Some experience on slope bio-engineering in Thailand: research and practice

Apiniti Jotisankasa

PhD DIC

Geotechnical Innovation Laboratory, Department of Civil Engineering, Kasetsart University

International Workshop on Landslide Risk Assessment and Management for the ASEAN Member States

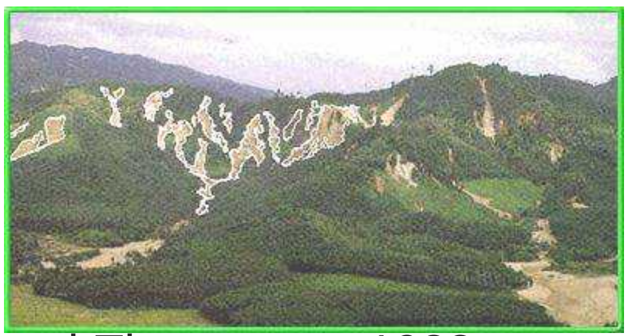
1 June 2017

Outline of presentation

- **Introduction** - Slope failure and erosion problems – Typical field response of slope
- **State-of-the practice in bio-slope engineering** – Vetiver grass & live stakes & their uses with soil bag and engineering structure
- **Research methodology** on seepage and strength in vegetated soils : **Mechanics** – **Hydraulics** –**Numerical analysis** – rain infiltration & slope stability interaction
- **Conclusions**

Landslide in Thailand

Petchaboon, 2001



Nakonsri-Thammarat, 1988

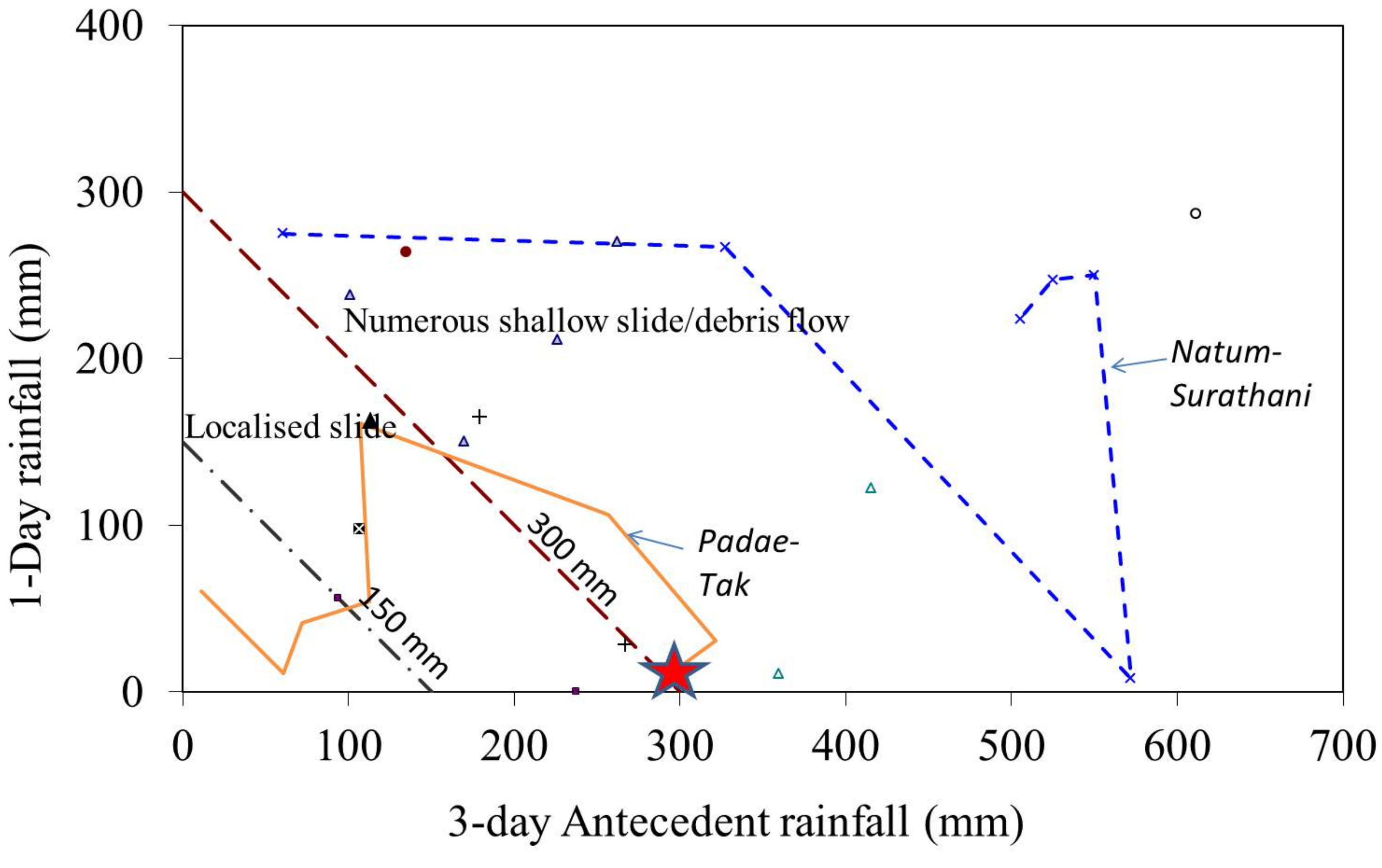
Uttaradit, 2006

Widespread shallow slides to debris flow in a large area

Erosion and shallow slides

- Slope erosion/Slope failure in Thailand, related to heavy rainfall

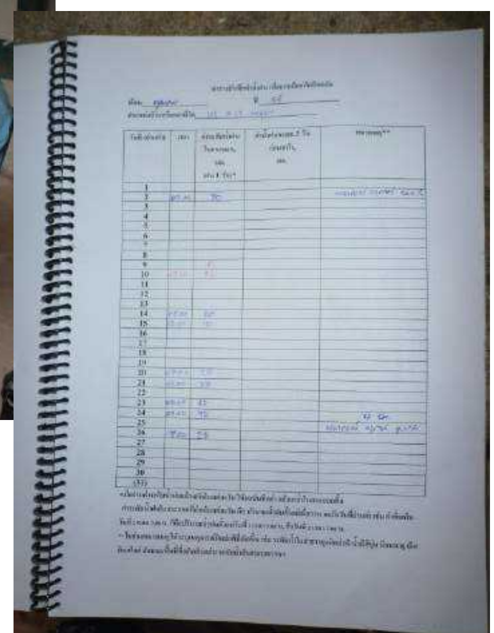
Rainfall patterns for past landslide events in Thailand



Capacity building for local community at risk of landslide

Training about critical rainfall

Simple rain gauge for early warning



Simple form for recording rainfall data by non-expert local people

Rainfall-induced slope failure

INFILTRATION leads to WETTING FRONT MOVEMENT or PERCHED GROUND WATER TABLE RISE

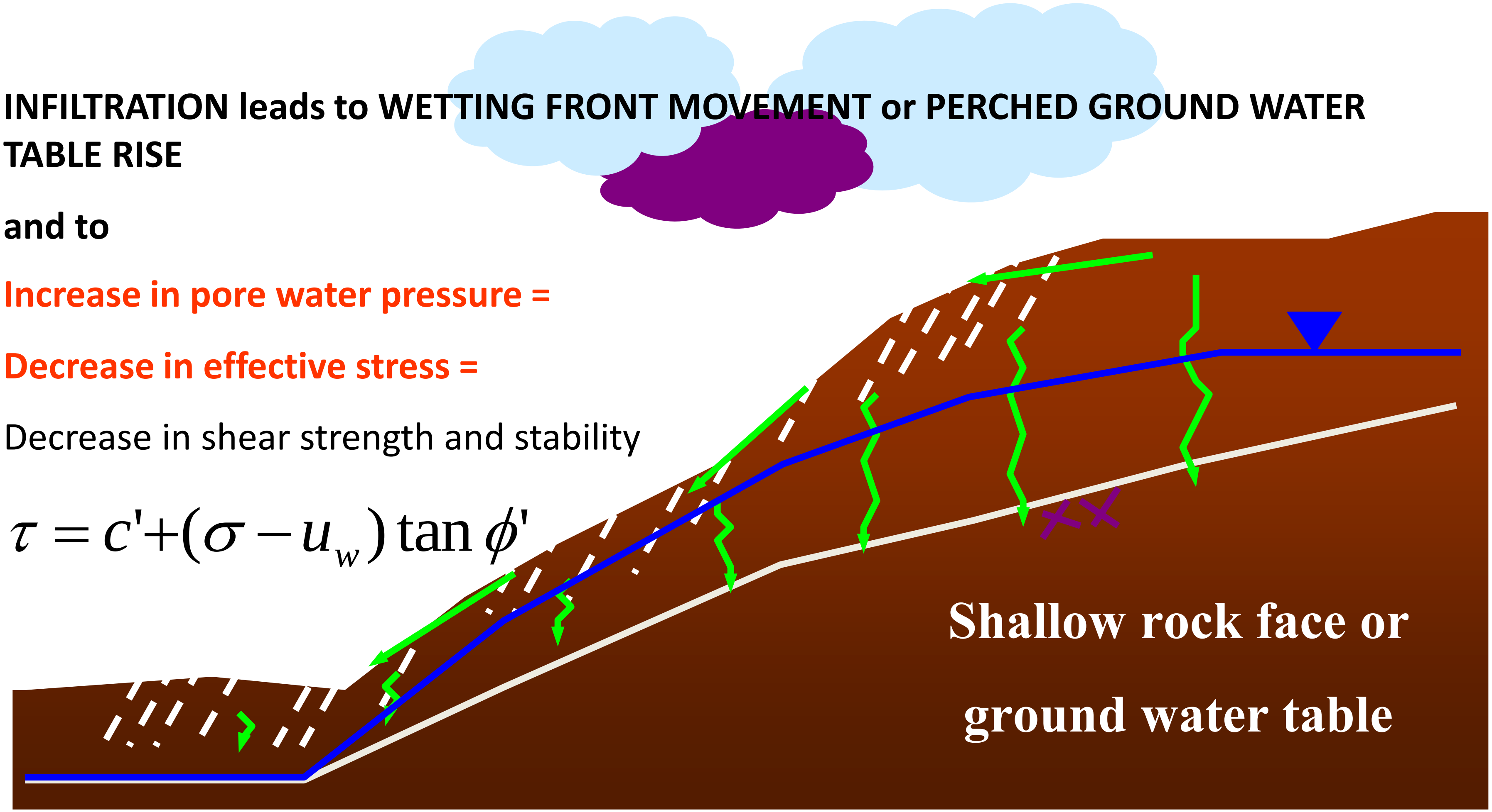
and to

Increase in pore water pressure =

Decrease in effective stress =

Decrease in shear strength and stability

$$\tau = c' + (\sigma - u_w)\tan\phi'$$

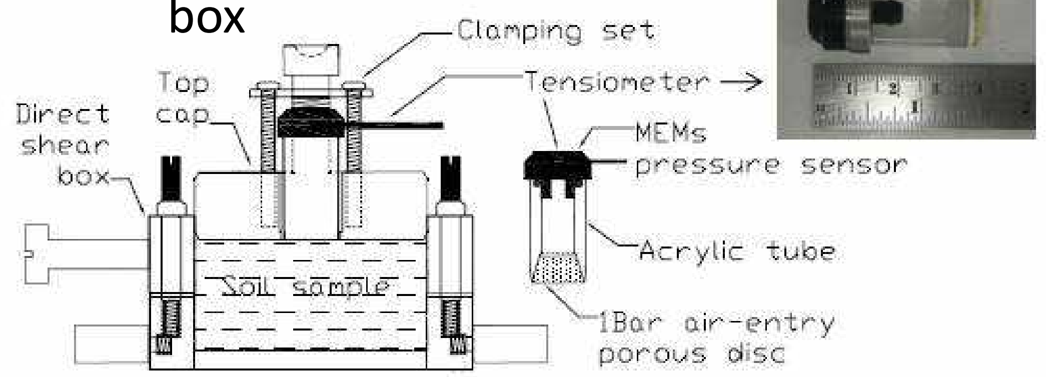


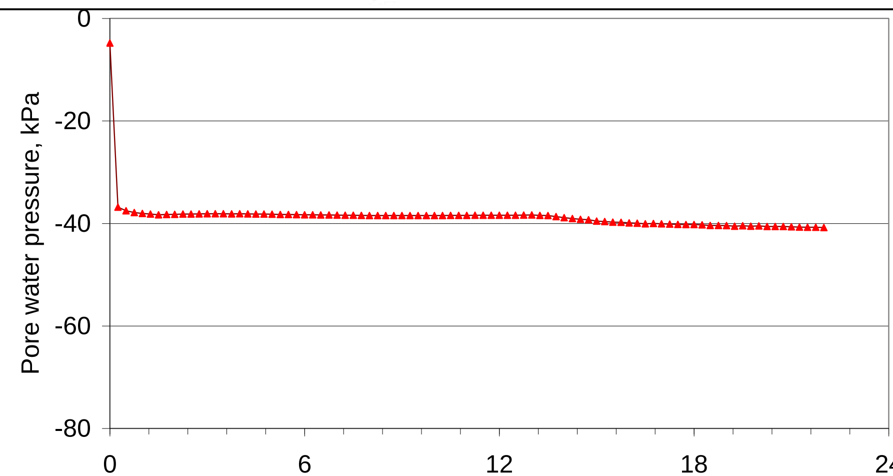
Soils are normally unsaturated and thus understanding the infiltration mechanism (soil-water characteristic, permeability function) is very important

Development of pore water pressure measuring device at Kasetsart University

- KU-Tensiometer
- (-80 upto 700 kPa)

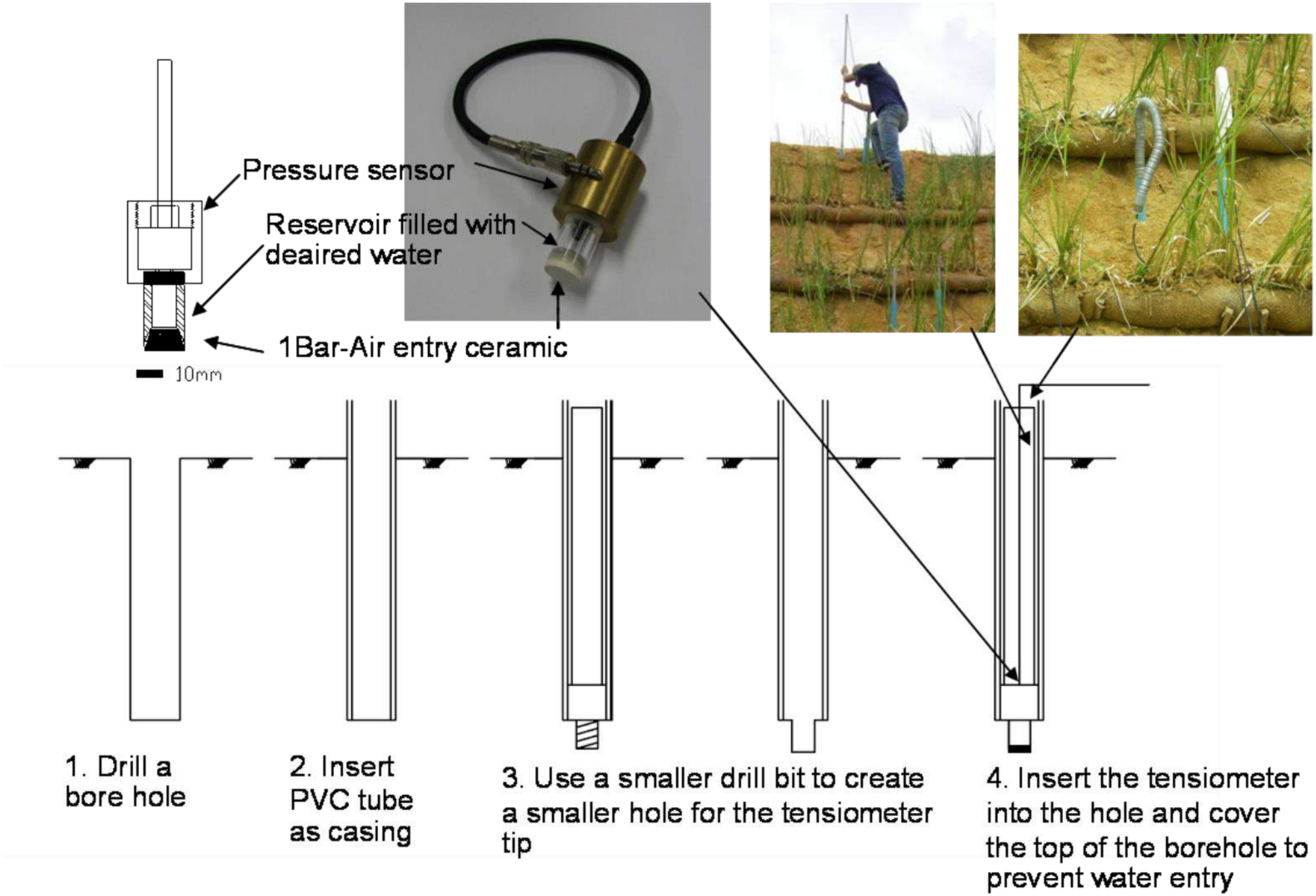
Incorporation with direct shear box



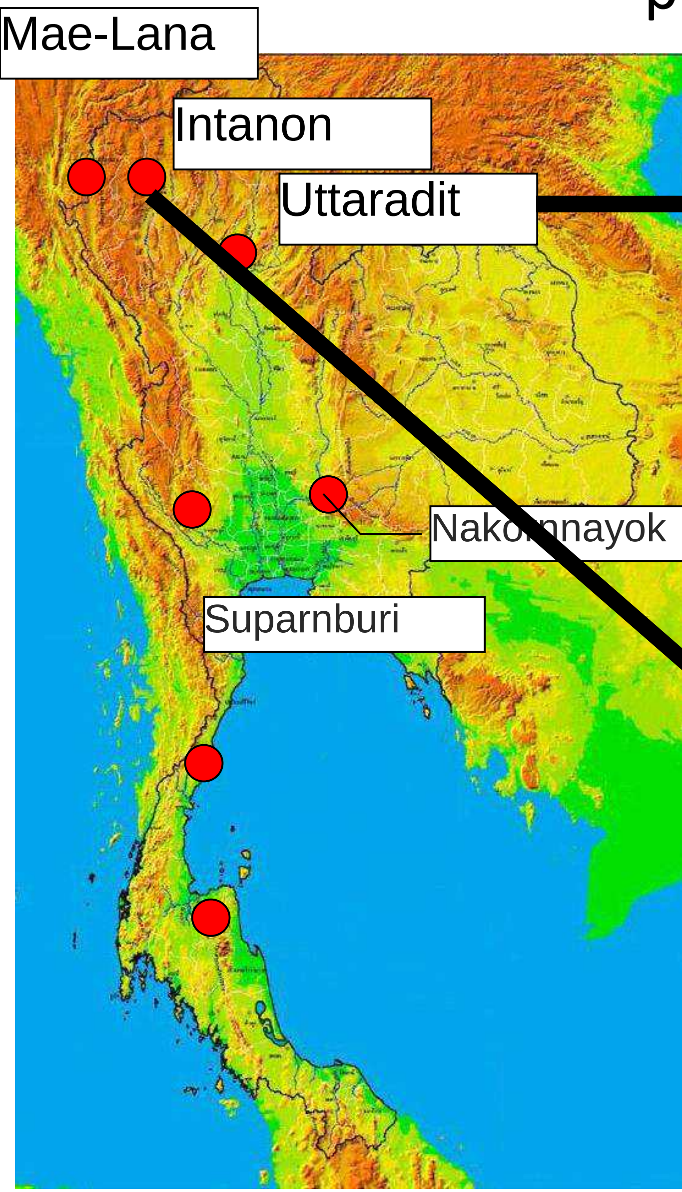


Jotisankasa, A. and Mairaing, W. (2010). Suction-monitored direct shear testing of residual soils from landslide-prone areas, **Journal of Geotechnical and Geoenvironmental Engineering, ASCE**, Vol. 136, No. 3, March 1, 2010.

Field use of tensiometer for monitoring both positive and negative pore water pressure



Some selected instrumented sites aimed at understanding relationship between pore water pressure and rainfall



Large-area shallow failure

Localised slope failure
(highway slope)

Uttaradit site (Mae-Poon)

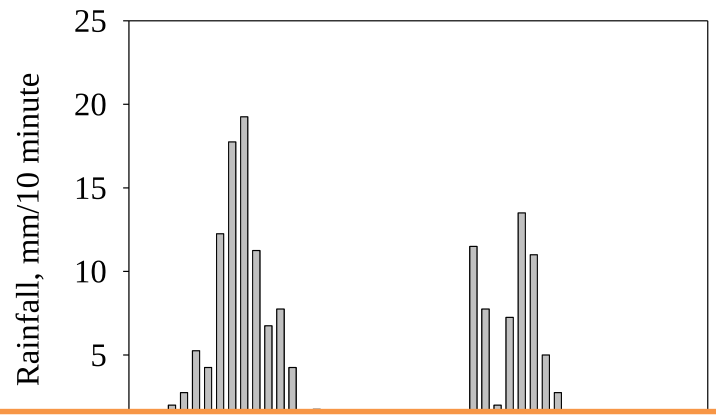
Uttaradit landslide 21-23 May 2006

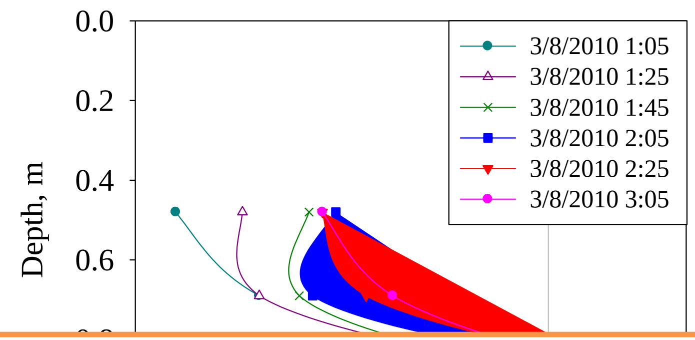
triggered by approx. 400mm of rain in a day

Uttaradit
North of Thailand

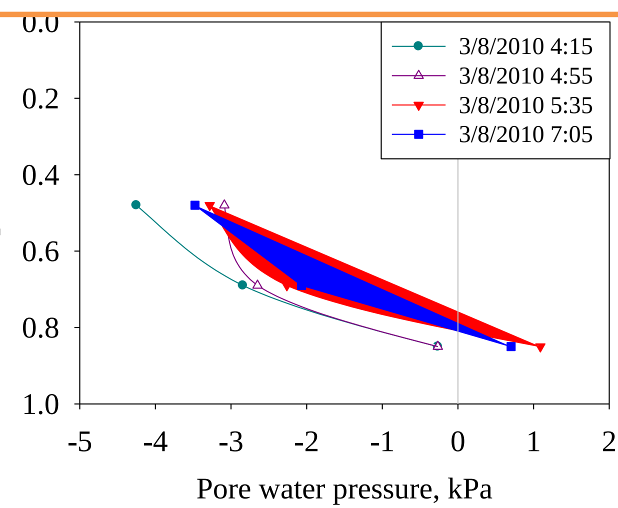
ADPC(2006)

Pore pressure changes during intense rainfall causing flashflood – 3 Aug 2010



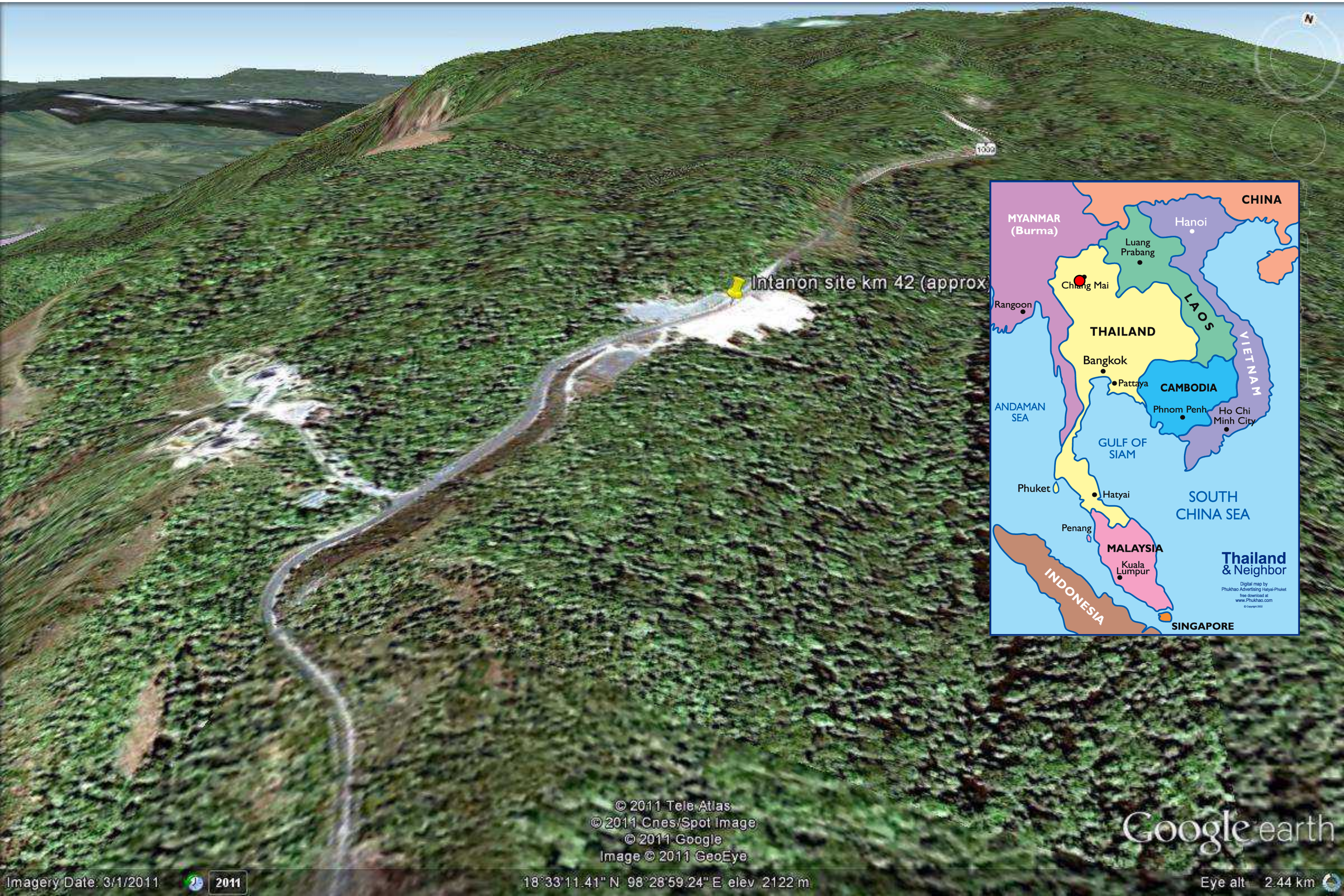


Identifying the critical envelope of pore water pressure profile during flashflood (Temporary increase in perched water table/ positive pore pressure near contact between soil/rock)



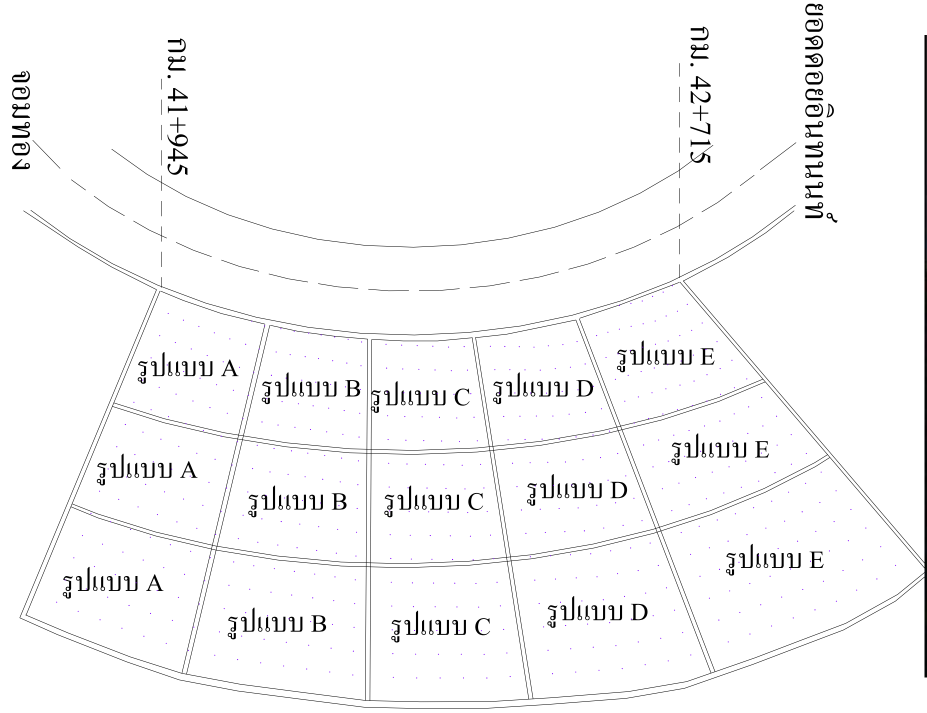
Doi-intanon test site km -42

- Highway no. 1009 - 108 (Jomtong) – intanon km.41+945 – km.42+715 shallow failure during surface erosion and internal erosion during heavy rainfall (high altitude: around 2500 m MSL)– Highway to highest peak of Thailand

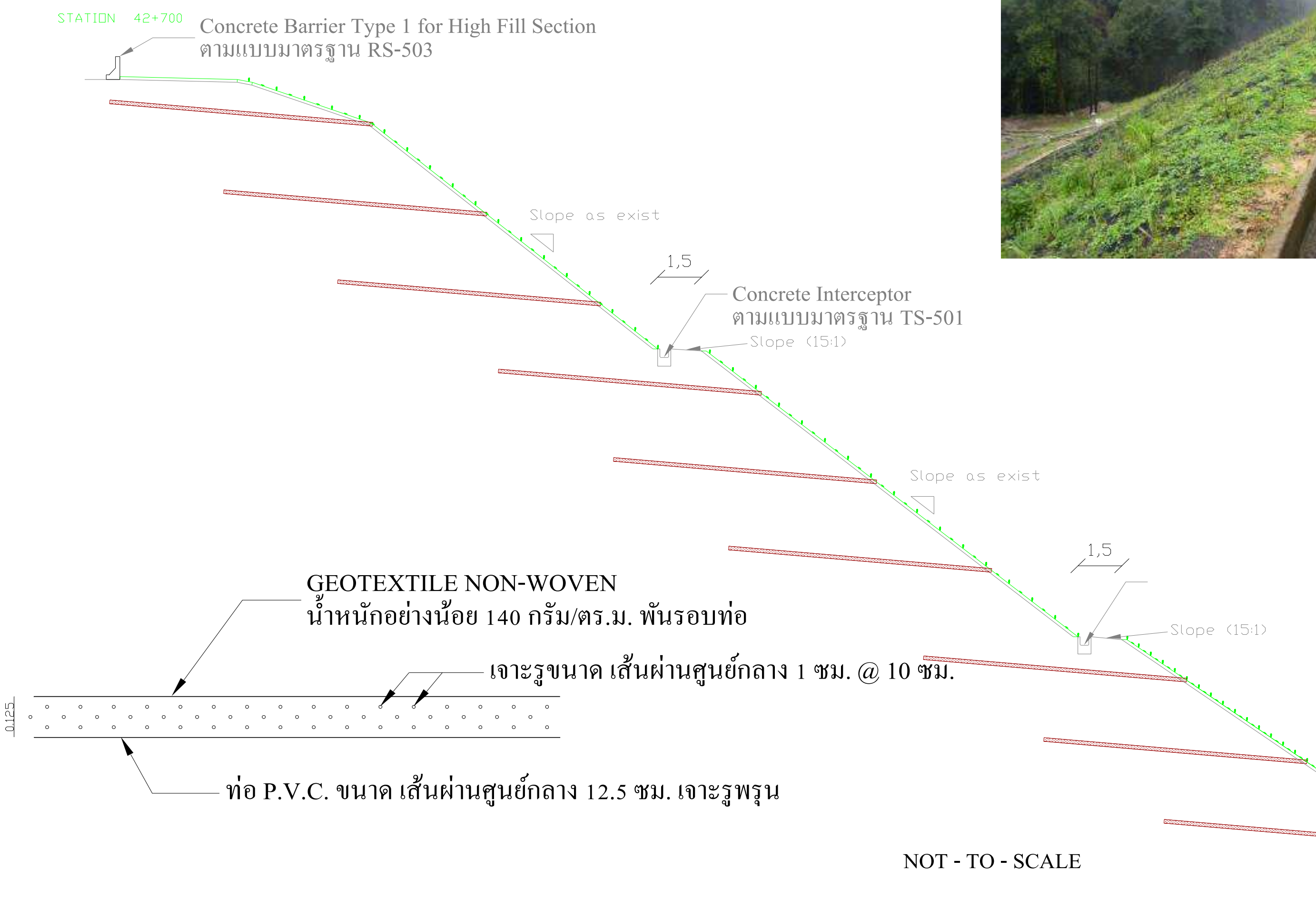

Intanon site km 42 (approx)
© 2011 Tele Atlas
© 2011 Cnes/Spot Image
© 2011 Google
Image © 2011 GeoEye
Google earth
Imagery Date: 3/1/2011
2011
18°33'11.41" N 98°28'59.24" E elev 2122 m
Eye alt 2.44 km
MYANMAR (Burma)
CHINA
Hanoi
Luang Prabang
Chiang Mai
LAOS
Rangoon
THAILAND
VIETNAM
Bangkok
Pattaya
CAMBODIA
ANDAMAN SEA
Phnom Penh
Ho Chi Minh City
GULF OF SIAM
Phuket
Hatyai
SOUTH CHINA SEA
Penang
MALAYSIA
Kuala Lumpur
INDONESIA
SINGAPORE
Thailand & Neighbor

Erosion control and stabilization method

- Vegetation and engineering cover with Horizontal drains
- 5 methods used

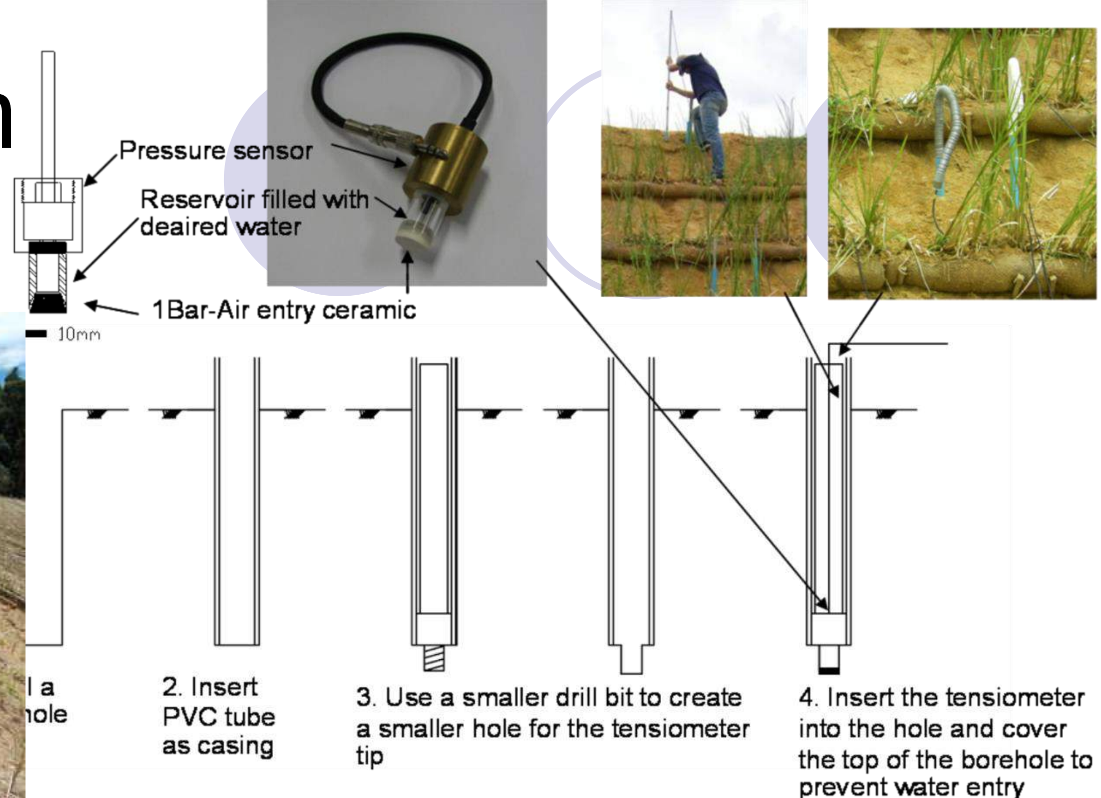


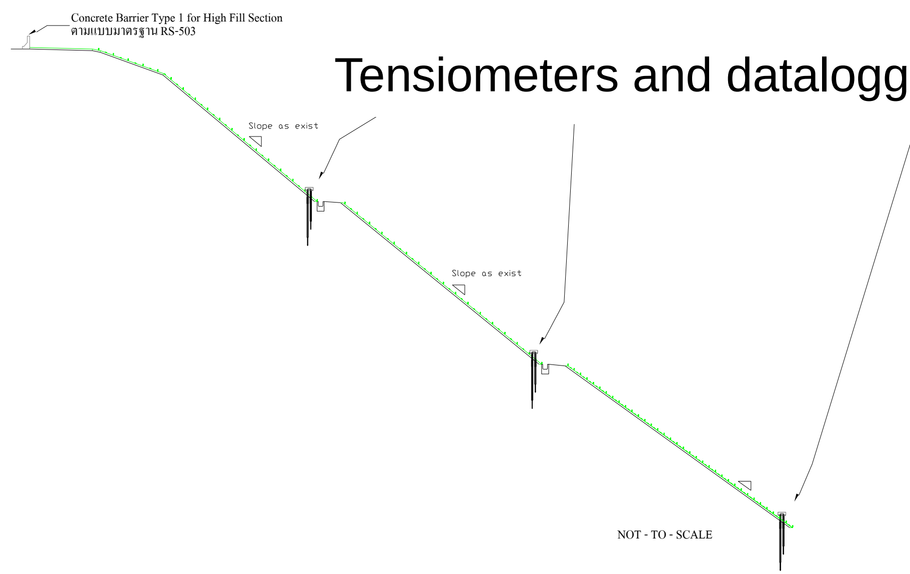
Horizontal drain and Surface drain installations to reduce pore water pressure



Instrumentation

- 60 KU-tensiometers for positive and negative

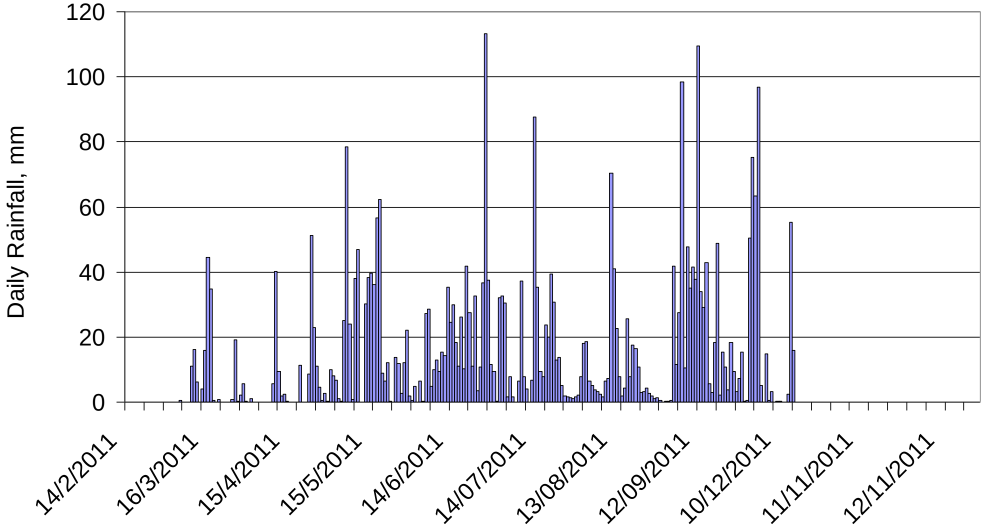




Tensiometers and datalogger

Monitoring of rainfall using tipping bucket rain gauge

Max daily rain = 110 mm (Moderate rainfall, much less than in Southern Thailand, but long duration)



Rainfall in 2011

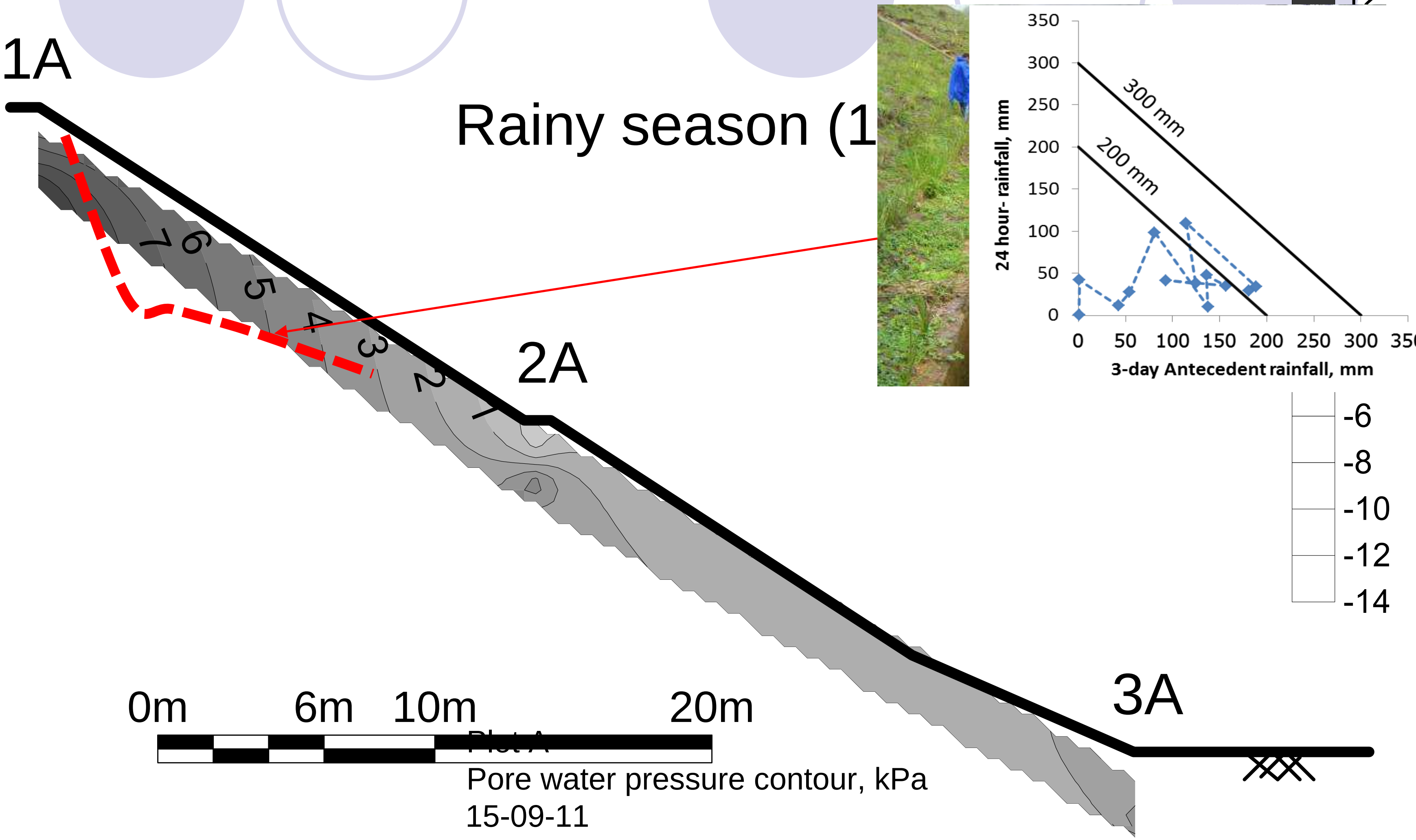
1st evaluation after 1,350 mm rain

2nd evaluation after 3,462 mm rain

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall, mm	0	0	163	184	591	621	471	318	731	384	0	0

Typical pore water pressure in slope

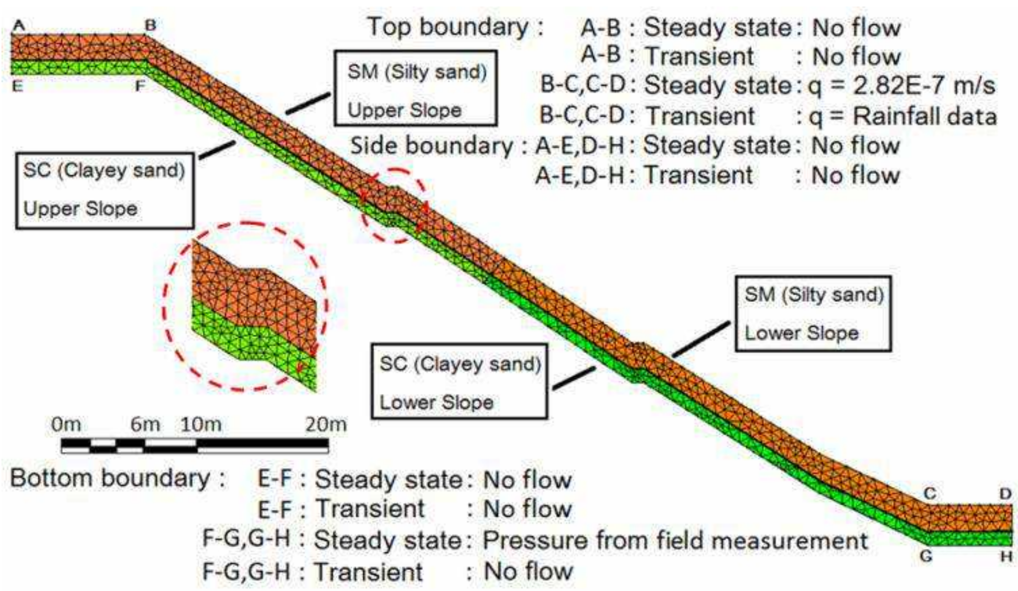
Rainy season (1

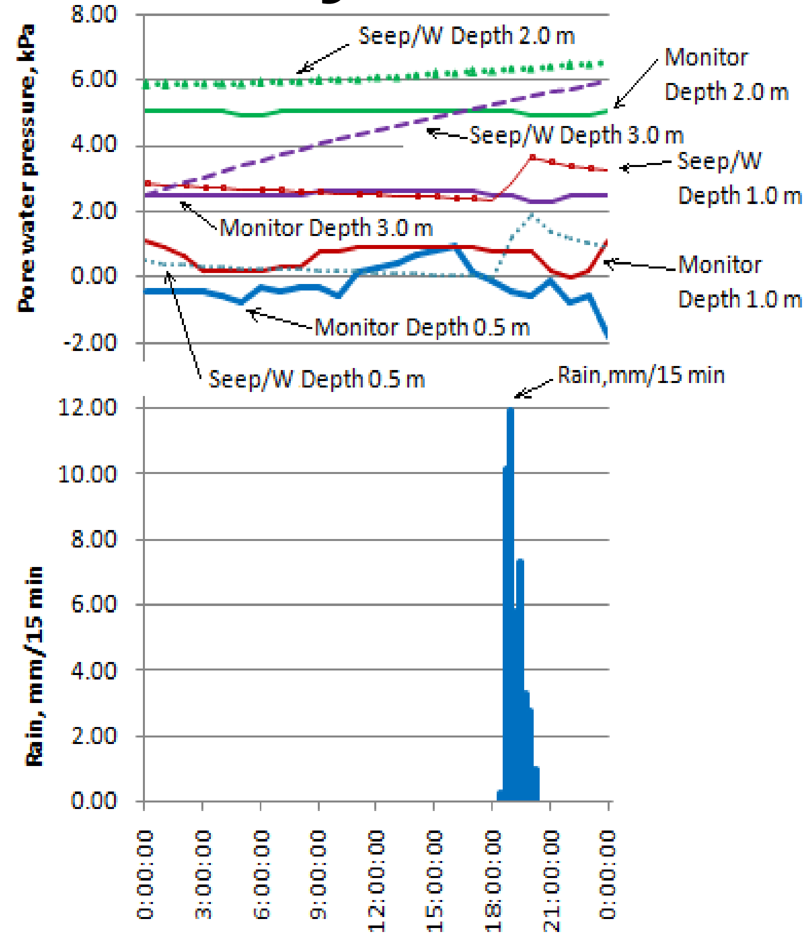


Erosion and failure surface agree with pore water pressure results

Internal seepage erosion

Numerical seepage analysis





- Comparison between measured and simulated pore water pressure variation with time: good agreement at depth lower than 2 m: less agreement at greater depth due to 3D effect

STATE OF THE PRACTICE IN BIO-SLOPE ENGINEERING

Vetiver grass system for erosion prevention and shallow stabilization

- *Chrysopogon zizanioides* or formerly known as *Vetiveria zizanioides*
- Traditionally planted as hedgerows parallel to the slope contour
- Of very dense fine vertical root system that penetrates as deep as 3-4 meter in some applications
- Effective for shallow slope stabilization, reduction of runoff erosive energy and sediment trap

(Hengchaovanich, 1998, Truong et al., 2008)

Source: Department of Highways

Implemented for erosion control and slope stabilization along highways

Photo Courtesy of Dr. Weerachai Na-Nakorn


Implemented for erosion control and slope stabilization along highways
อ.ทองผาภูมิ จ.กาญจนบุรี
Photo Courtesy of Dr. Weerachai Na-Nakorn


Photo Courtesy of Dr. Weerachai Na-Nakorn


Photo Courtesy of Dr. Weerachai Na-Nakorn

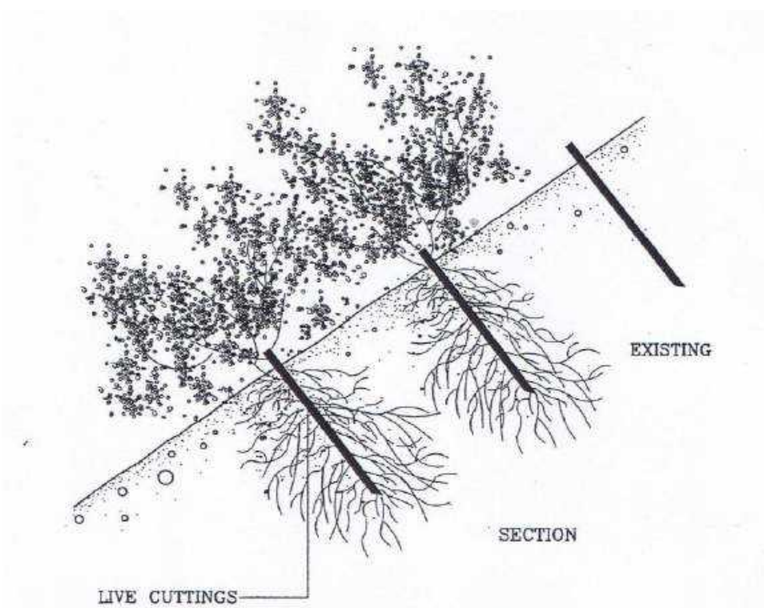
Alternate planting

- Different plant species playing different roles in stabilizing and maintaining the slope
- Vetiver grass (Capture and restrain + Reinforcement and support + Improve habitat)
- Pinto legume (Cover and armor + Improve habitat)

•Photo Courtesy of Mr. Surapol Sagnuankaew

Live stake & Live pole

- The technique involves inserting and tamping of easily rootable woody cuttings (usually 12 to 38mm in diameter and 0.6 to 0.9m long) relatively deep into the ground (about 80% of its length)
- Live pole is the term used to describe a bigger version of a live stake, normally 50mm in diameter, and installed to a depth of about 1 meter vertically in a pre-drilled hole.
- Normally considered to act as a small reinforcing pile when installed.
- Standards and various practical handbooks available (ASTM: D 6765 – 02; Coppin et al. 1990; Gray and Sotir 1996; Eubanks and Meadows 2002; Goldsmith et al. 2014).



Live staking. Robbin Sotir & Associates

Source. Lewis, 2000

Trial of different species for live stake:

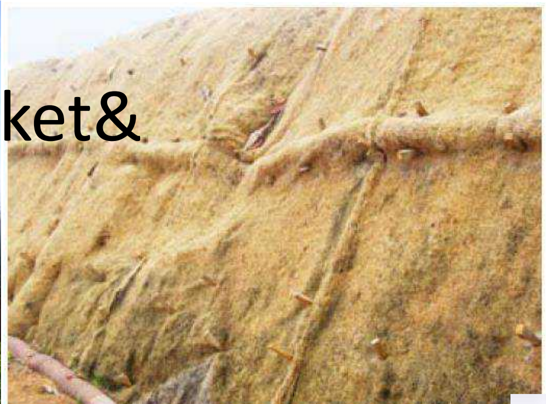
Jotisankasa, A. (2013) Application of local plant species for live stake as a bio-slope stabilization method in Thailand. Proceedings of the fourth Tokyo Tech-KU Joint Seminar on Infrastructure Development, October 31-November 1, 2013, Tokyo Institute of Technology

Erosion control cover system

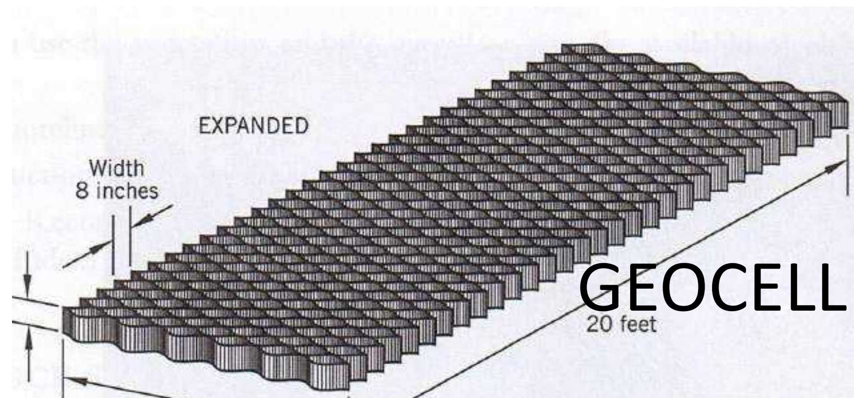
- **Different Soil cover systems/**Soil blanket (natural fibre)/Soil log/Erosion control mat/Geocell)/ *what are the relative performance??*

Sawangsuriya, A., Jotisankasa, A., Sukolrat, J., Dechasakulsom, M., Mahatumrongchai, V., Milindalekha, P. and Anuvechsirikiat, S (2013) Comparison of Erosion Susceptibility and Slope Stability of Repaired Highway Embankment. Geo-Congress: Stability and Performance of Slopes and Embankments III Geotechnical Special Publication, Vol 231

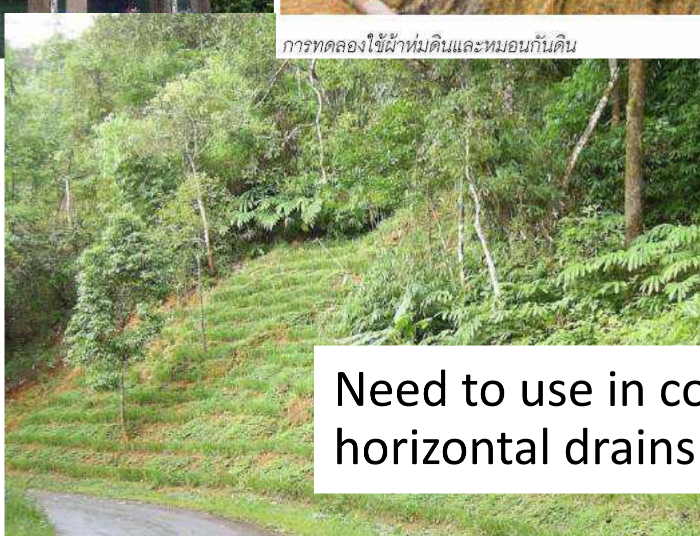
Soil blanket&
Soil log



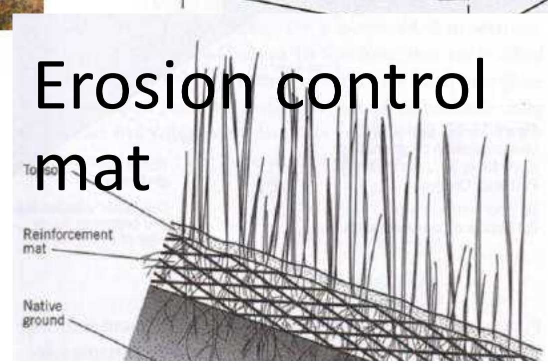
การทดลองใช้ผ้าห่มดินและหมอนกันดิน

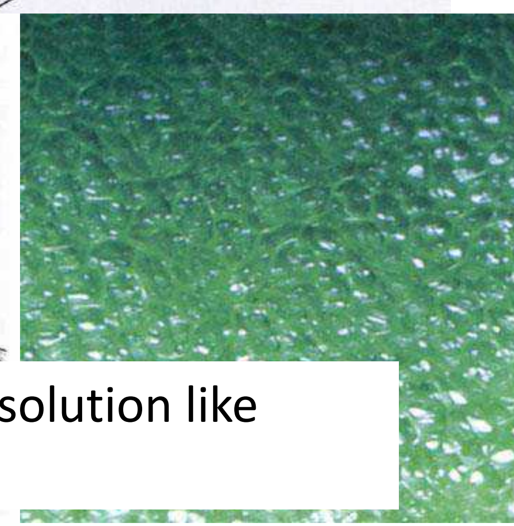


GEOCELL



Erosion control
mat

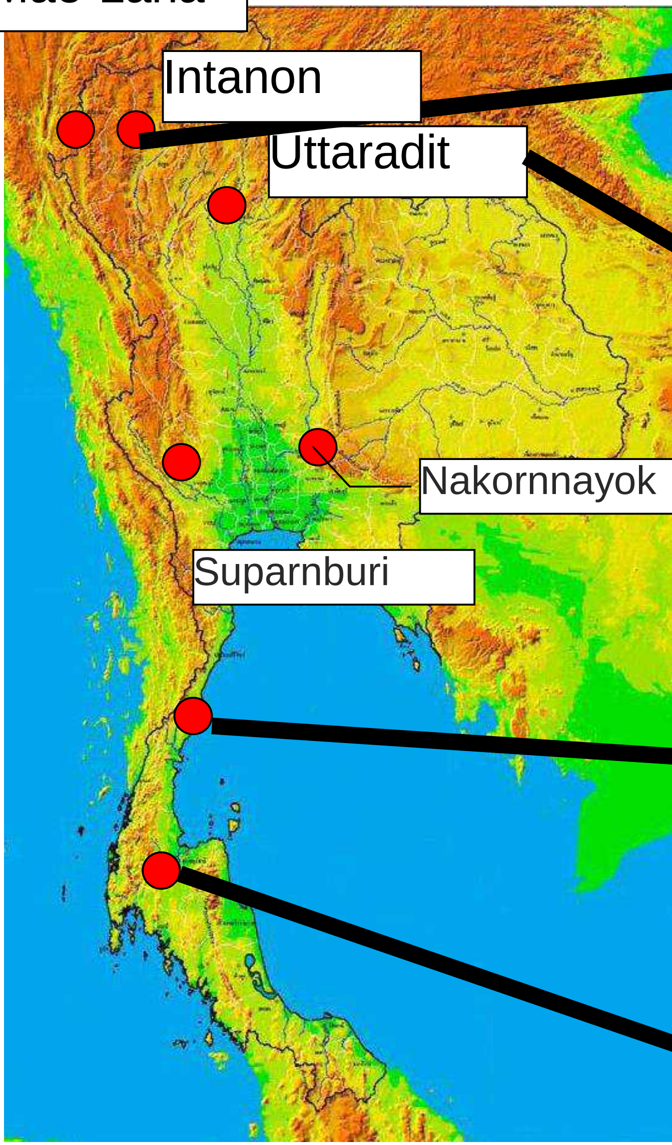


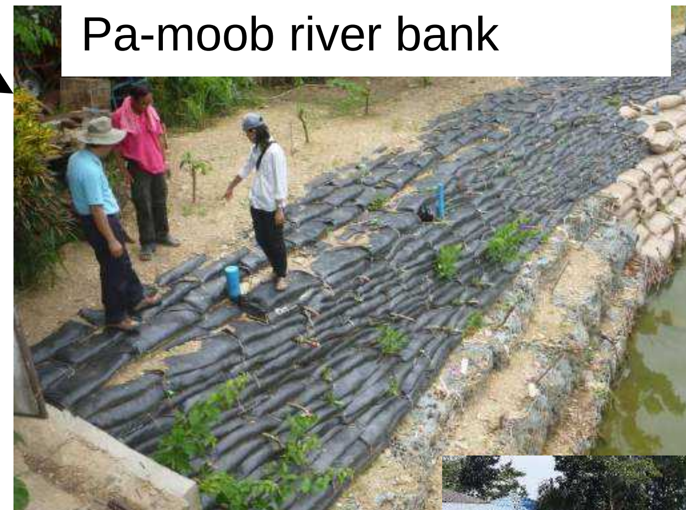


Need to use in conjunction with engineering solution like horizontal drains or reinforced soil slope

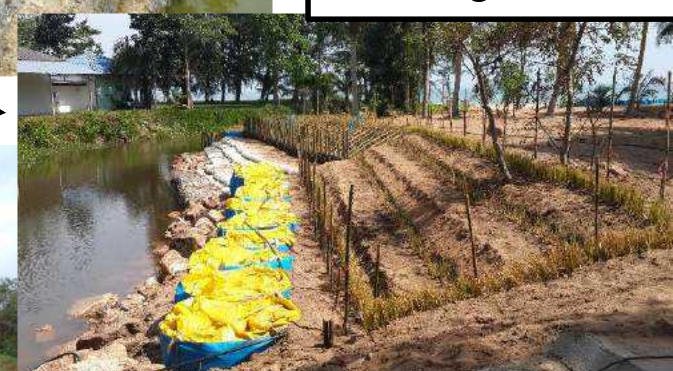
Figure 16.20 Turf reinforcement mat used to foster development of plant roots (after Gray & Sotir, 1996).

Bio-engineering test sections by Kasetsart University (Geotechnical Innovation Laboratory) and partners



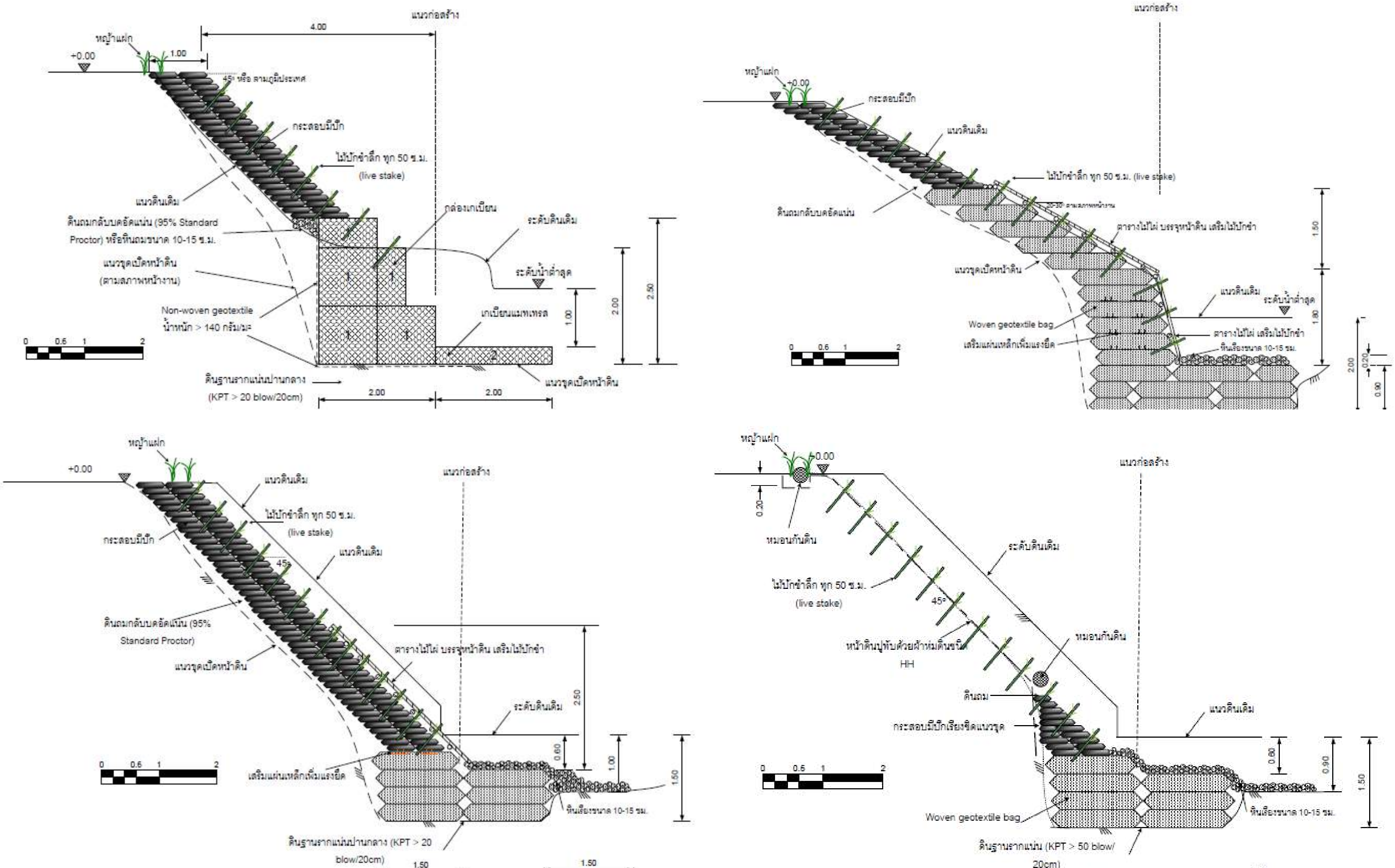


Coastal & river bio engineering at Bangberd



Highway no 44. Krabi

Pa-moob river bank bioengineering- Uttaradit province- funded by the royal initiative project of Chaipattana foundation



4 different designs of bio slope engineering including green gabion, geotextile bags, vegetated flapped soil bags, erosion control mat, erosion control logs

Construction

Flapped soil bag (*Do-Now*) with extension wings

Live stake of *Bougainvillea spectabilis*

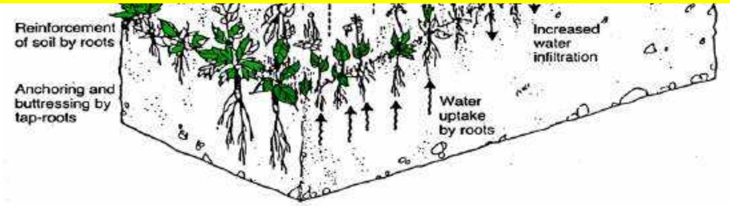
18 Feb
2016

BASIC RESEARCH IN SOIL BIO-ENGINEERING

Various aspects of influence of vegetation on slope stability

- **In 2011, H.M. the king Bhumibol of Thailand, suggested practitioners to exercise certain caution when applying Vetiver on steep slopes and encouraged researchers to investigate into this aspect.**
- **Aim at revisiting engineering characters of vetiver- benefit, limitation and adverse effect)**

strength.



- Conventionally, vegetation-covered and root-permeated ground reported to be of higher permeability and infiltration rate (Styczen & Morgan, 1995).

Higher infiltration- Higher pore water pressure = Reduced stability

- However, Rahardjo et al. (2014) suggested that the Vetiver grass tended to act as slope covers to minimize the infiltration of rainwater into slopes.

Still unresolved issues

Theory & Assumptions

- Unsaturated seepage- **permeability** and moisture are function of positive & negative pore water pressure

$$\frac{\partial}{\partial x}\left[k_x \frac{\partial h}{\partial x}\right] + \frac{\partial}{\partial y}\left[k_y \frac{\partial h}{\partial y}\right] + Q = m_w \left[\frac{\partial u_w}{\partial t}\right]$$

Permeability

Soil-water retention curve

- Shear strength (considering root reinforcement and suction)) -

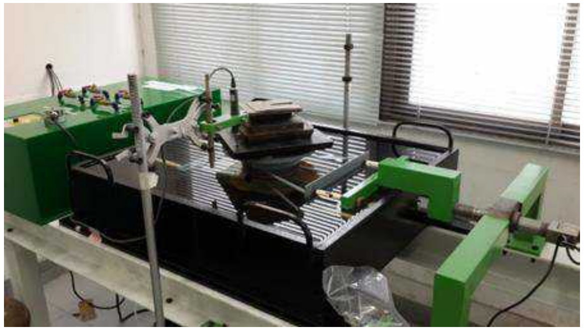
$$\tau = c^r + c' + \sigma_n \tan\phi' - u_w \tan\phi^b$$

Root reinforcement

Pore water pressure - affected by infiltration (not considering transpiration)

Research approach

FIELD



Field observation

Actual root distribution

(Root area ratio)

Pullout-capacity/Field

direct shear test

Empirical knowledge/ experience from practitioners

EMPIRICAL EXPERIENCE

LAB

Laboratory investigation

Root cohesion,

Soil permeability,

Soil-water retention curve,

of root-reinforced sample

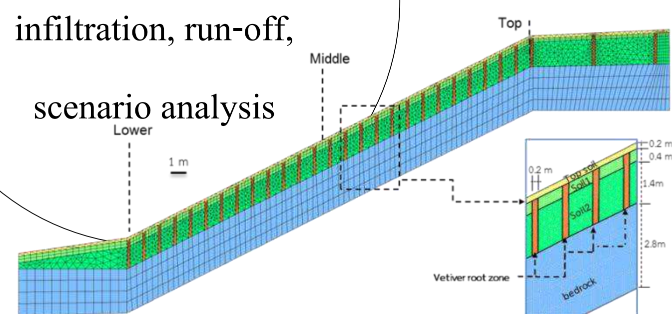
Numerical modelling

slope stability, rainfall-

infiltration, run-off,

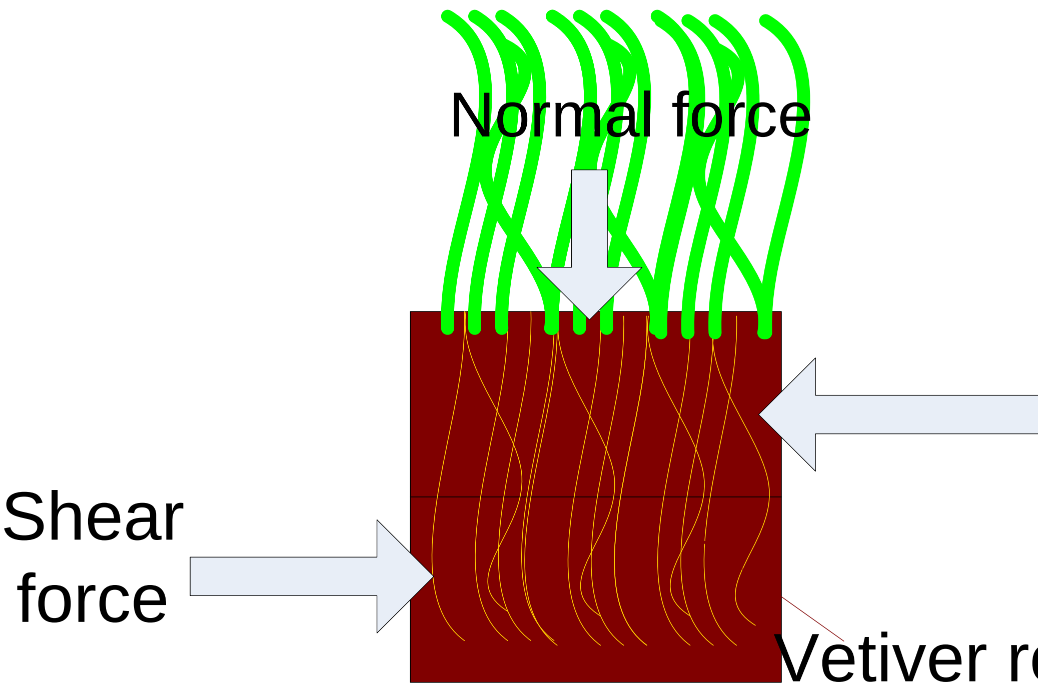
scenario analysis

NUMERCIAL SIMULATION

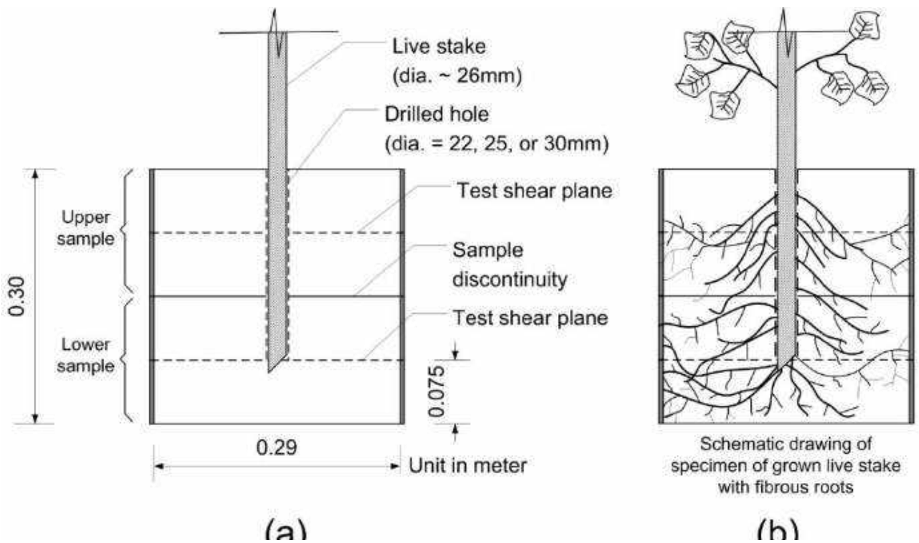


Direct shear tests on vetiver reinforced specimen and live stake specimen

- Large direct shear tests on clayey sand Transparent acrylic tube as sample holder (For investigating the root distribution)
- Test in soaked condition and unsaturated condition

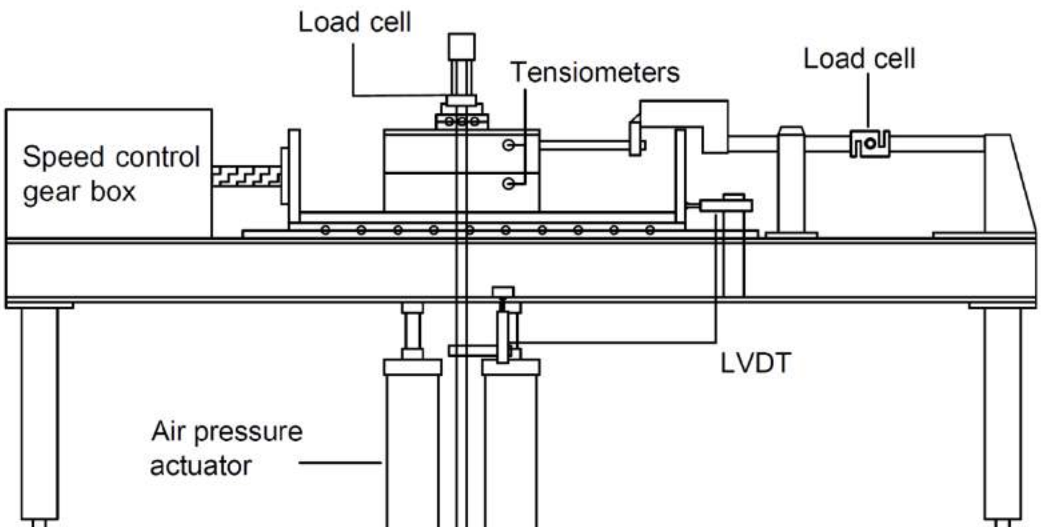


Large direct shear test on live stake sample (Jatropha)



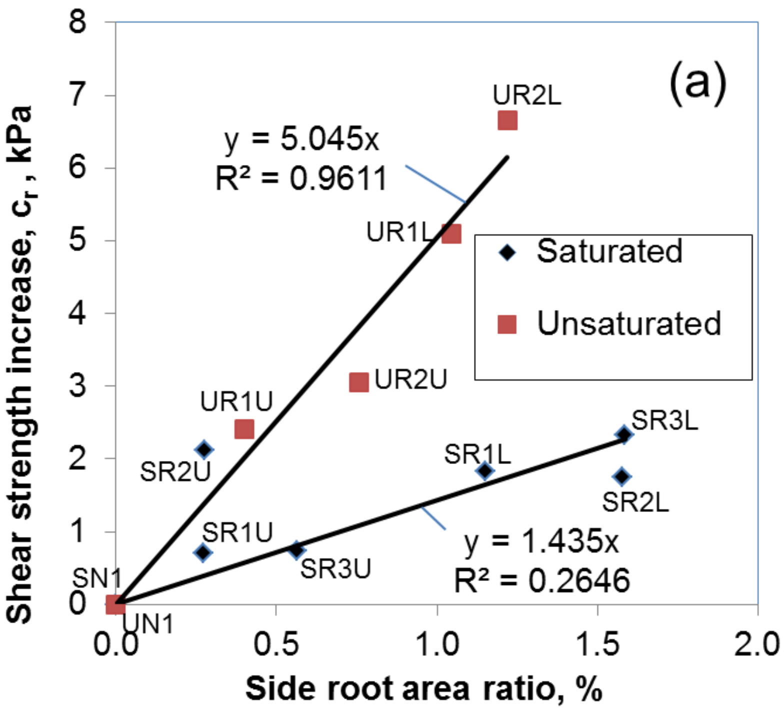
(c)

Large direct shear tests were conducted on compacted clayey sand, reinforced with Jatropha live stakes of various ages, under saturated and unsaturated conditions.



Jotisankasa, A. and Taworn, D. (2016). Direct Shear Testing of Clayey Sand Reinforced with Live Stake. Geotechnical Testing Journal, ASTM, Vol. 39, No.4, July 2016, 608-623.

Effects of soil suction on the rate of strength increase due to root content



$$c_r = k_1(s) \cdot RAR_{side}$$

$$k_1(s) = \eta(s) \cdot k_{1-sat}$$

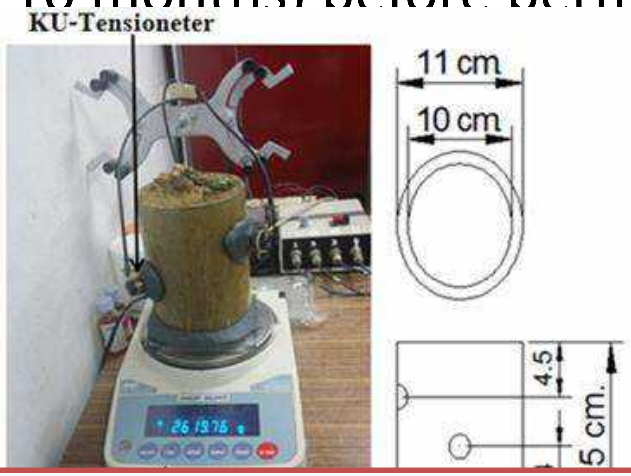
$$\eta(s) = \eta_b \cdot \eta_t \cdot \eta_m \cdot \eta_o$$

Model for correction of root cohesion due to suction effect

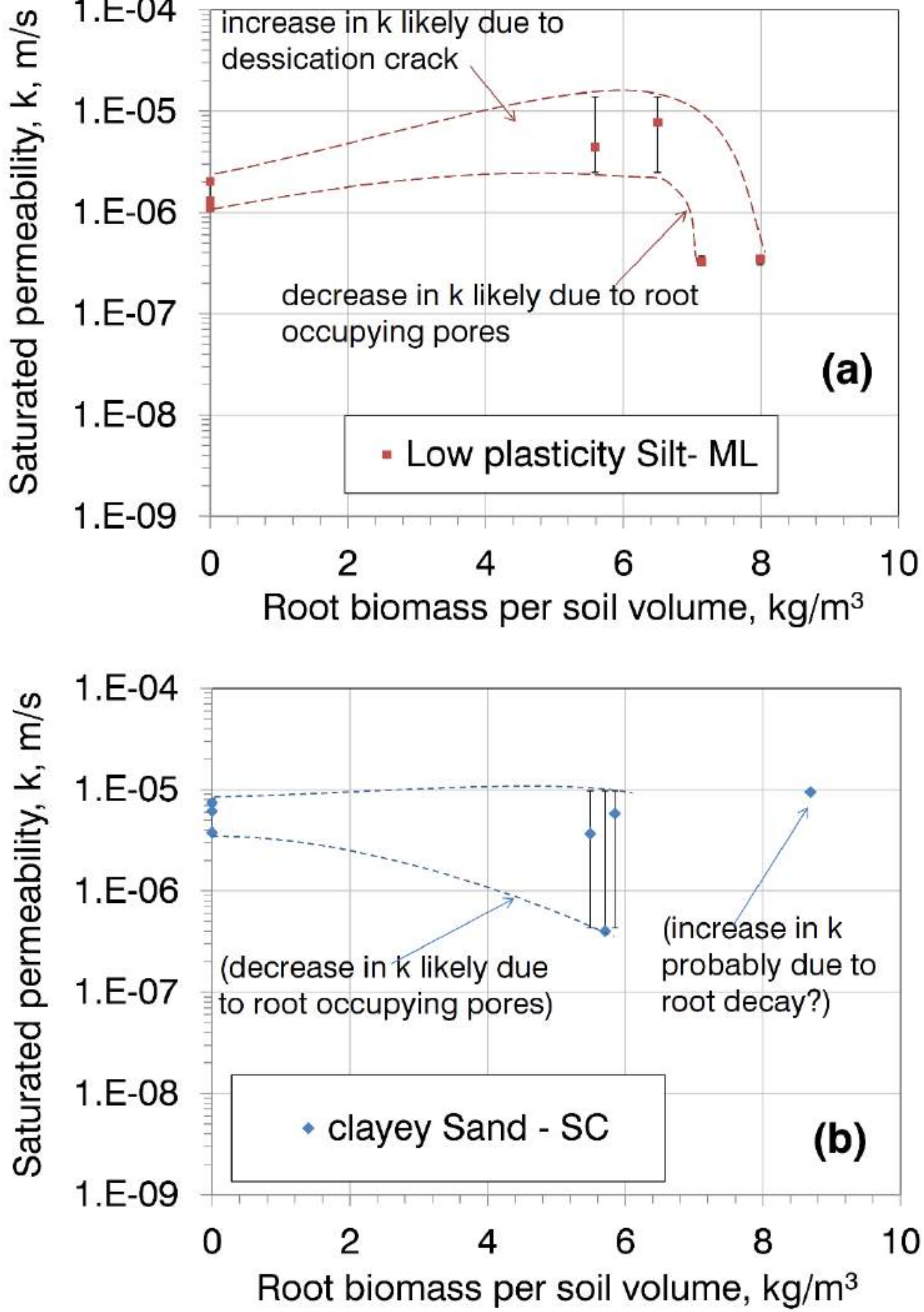
η_b is the correction factor for suction effect on bond stress;
η_t is the correction factor for the suction effect on average root tensile strength;
η_m is the correction factor for the suction effect on average root tensile modulus;
η_o is the correction factor for the suction effect on shear zone thickness and root orientation.

Effects of grass roots on soil-water retention curve and permeability function

- To investigate the influence of root on soils' permeability and soil-water retention curves
- Three major soil types were used for tests, namely clayey Sand (SC), low plasticity Silty soil (ML), and high-plasticity Clay (CH), commonly found in Thailand
- Vetiver was planted in specimens for various duration (upto 10 months) before permeability test



Jotisankasa, A. and Sirirattanachat, T. (2017). Effects of grass roots on soil-water retention curve and permeability function. Canadian Geotechnical Journal. Accepted for publication on 19 February 2017.

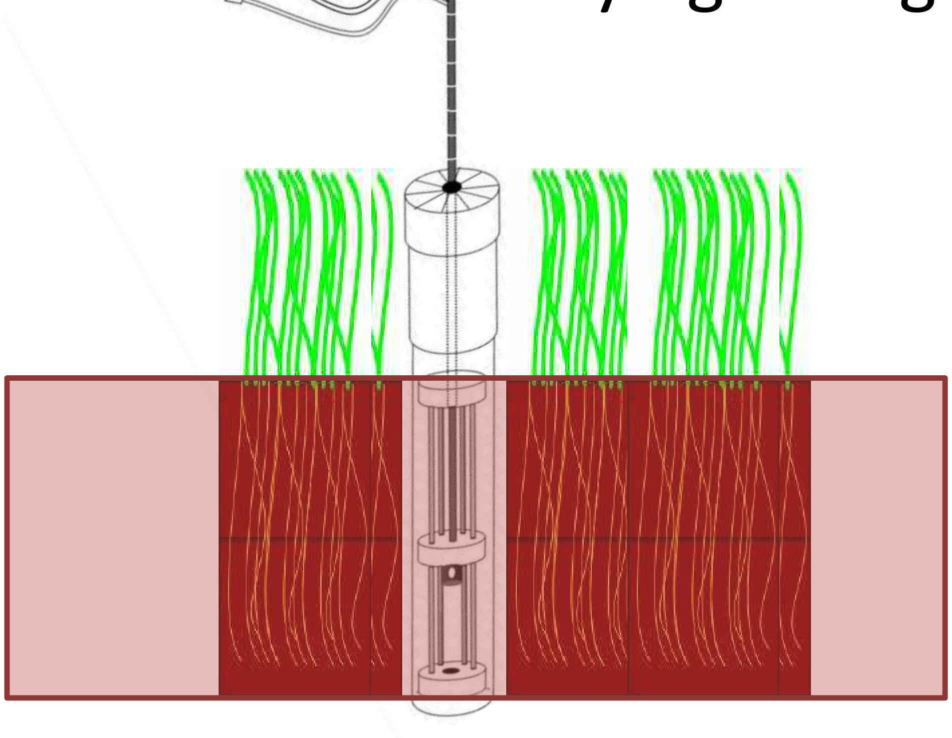


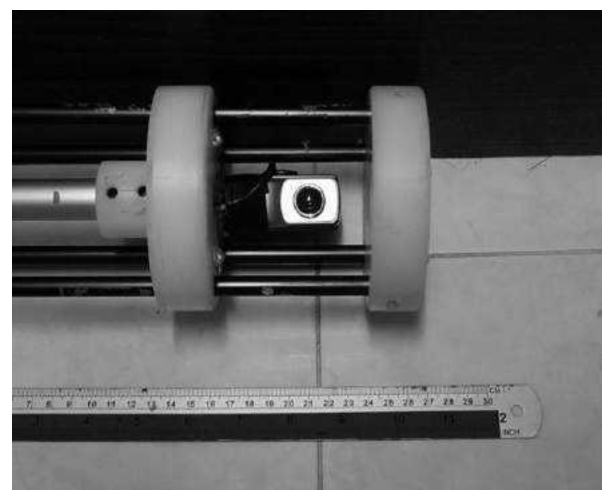
Influence of vetiver root percentage on saturated permeability

- The overall influence of **roots** in this study seems to decrease the permeability of ML soils once fully grown (Due to root penetration into soil macro void
- As for **SC soils**, however, the trend is still not clear, (both decreasing and increasing effect)

Field observation of root degradation

- Minirhizotron system has been used, for observing fine roots intersecting the surface of a transparent tube buried in the soil (a non-destructive method)
- Useful for studying changing conditions of roots





Field observation of vetiver roots

- Field site on top of 45° degree slope in Surathani, South Thailand, (Sandy soil)
- Before and after photos of vetiver grass that disappeared from the slope due to invasion from native species

Minirhizotron

Before

After

March. 2013 - Measurement near Vetiver grass

Oct. 2014 Measurement at same location, Vetiver disappeared due to invasión by native species

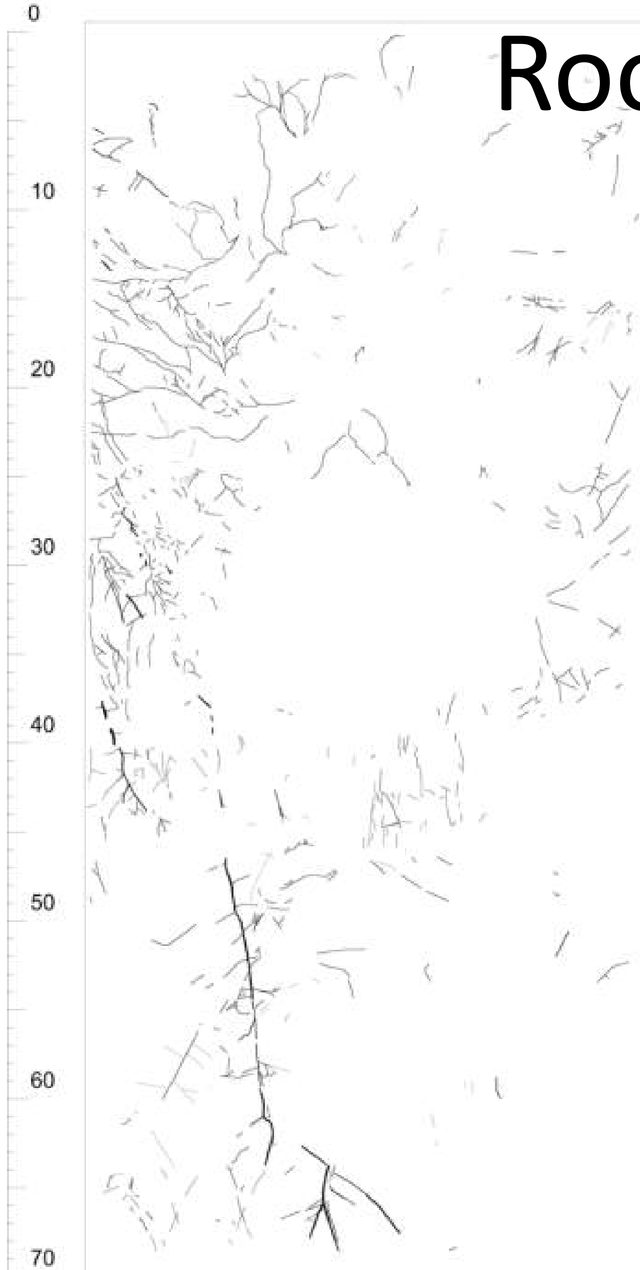
Mar. 2013

Oct 2014

New roots of native species

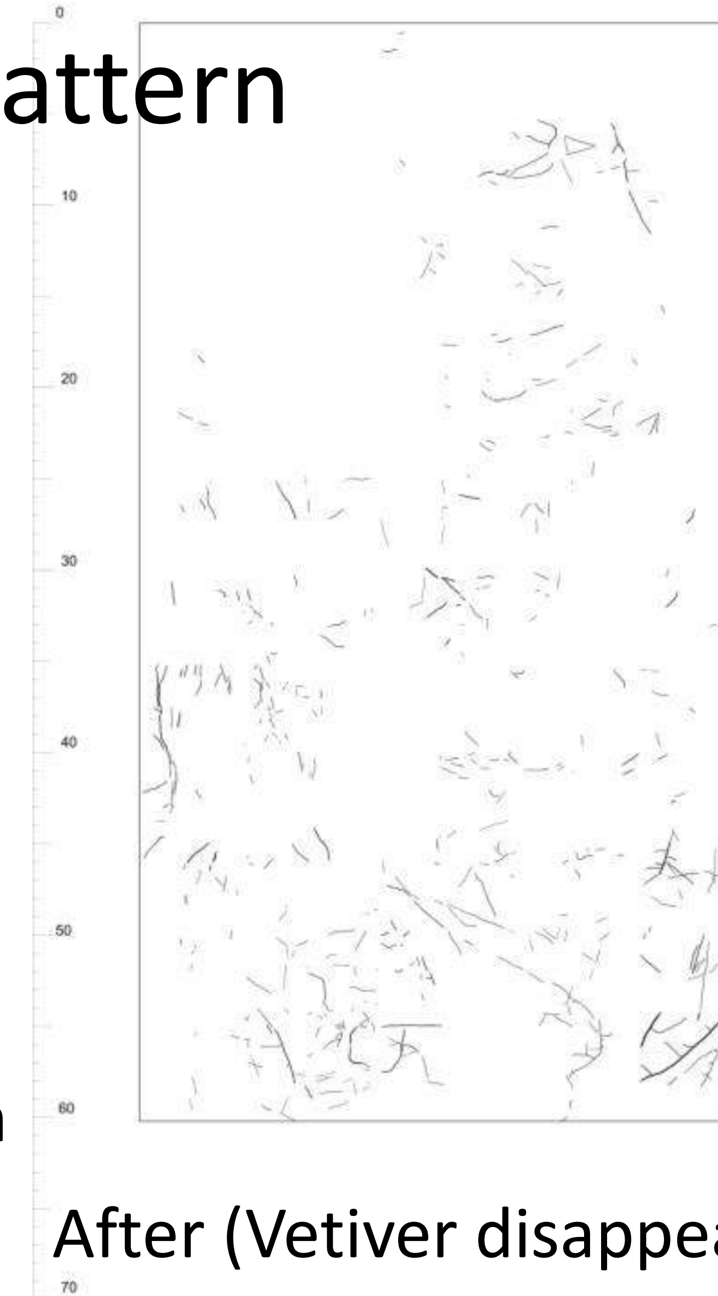
New voids generated around degraded roots

Root pattern



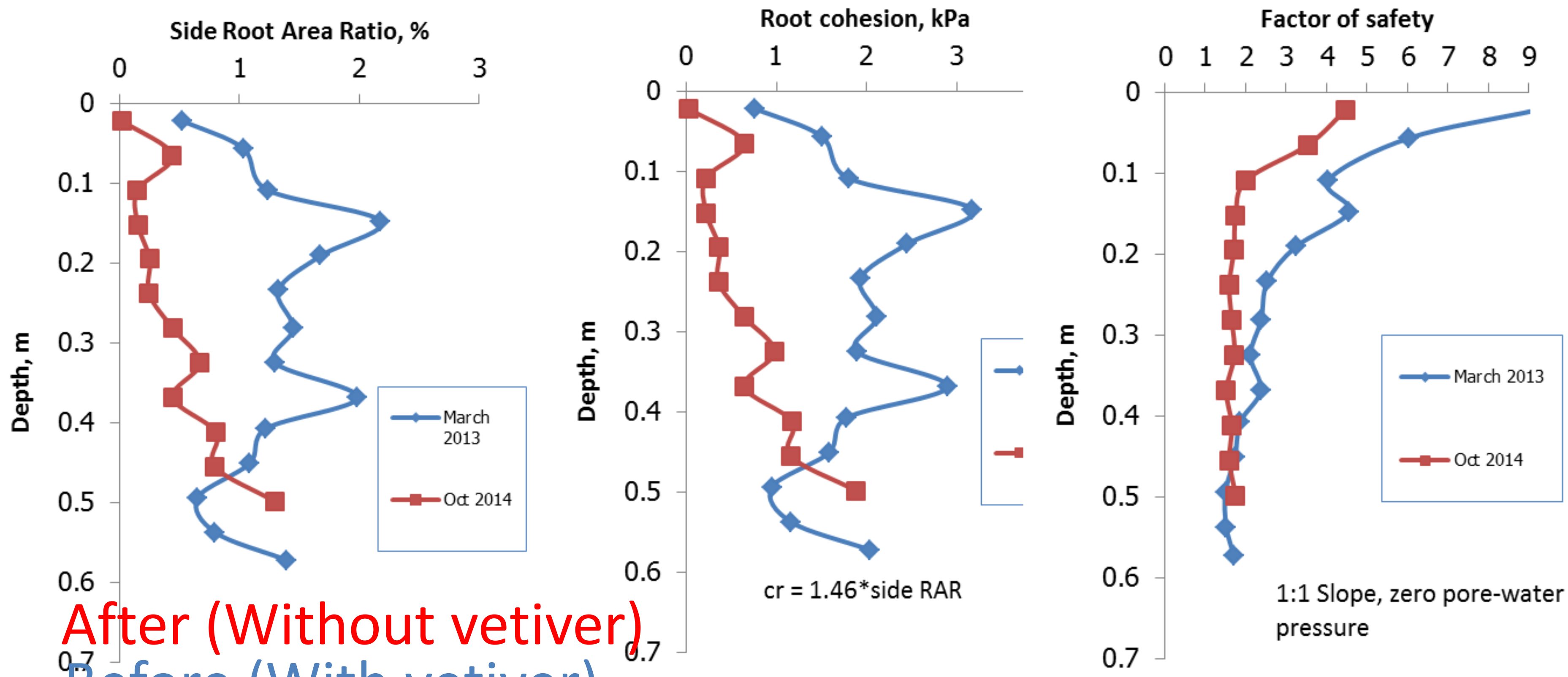
cm

Before (With vetiver)



cm

After (Vetiver disappeared)



After (Without vetiver)

Before (With vetiver)

- After the Vetiver disappeared and its roots decayed, the root area ratio decreased significantly leading to loss in root cohesion and decreased factor of safety.
- This emphasizes the importance of frequent maintenance of the VS in practice in order to sustain long-term slope stability.
- How does this increased void potentially affect infiltration and stability of slopes?

Numerical analysis of rain infiltration into slope with/without vetiver

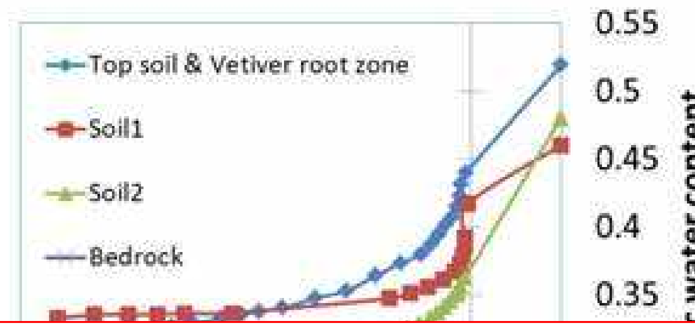
Objectives

- To explore both advantage and potential risk of vetiver grass on slopes by way of numerical modeling.
- The Finite Element Method was used to analyze infiltration of rain into slope
- Limit-equilibrium method for slope stability calculation
- 2 hypothetical slopes with gradient of about 27^o and 60^o. For both cases, the slopes were modelled with and without vetiver row in order to compare the effects of vetiver on stability.

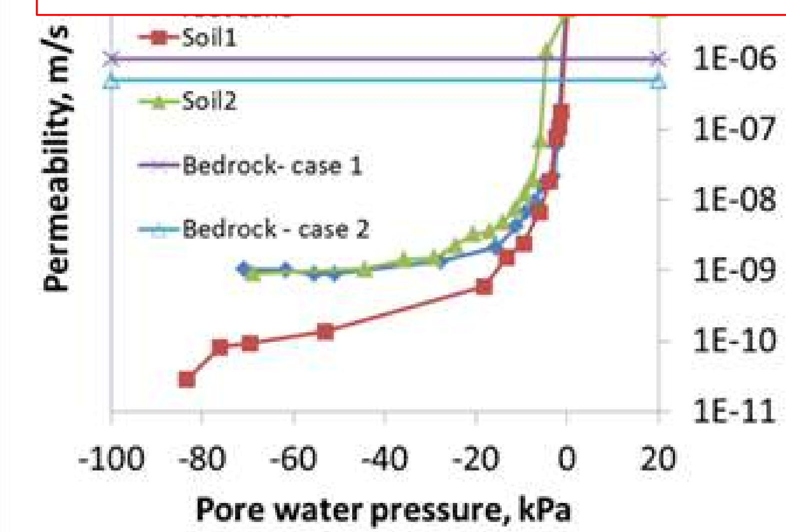
Soil properties in the analysis

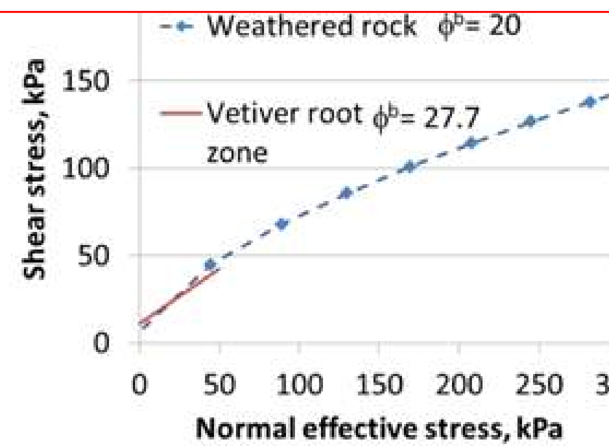
Material	γ_{sat} kN/m^3	$c'+c^r$ kPa	ϕ' deg.	ϕ^b deg	γ_{moist} kN/m^3	
Top soil	17	22.8	17.6	13.9	16.5	*
Soil 1	18.5	2	32	27.7	18	*
Soil 2	18.7	2	32	27.7	18	*
Veti[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	**

Sou[illegible]
(201[illegible]

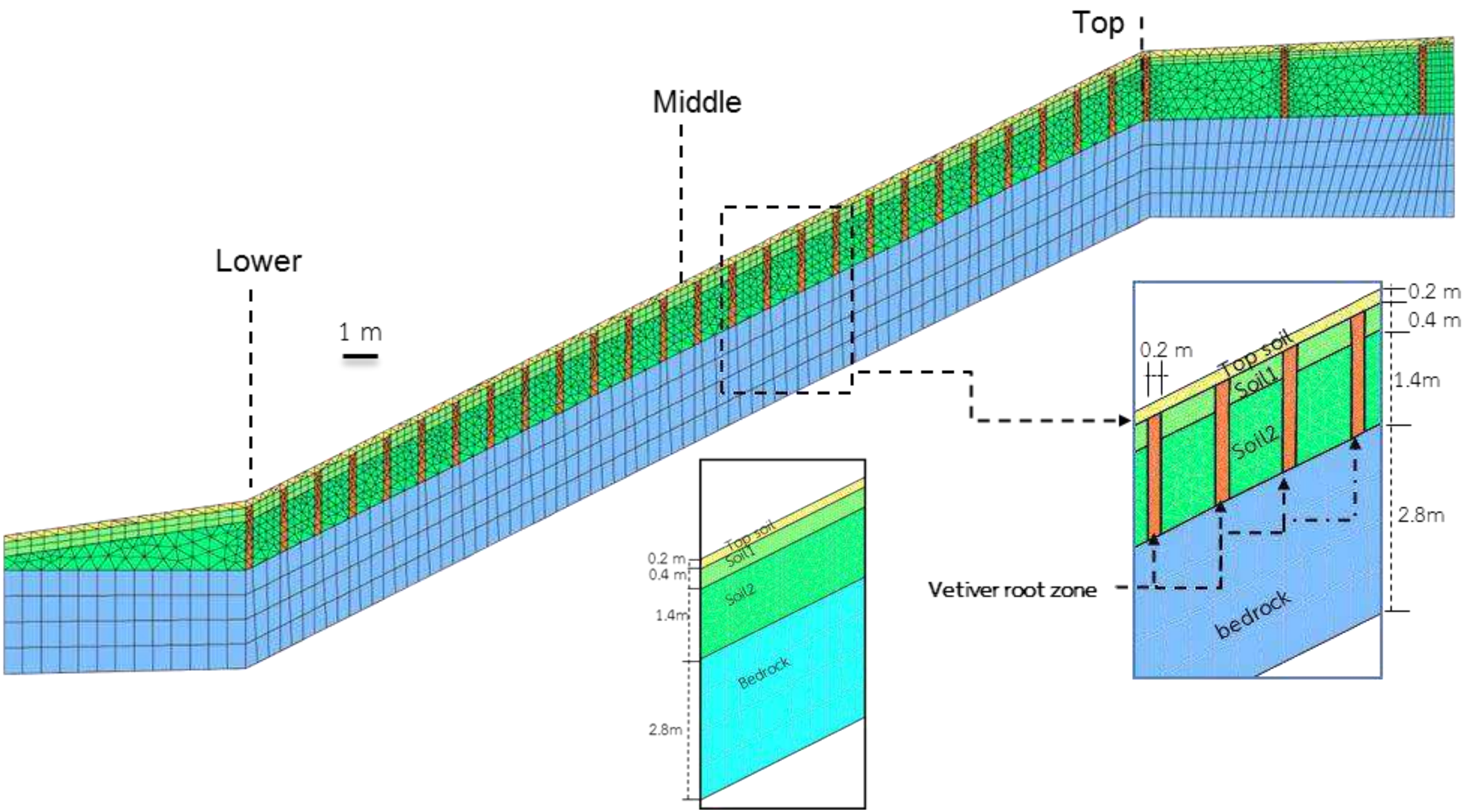


Permeability of root zone is assumed to be 2 times permeability of no-root zone (more permeability root zone or effect of decayed roots considered)
Root cohesion,Cr, of 20 kPa assumed.



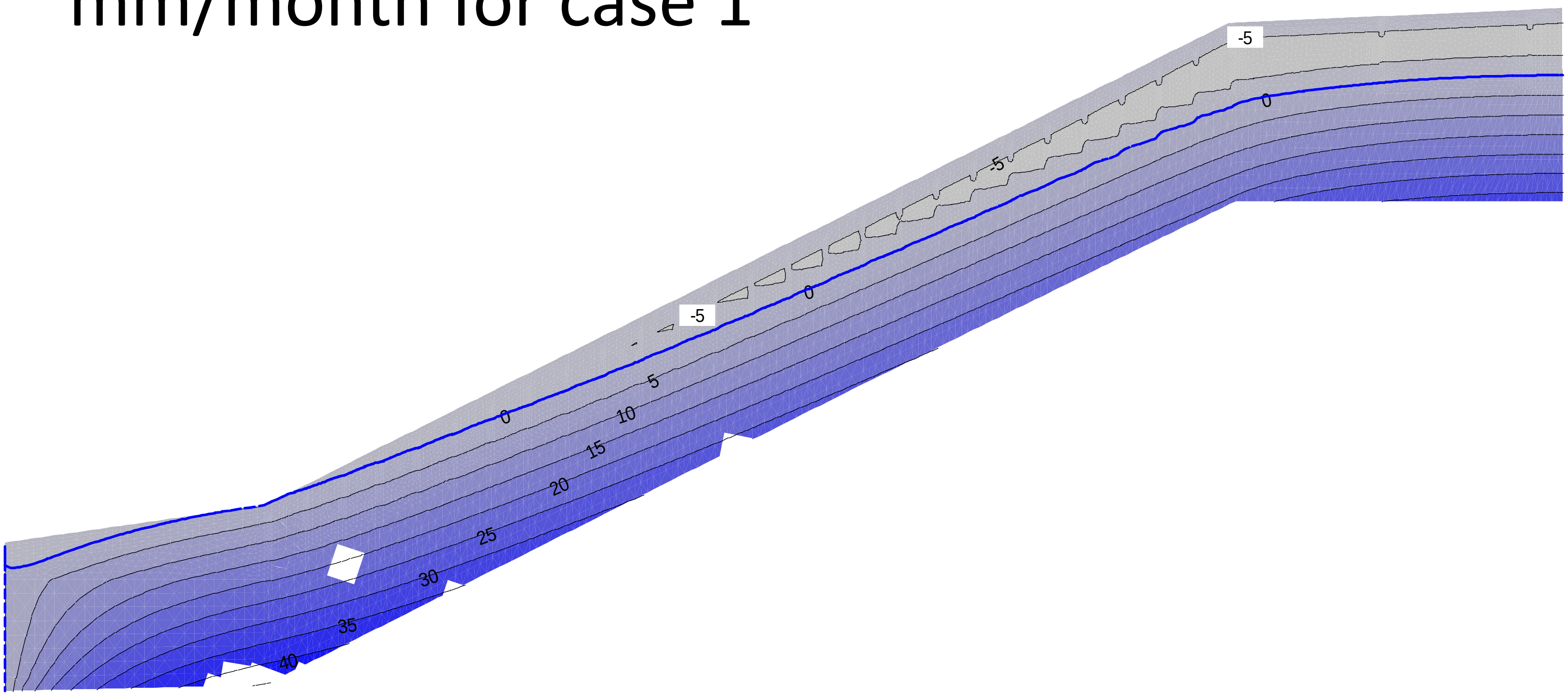


Natural slopes (26 degree) with/without rows of vetiver grass

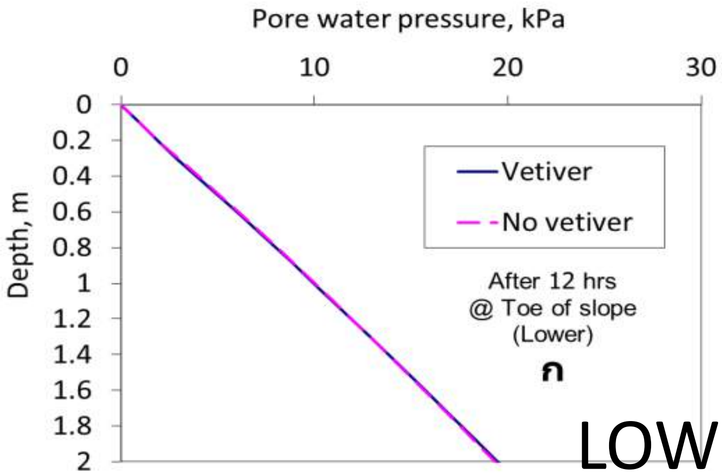


Initial condition from steady state analysis

- Contour of pore water pressure (kPa)
- (time= 0 hr) Average infiltration of 300 mm/month for case 1

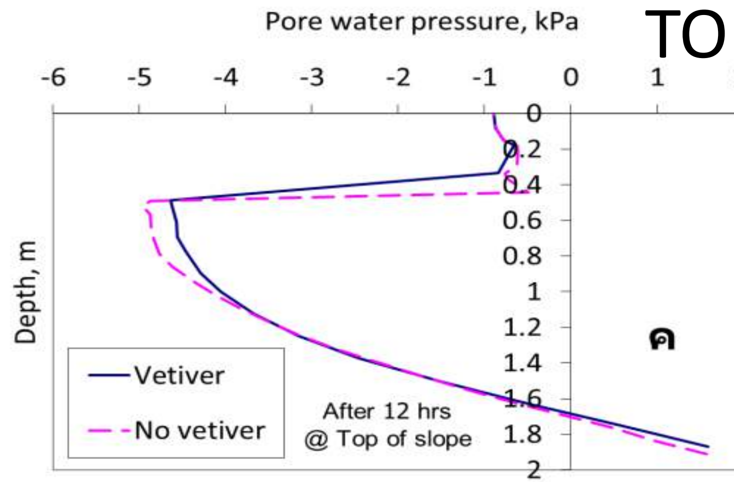


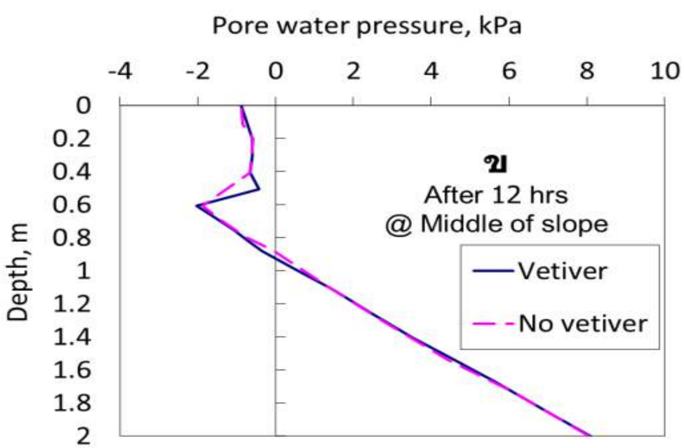
Comparison between pore waterpressure in slopes with vetiver rows and without vetiver rows (at 12 hours time = 43 mm of rain)



LOWER

TOP

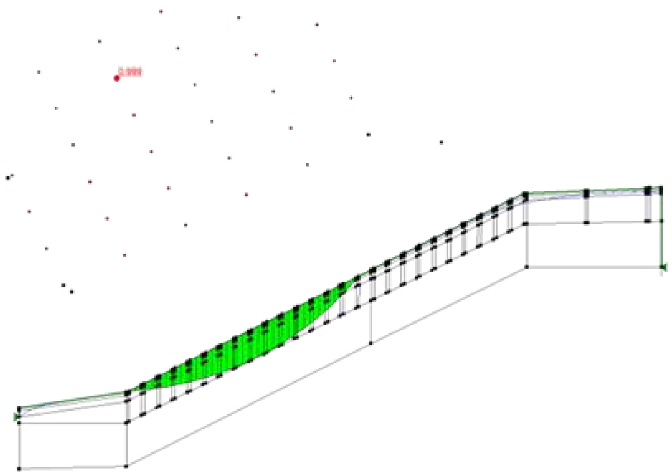


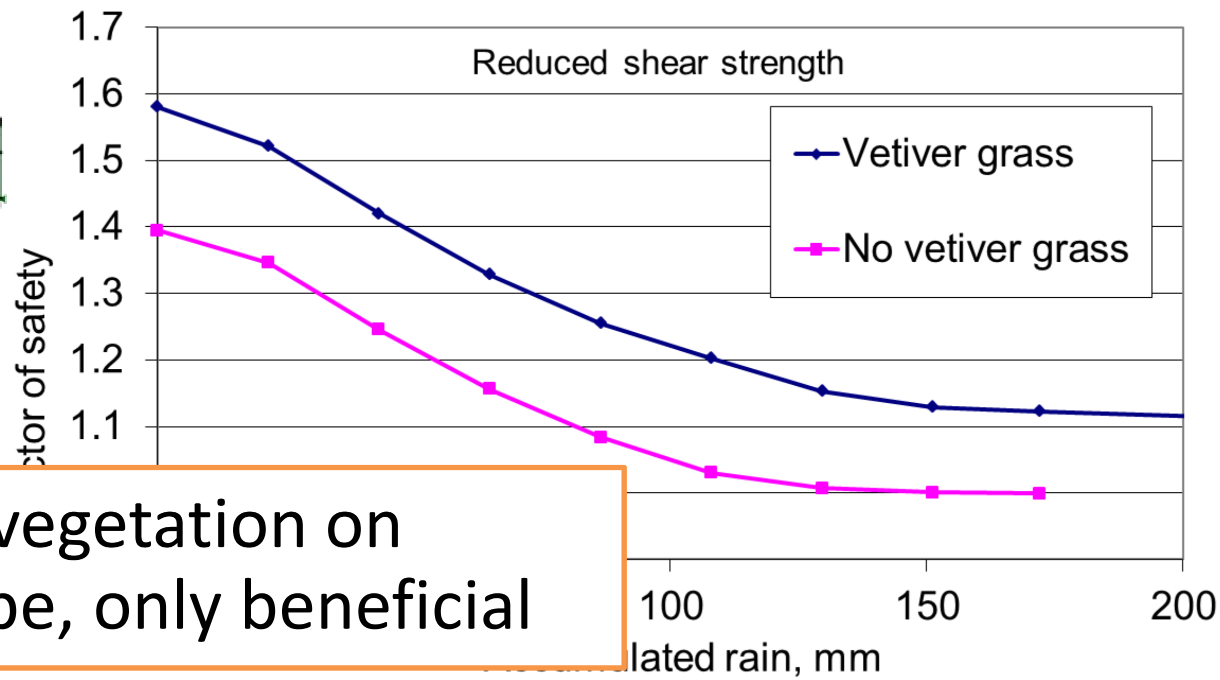


MIDDLE

- There was **<u>only very slight difference</u>** between the two cases.
- Except at the top part of slope, for slope with vetiver rows, the root zone appeared to conduct some water to a greater depth
- All in all, there is not much significant difference between the pore water pressure of 26o slopes with or without vetiver.

Natural slope 26 degree



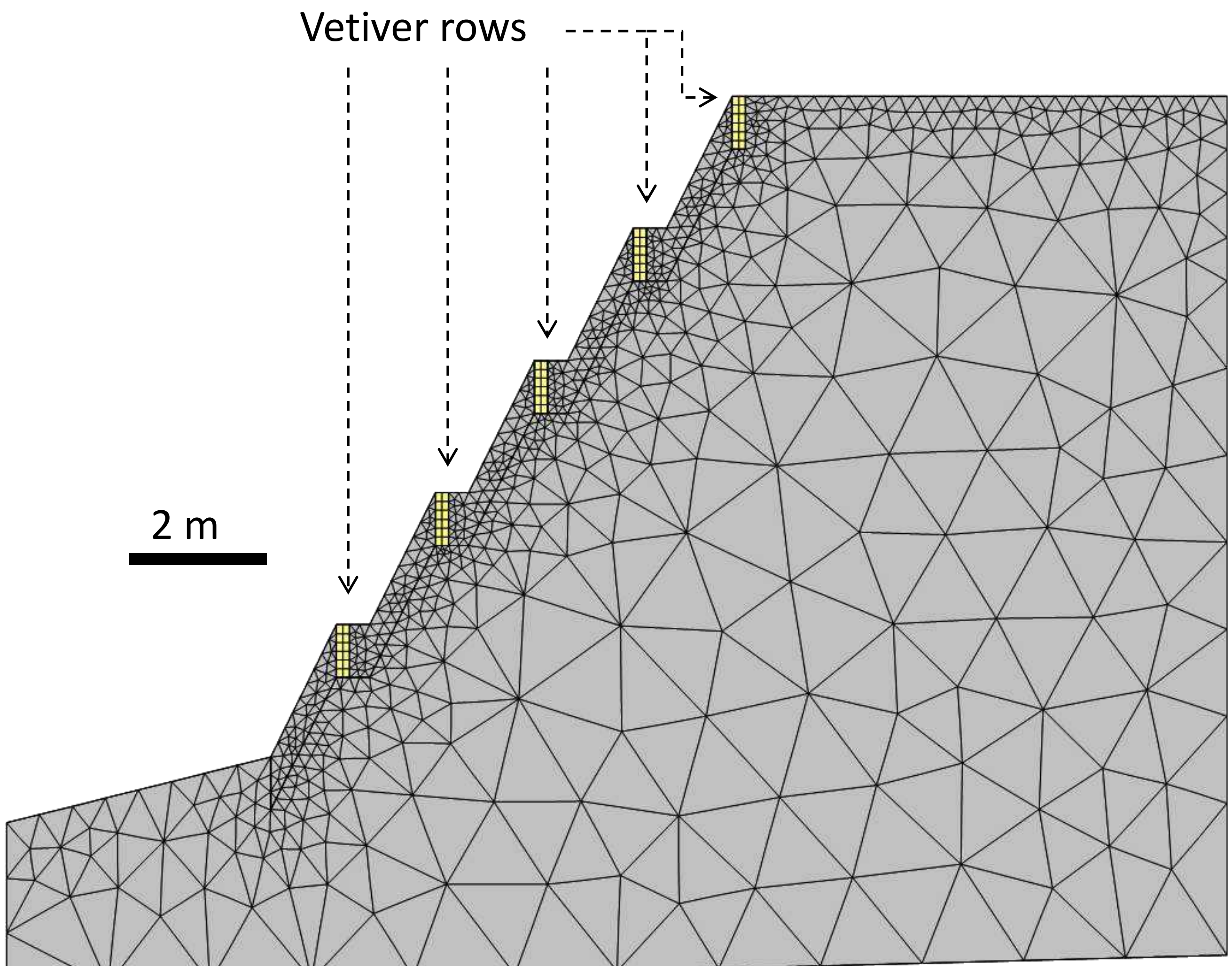


No adverse effect of vegetation on stability for 26.6^{o} slope, only beneficial

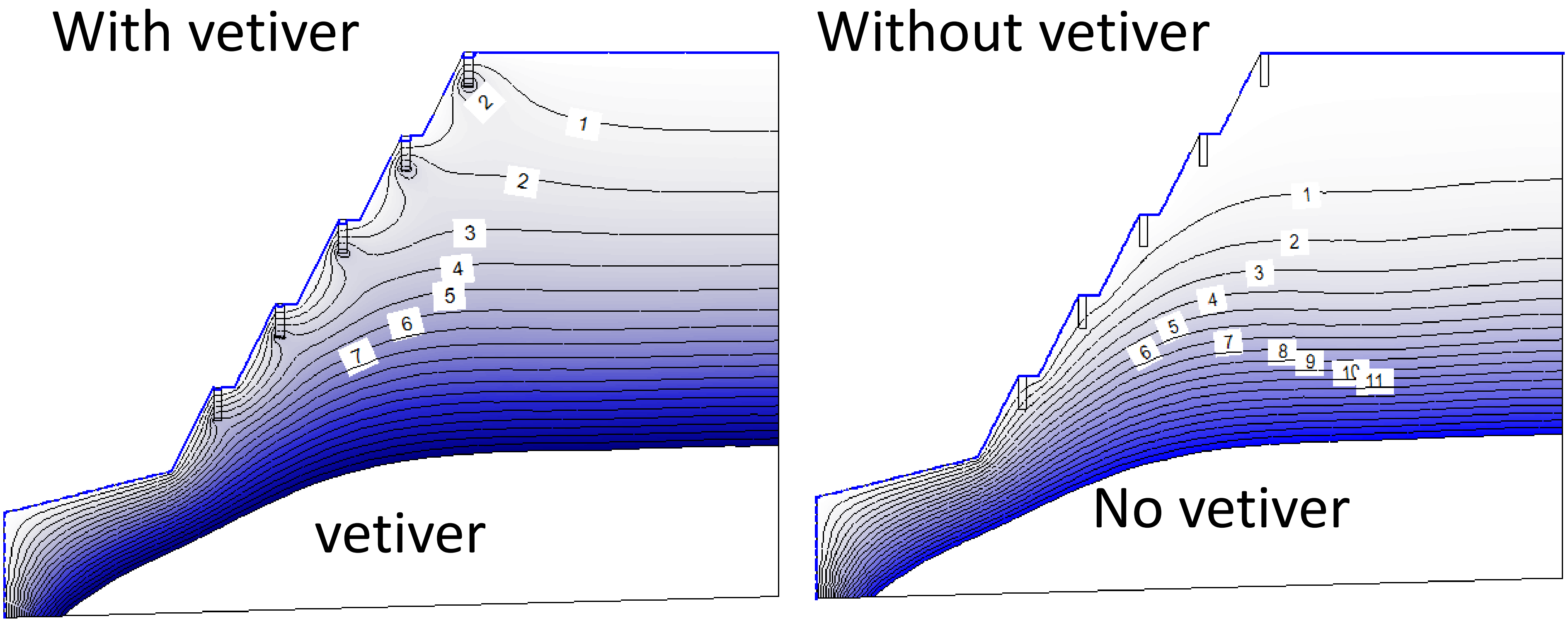
- Limit Equilibrium slope stability analysis carried out based on pwp from transient seepage analysis
- The slope without vetiver grass appeared to fail (FS=1) when the total rainfall reached about 120-170 mm
- The increased cohesion due to roots (c_r) more than offsets the higher permeability of root zone that induce greater infiltration into slopes, for the case of 26.6^{o} slope

Rock cut slope (60 degree) with/without rows of vetiver grass

- 10 m high slope (2 m high step) vetiver planted on each bench

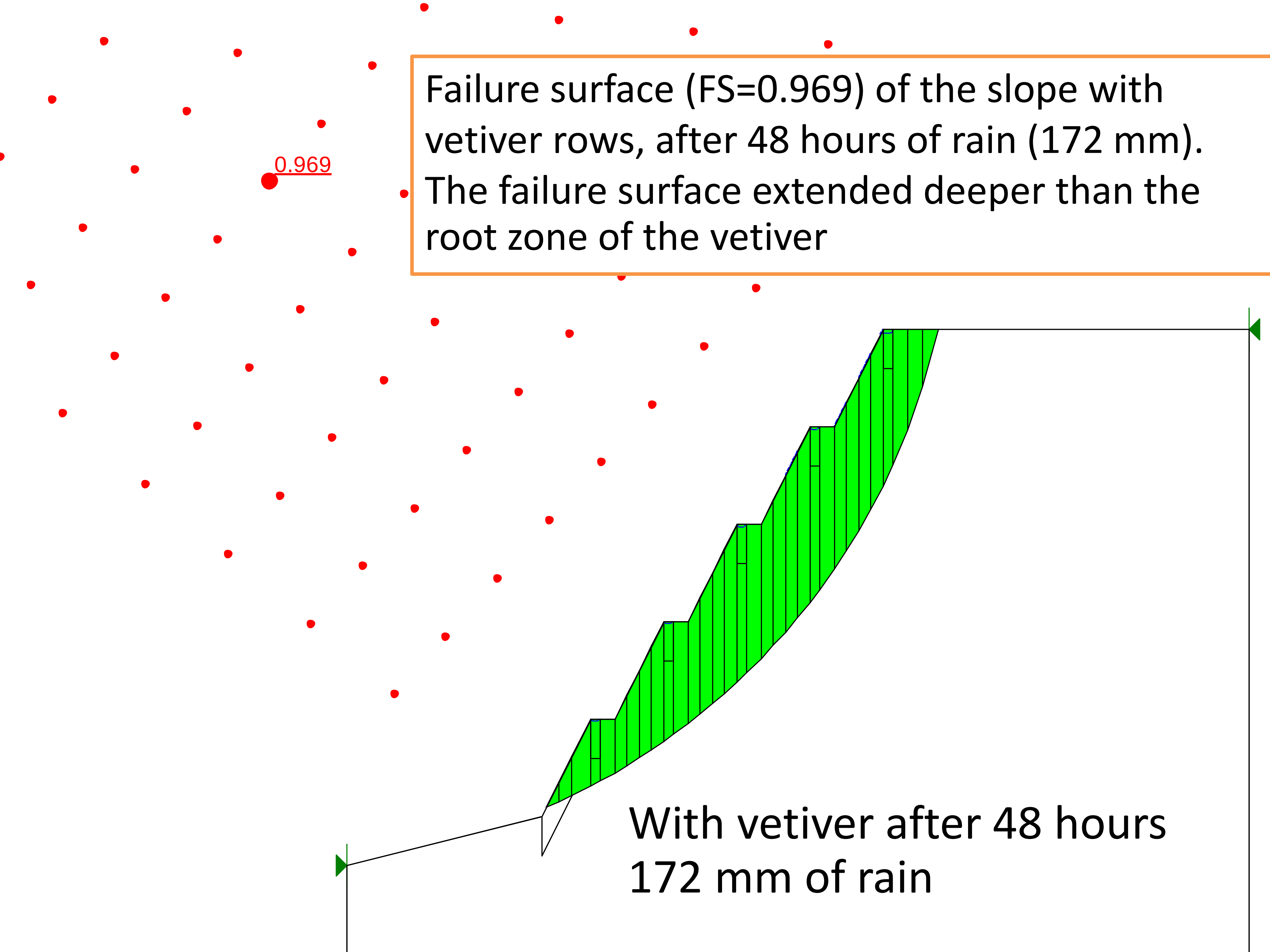


Pore water pressure variation
After 24 hours = 84 mm



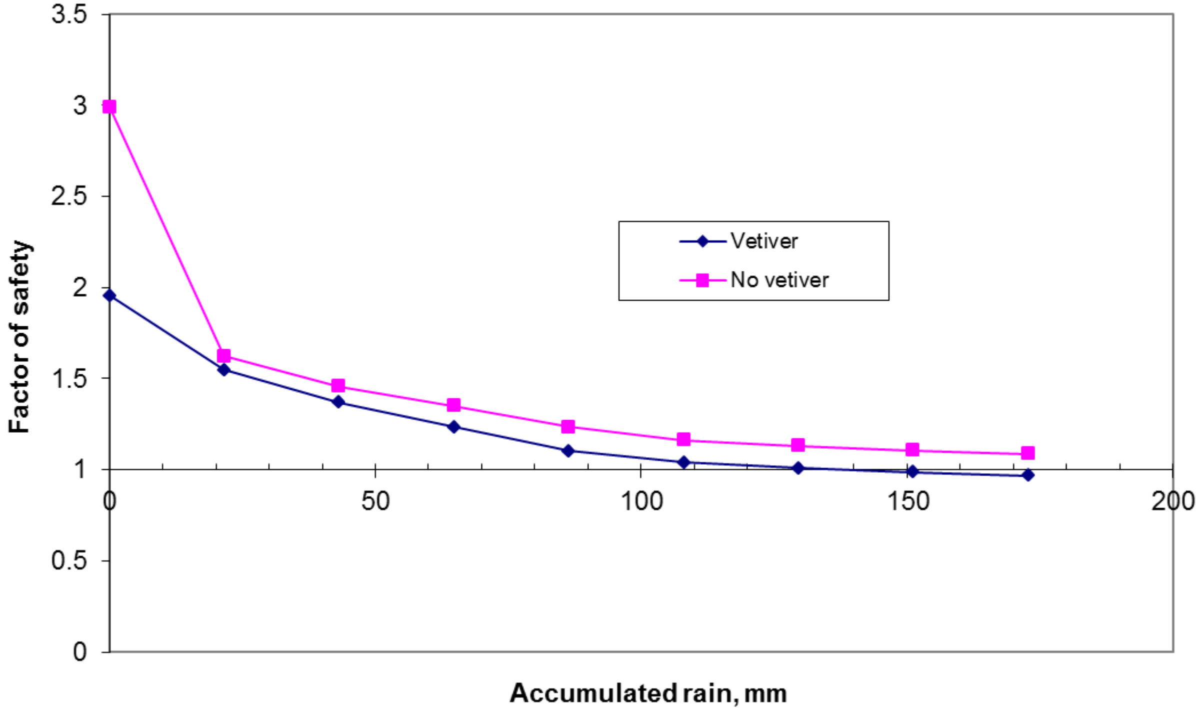
- With vetiver hedgerows on slope, groundwater can infiltrate to a greater depth through the **assumed more permeable root zone**, resulting in **higher pore water pressure in the slope**.
- Without the vetiver rows, part of the rainfall would not permeate the ground and tend to become runoff.

Failure surface (FS=0.969) of the slope with vetiver rows, after 48 hours of rain (172 mm). The failure surface extended deeper than the root zone of the vetiver



With vetiver after 48 hours 172 mm of rain

Weathered rock slope 60 degree



- Factor of safety for the 60^{o}slope **with permeable root zone** is about **10% lower than the slope without root zone** due to **the increased pore water pressure** induced from **increased infiltration** through the root zone.

Possible threats and opportunities : roles for soil bio-slope engineering

Nan

Betong, Yala

Conclusions

- Vegetation has been used to prevent shallow slides and erosion in various geotechnical and geo-environmental structures
- This studies highlighted the importance of **validating the landslide prediction model with real field slope response**, importantly the suction and pore water pressure response due to rainfall
- Accurate prediction of **vegetation contributions** to mechanical and hydraulic behavior of soil and slope stability are of great importance for **landslide prediction and prevention.**
- A new technique of **root observation in the field**, combined with **laboratory test** and **numerical simulation**, helps practitioners to **better understand** the engineering characteristic of the vetiver system and live stake, both mechanical and hydraulic.

Some selected publications

- Jotisankasa, A. and Mairaing, W. (2010). Suction-monitored direct shear testing of residual soils from landslide-prone areas, *Journal of Geotechnical and Geoenvironmental Engineering, ASCE*, Vol. 136, No. 3, March 1, 2010.
- Mairaing, W., Jotisankasa, A. and Soralump, S. (2012). Some applications of unsaturated soil mechanics in Thailand: an appropriate technology approach. *Geotechnical Engineering Journal of the SEAGS & AGSSEA Vol. 43* No.1 March 2012 ISSN 0046-5828. pp. 1-11.
- Jotisankasa, A., Mahannopkul, K., and Sawangsuriya, A. (2015). Slope Stability and Pore-Water Pressure Regime in Response to Rainfall: a Case Study of Granitic Fill Slope in Northern Thailand. *Geotechnical Engineering Journal of the SEAGS & AGS*SEA Vol. 46 No.1 March 2015 ISSN 0046-5828. pp. 45-54.
- Jotisankasa, A. and Taworn, D. (2016). Direct Shear Testing of Clayey Sand Reinforced with Live Stake. *Geotechnical Testing Journal, ASTM*, Vol. 39, No.4, July 2016, 608-623.
- Jotisankasa, A. and Sirirattanachat, T. (2017). Effects of grass roots on soil-water retention curve and permeability function. *Canadian Geotechnical Journal*.
- Rahardjo, H., Satyanaga, A., Hoon, K., Sham, W.L., Aaron, Ong, C.L., Huat, B.B.K., Fasihnikoutalab, M.H., Asadi, A., Rahardjo, P.P., Jotisankasa, A., Thu, T.M. & Viet, T.T. (2015) “Slope Safety Preparedness in Southeast Asia for Effects of Climate Change” In Joint Technical Committee JTC-1 JTC-1 TR3 Forum ‘Slope Safety Preparedness for Effects of Climate Change’ 17 and 18 November 2015 Naples, Italy
- Jotisankasa, A., Mahannopkul, K., Teerachaikulpanich, N., Miyashita, T. and Tada, Y. (2015), Investigation of high-seepage zones in slopes using the Groundwater Aeration Sound (GAS) survey technique in Thailand, Proceedings of the 15th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering, Fukuoka, THA03

Acknowledgements

The authors gratefully acknowledge the financial support and encouragement by

- Chaipattana Foundation,
- Sustainable Energy Foundation,
- Kasetsart University Research and Development Institute (KURDI), Thailand.
- Office of the Royal Development Projects Board
- Ban-natum & Lablae communities
- Department of Highways

Thank you very much for your attentions