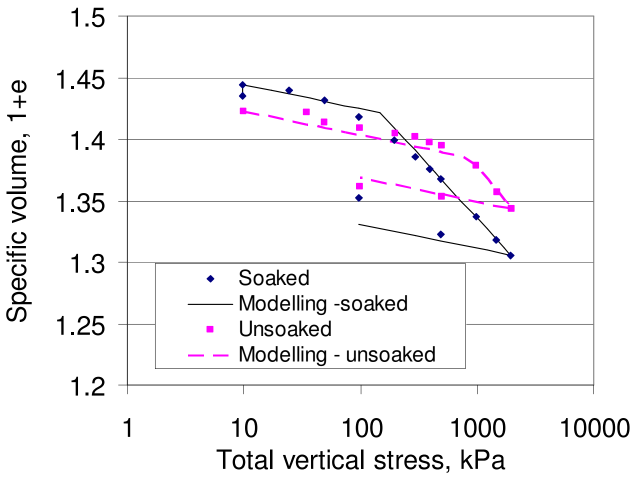


Figure 21 Comparison between curve fitting using Elasto-Plastic framework and oedometer test results on compacted argillaceous fill

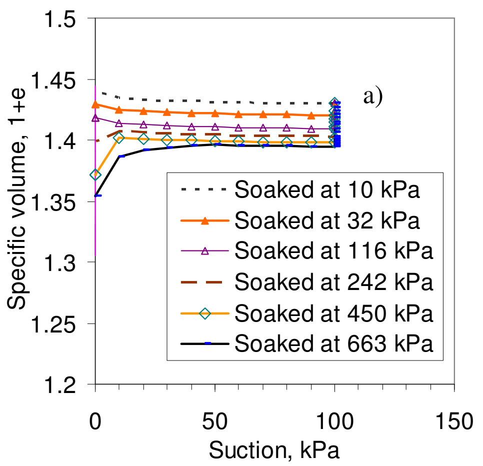


Figure 22 Volume change behaviour of argillaceous fill during soaking at different vertical stresses and Loading-Collapse yield curve

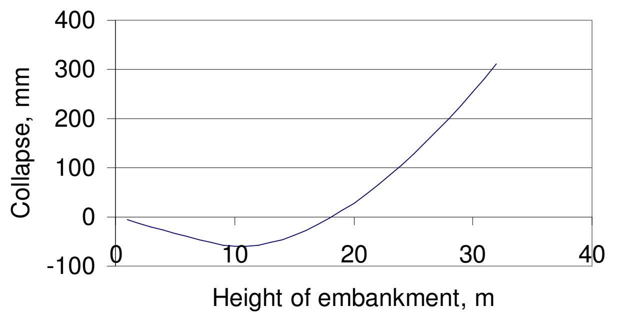


Figure 23 Estimated collapse/swelling for embankment of various heights (suction reduced from initial value of 100 kPa to zero)

4. OTHER APPLICATIONS

Some of other works about unsaturated soils in Thailand are briefly reviewed here. In the north-eastern part of Thailand, there is a wide deposit of loess materials which exhibits collapse-on-wetting phenomena and frequently causes problems with shallow footing. Early studies were conducted based on total stress approach (e.g. Udomchoke, 1991, Phien-wej et al, 1992) and more recent works using two stress-variable approach (e.g. Punrattanasin et al., 2002, Nuntasarn, 2011) aimed at characterizing collapse-on-wetting, shear strength and bearing capacity of the soil as well as ways to improvement of the material.

Shrinking-swelling clays also pose threats to various infrastructures in Thailand, such as highways, dams, shallow footing etc. The problem will be more serious particularly if the climate change continues to be more severe. Sawangsuriya et al. (2011) and Jotisankasa et al. (2011) (in this proceedings) reported their studies about the longitudinal cracks along asphalt pavement shoulder in the central region of Thailand, involving shrink-swell behaviour of compacted high plasticity clay subgrade. Development of new classification system for such material based on total suction measurement has been proposed. A detailed study on the mechanism of longitudinal cracks was carried out, which involved determination of SWCC and desiccation deformation of the clay subgrade, as well as infiltration-induced slope instability.

Various geo-environmental problems involving unsaturated soils in Thailand, such as contaminant transport and soil salinity, have been studied and also reported in this proceedings (e.g. Sudsaeng et al., 2011, Iizuka et al., 2011). In addition, bio-slope stabilization technique, such as Vetiver grass is one of the most popular methods in Thailand for reducing landslide risk and soil-water conservation. More studies will be needed to characterize the moisture and pore pressure regime for different grass types on slope. Udomchoke et al. (2011), for example, studied the influence of vetiver's roots on soil-water characteristic and pore-size distribution of soil in the hill evergreen forest of Chiang Mai Province.

5. FUTURE OF UNSATURATED SOIL MECHANICS EDUCATION IN THAILAND

One of the challenges facing unsaturated soil mechanics education in Thailand comes from such frequent question as: *"why bother doing unsaturated soil mechanics, if engineers always design foundations in the worst condition which is fully saturated"*. While this notion may be partially true for shear strength and bearing capacity problem, the volume change problem of soil induced by changing soil moisture condition still remained the major application of unsaturated soil mechanics in practice, in additional to other landslide and dam applications reported earlier. It is also believed that many contractors unknowingly rely on suction for stability of temporary excavation work at steep gradient. It will be beneficial to educate them to be able to precisely quantify such temporary stability and promote more safety in their work. Equation (11) shows the simple way to demonstrate the influence of suction on excavation stability by calculating the critical unsupported excavation height, H_{LE} (Fredlund & Rahardjo, 1993).

$$H_{LE} = \frac{4}{\gamma_s} \cdot (c' + c^s) \tan\left(\frac{\pi}{4} + \frac{\phi'}{2}\right) \qquad (11)$$

Unconfined compression tests have been one of the popular shear strength testing methods among practical engineers in Thailand for its simplicity and low cost. It is thus of great importance for the users of such method to understand the contribution from suction to unconfined compressive strength and beware of its misuse. Therefore, the measurement of suction before or during the unconfined compression tests is highly recommended in practice (Figure 24), be it for fully saturated or unsaturated soils (e.g. Chantawarangul, 1983, Jotisankasa et al., 2007).

Measurement of negative pore water pressure of variably-disturbed thin-walled soft clay samples is also quite illuminating for students when explaining the origins of unconfined compressive strength of saturated soft clay. For example, the reason why soft Bangkok clay with a very small amount of suction of 0.5 kPa can just stand up in the laboratory. Assuming typical values for Soft Bangkok clay ($c' = 0$, $\phi' = 23$ deg. $c^s = \chi \cdot s \cdot \tan\phi' = 0.21$ kPa), the value of H_{LE} is calculated to be 7.8 cm, which corresponds to the common height of the soft clay which apparently has no strength, yet capable of vertical standing.

This simple demonstration will help considerably to explain students about the concept of additional strength due to suction.

Figure 24 Suction-monitored unconfined compression test as an illuminating lab demonstration for MEng students at Kasetsart University

6. CONCLUSION

This paper reports on some application of unsaturated soil mechanics in Thailand, including rainfall-induced landslide, as well as other volume change and seepage behaviour for dam safety. The concept of appropriate technology has been considered in various aspects of studies, particularly, for simplified testing of unsaturated soils by employing the in-house-built miniature tensiometer and relative humidity sensors with conventional standard apparatus.

For rainfall-induced landslide, the unsaturated properties have been used in correlating rainfall intensity with slope instability and developing a critical rainfall envelope which has been used in GIS to create dynamic hazard map as well as providing a real-time early warning of landslide. A case of volume change analysis based on Loading-Collapse yield concept is also highlighted with application on dam safety. Some challenges and opportunities of unsaturated soil mechanics education in Thailand are highlighted.

Finally it is hoped that engineers and researchers in developing countries in Asia-Pacific, dealing with similar unsaturated soils problems in a situation comparable to Thailand, perhaps can adopt some of the economical methods explained here and develop their own approach based on appropriate technology concept.

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