

# Online Sensor Platform for Earth Slope Resilience in Thailand

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## ABSTRACT

Prolonged precipitation, rapid stream flows and natural hazards cause severe impacts on resilient infrastructure, e.g., landslides, earth structure failures, flood travel lanes, wash out roadways, destabilize stream conditions etc. Changes in precipitation, moisture, wet-dry cycles and groundwater levels threaten all parts of the earth structure system, e.g., soil and rock slopes, causing roadway deformation, soil movement, slope erosion and destabilized soil and rock slopes etc. Road transportation agencies shall consider these impacts and adaptation early in the project development progress to ensure climate resilience is fully incorporated into the project design and construction, how the proposed earth slope is vulnerable to change, what adaptation measures effectively increase resilience, and how to implement the selected measures. Monitoring a set condition and streaming data back directly from the projects help transportation operators planning and designing for the type of climate that earth slope will be exposed to over its lifetime. Uncertainty in climate data and natural variations in the climate system can be dealt with by utilizing online sensor platform, which harvest and present data from smart sensors to track and present critical information. The sensors continuously monitor the relevant variables, namely pore-water pressure, suction, soil moisture content, rainfall, soil movement at the surface and below the ground, processing data points constantly, feeding data back in their real time and quickly response when conditions change, as well as streaming information to the dynamic dashboards for accessing instant updates on any device.

**Keywords:** *climate change, resilience, sustainable, monitoring, performance*

## 1. INTRODUCTION

Residual soil and weathered rock slopes are typically found in mountainous and hilly terrains in most tropical regions like Thailand and ASEAN countries. These earth slopes are often in the unsaturated condition with negative pore-water pressure or matric suction [1]. The presence of matric suction is a favorable condition because it has a beneficial effect on the shear strength of unsaturated soils and thus increases the stability of slopes. However, when the rainfall infiltrates into slope, the pore-water pressure increases, the matric suction decreases, and thus reducing the stability of the slope. This phenomenon causes the slope to become more prone to failure, which is commonly known as rainfall-induced slope failure and is one of the most destructive natural disasters that is often random and sudden events that are often hard to predict.

According to [2,3], rainfall is the main cause of landslides and slope instability. Rainfall-induced slope failures and surface erosions have been increasingly becoming more severe in Thailand and many other ASEAN countries in the tropics due to more frequent extreme climate conditions and potential climate impacts. More frequent slope failures have been reported in Thailand, due in part to climate change, intense rainfall in a short duration, prolonged rainfall, and rapid development of infrastructure without due respect to the

changing ecological and hydrological conditions in the natural slopes. About 50% of the slope failures in highway network of Thailand are related to severe erosion due to overflow in drainage, sub-drainage, and subsequently shallow slide. In response to these concerns, the online sensors are becoming very necessary to monitor various variables related to the movement in critical slopes, e.g. pore-water pressure, soil moisture, ground deformation, precipitation etc. The Internet of Things (IoT) technology has been gradually accepted by highway agencies, road transportation operators, city and municipality authorities, local communities, researchers, and policy makers in such a way that appropriate decision and immediate action can be taken to rectify the slope instability.

In this study, four test sections were built along the national highways' cut and fill slopes in the Northern Thailand, which were well-known for their mountainous, hilly terrains, tourist attractions, and were often subjected to land sliding hazards under natural and engineered slopes. A series of online monitoring sensor and field instrumentation consisting of soil moisture sensor, piezometer, tensiometer, inclinometer, tiltmeter, rain gauge, settlement point, data acquisition system, and IoT platform have been deployed at each site in order to simultaneously collect the field measurement data under Thailand's tropical climatic conditions.

## 2. SOIL BIOENGINEERING TECHNOLOGY AND SLOPE MONITORING SYSTEM

### 2.1. SOIL BIOENGINEERING TECHNOLOGY

The soil bioengineering technique for road slope engineering in Thailand involves the utilization of various plant materials (live cuttings, live stakes, seedlings, vetiver grass) [4] together with both permanent structures (such as concrete gravity wall and geosynthetics bags and mats) [5] and temporary biodegradable structures (such as bamboo fence/grid, jute net or coconut coir). These materials function together and supplement each other as shown conceptually in Figure 1. While the engineering structures perform best in their initial condition, they would likely deteriorate with time at varying rates. In contrast, the plant materials would need some period to grow before they fully function at their best in the fully grown condition. In this sense, the biodegradable structure such as bamboo fence/grid, natural soil blanket, would help in maintaining the plants at this initial stage. By the time structures deteriorate, the plant would take over the stabilizing roles and restore the ecological condition of the site. Recently, more innovative ideas, such as capillary barrier system utilizing biochar amended soil (Figure 2), were also experimented in trial slope sections in Thailand. This nature-based solution is also in line with the Bio-Circular-Green Economic Model (BCG) promoted by the Royal Thai government.

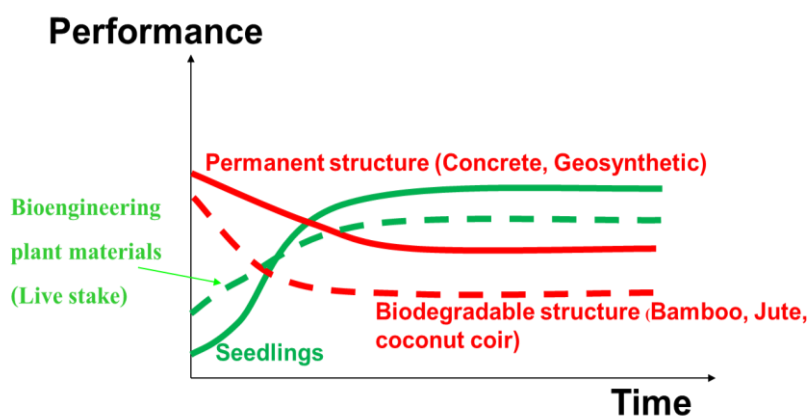


Figure 1 - Conceptual performance of bioengineering technique using plant materials and engineering structures

In this study, three main bioengineering slope covers included a) vetiver system (VS) [4] with bamboo fence, b) erosion control blanket (ECB) with erosion control log (ECL) [6] and c) capillary barrier system (CBS) [7]. Toe erosion was protected by using vegetated flapped soil bag and screw piles. These approaches were also possible to use marginal materials and local products e.g. biochar, soils, local plants, reclaimed & recycled materials etc. The biochar was derived by pyrolysis process of local biomass or agricultural waste such as corncobs and roadside tree trimmings etc. Apart from improving the plant survival rate and their slope reinforcement, the biochar amended soil also enhanced the carbon sequestration and potentially act as carbon sink to mitigate the CO<sub>2</sub> emission.

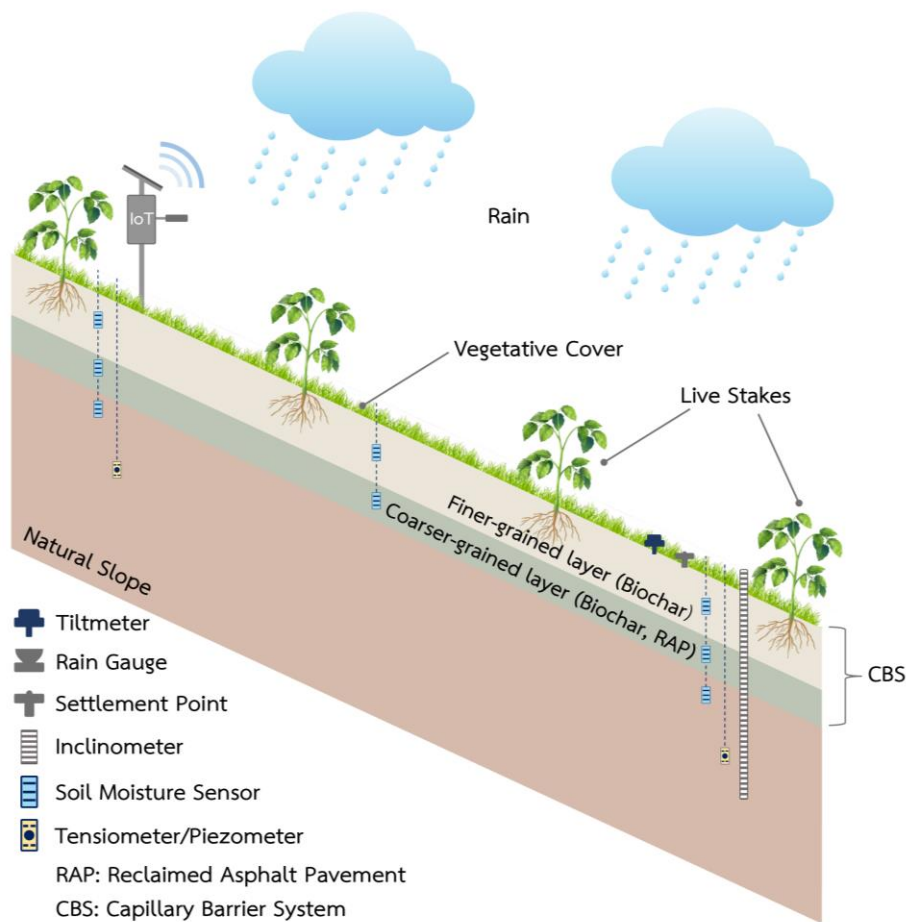


Figure 2 - Capillary barrier system (CBS) and field instrumentations

## 2.2. SLOPE MONITORING SYSTEM

Different type of sensors was deployed such as piezometer and tensiometer for measuring positive and negative pore-water pressures, soil moistures sensors, tiltmeter and inclinometer for measuring ground movement and subsurface deformation, and tipping bucket for measuring rainfall intensity [8]. Every variable was then transmitted to the web-based cloud technology (IoT) (Figure 3) where the data acquisition and engineering analysis were employed to identify risks with respect to the pre-specified threshold and criteria, for instance critical rainfall envelope, current factor of safety, and overall hazard level. Guidelines and proactive protocols were proposed in correspondence to different levels of land sliding hazard.

### 2.2.1 Inclinometer/ Tiltmeter

Lateral soil movement of the slope was monitored using tiltmeter and inclinometer for soil surface and sub-surface movement, respectively. Both types of sensor were dependent on

high accuracy accelerometer for measurement of tilting degree from the vertical axis with the sensitivity of 140 mV/degree. A series of in-place inclinometer was fixed in the borehole during the measurement period with the space interval of about 1m. The tiltmeter was attached to a steel rod that was driven to about 0.7m depth on the slope surface. While the tiltmeter was useful for identifying the risk of shallow slide, the inclinometer was more applicable for detecting the movement of deep-seated failure.

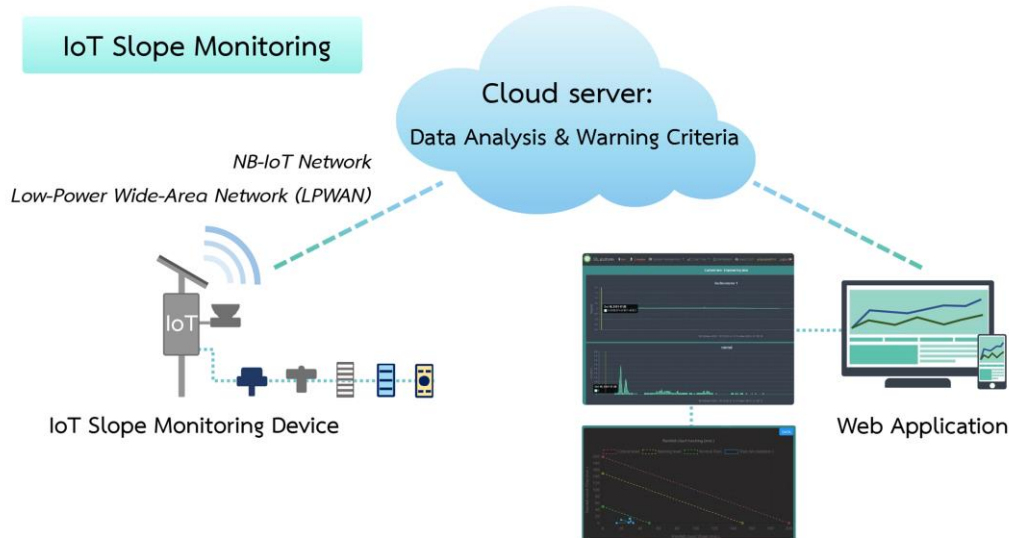


Figure 3 - Internet of Things (IoT) slope monitoring system

### 2.2.2 Rain Gauge

A tipping bucket rain gauge was used in this study with the reading interval per 5 mins and the accuracy of 0.2 mm per rain count. The cloud platform was able to calculate and generated the real-time daily rainfall and 3-day antecedent rainfall, which was then compared with the critical rainfall envelope, typically shown in Figure 4 to calculate the slope failure probability in a real-time manner.

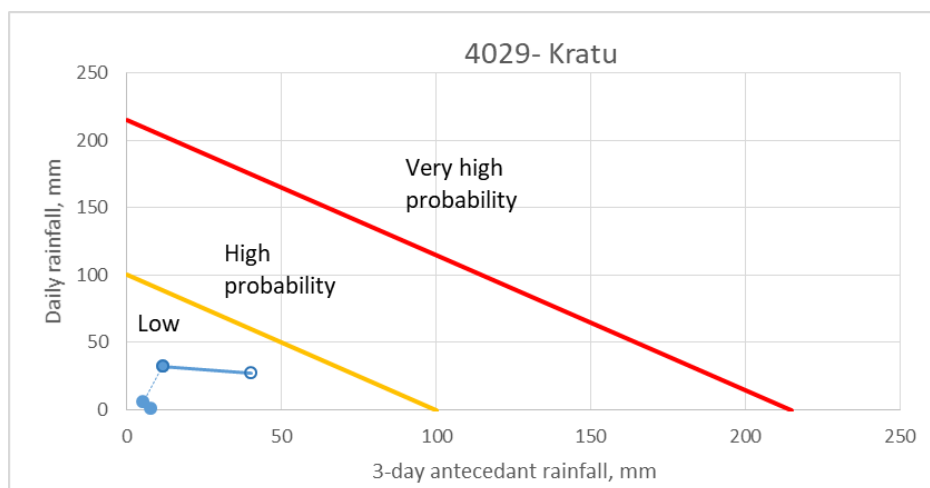


Figure 4 - Typical rainfall envelope used to estimate the slope failure probability

### 2.2.3 Soil Moisture Sensor

Soil moisture sensor measured the dielectric constant of the soil which was related to the volumetric water content (dimensionless,  $\text{cm}^3/\text{cm}^3$ ) of the soil. This sensor reading (in voltage) was calibrated with the volumetric water content of the soil. The water content represented a soil wetness that also corresponded to the pore-water pressure and suction of the soil through the soil-water retention curve.

## 2.2.4 Tensiometer and piezometer

In this study, Kasetsart University (KU) tensiometer developed by [9] was used to measure both positive pore-water pressure and negative pore-water pressure (e.g. soil suction). This kind of device is very important as the soil slope can be unsaturated and thus the pore-water pressure becomes negative at most times of the year, while becoming positive pore-water pressure during prolonged rainfall which can triggered the slope movement and failure. The measurement of pore-water pressure was therefore very useful because the effective stress of the soil, shear strength and factor of safety could be calculated real-time based on the measured pore-water pressure and some slope stability models (e.g. infinite slope model, previously calculated stability analysis), which were subsequently reported in the online platform.

## 3. EXPERIMENTAL SITES FOR ONLINE MONITORING

### 3.1. DESCRIPTION OF TEST SECTIONS

In July 2022, four test sections (Figure 5) have been completely constructed along the national highways' cut and fill slopes in the Northern Thailand including: (1) highway no. 1192 at km post 11+500, (2) highway no. 118 at km post 46+700, (3) highway no. 21 at km post 324+151, and (4) highway no. 21 at km post 329+700. These experimental sites were selected because of their geographical and tropical climate characteristics. Moreover, the highway slopes in the Northern Thailand were commonly known for their mountainous, hilly terrains, tourist attractions, and were often subjected to land sliding hazards under natural and engineered slopes due to its geological composition of decomposed granite and colluvium deposits as well as its average annual rainfall of 1,200 - 1,300 mm. The topographical and hydrogeological information have been also explored using visual survey, unmanned aerial vehicle (drone) survey, resistivity survey, groundwater aeration sound survey, soil exploration, and penetration test. Most importantly, a series of online monitoring sensor and field instrumentation consisting of soil moisture sensors, piezometers, tensiometers, inclinometer, tiltmeters, rain gauge, settlement points, data acquisition system, and IoT slope monitoring system have been deployed at each site in order to simultaneously collect the field measurement data under Thailand's tropical climatic conditions.

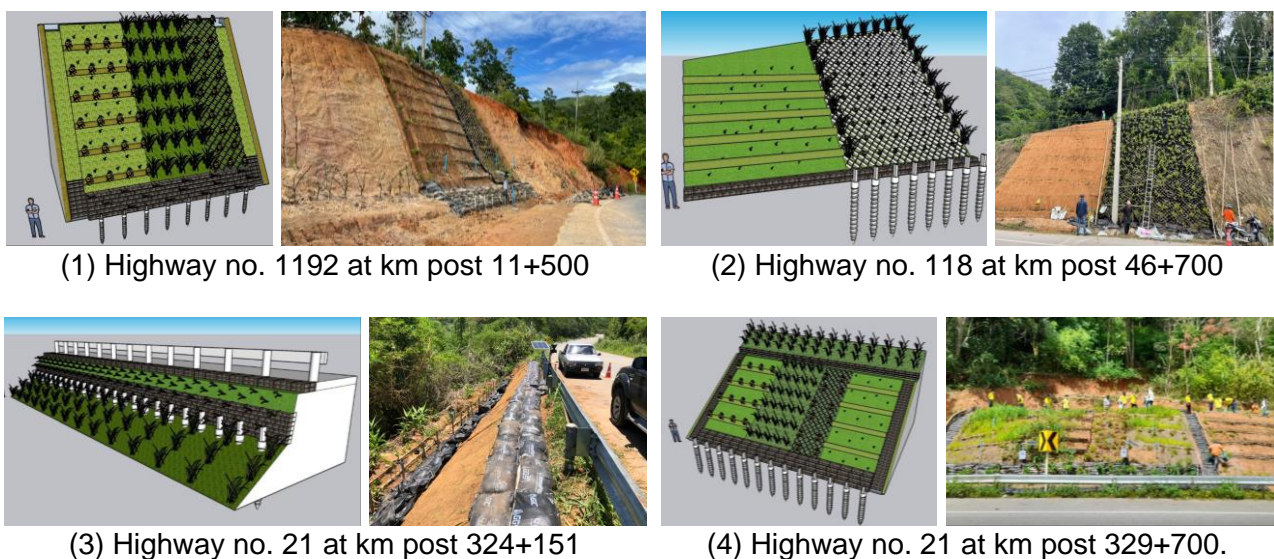


Figure 5 - Field test sections

Table 1 - Summary of the bioengineering techniques used in these four test sections

Test section ID	Location	Type	Details	Geological material
1	Highway no. 1192 at km post 11+500	Back slope (Cut)	Screw pile and flapped soil bags for toe stabilization. 3 types of soil cover, a) vetiver system, b) erosion control blanket/log, c) capillary barrier with biochar-soil for fine-grained layer and recycled asphalt aggregate (RAA) for coarse grain layer	Granitic soil with severe erosion problem
		Side slope (Fill)	Screw pile and vegetated flapped soil bags and vetiver grass system	
2	Highway no. 118 at km post 46+700	Back slope (Cut)	Same as 1a except that the coarse grain biochar was used instead of RAA	Granitic soil with severe erosion problem
3	Highway no. 21 at km post 324+151	Side slope (Fill)	Same as 1b	Colluvium soil in sedimentary rock and recurring water channel
4	Highway no. 21 at km post 329+700	Back slope (Cut)	Same as 1a except that the coarse grain biochar was used instead of RAA	Colluvium soil (Old landslide) in sedimentary rock



Figure 6 - Photographs of test section 4.

The details of the bioengineering techniques used in these four test sections (Figure 5) are summarized in Table 1. Similar systems were used for these sites, yet there are some differences in geological setting of the sites. Both side slope and back slopes were studied. The screw pile (2.5m deep) was installed at 1m spacing at the toe of slope (for back slope cases, No. 1a, 2 and 4) and at the slope crest (for side slope cases, No. 1b and 3). There are some variations of the bioengineering slope covers as explained earlier. The biochar-amended soil was used as fine-grained layer of the capillary barrier, while the recycled asphalt aggregate (RAA) was utilized as coarse-grained layer (for site No. 1a) and the coarse-grained biochar was used for site No. 2 and 4. Rooted live stakes of bougainvillea were inserted between flapped soil bags to improve both the reinforcement of the slopes and the aesthetic landscape. Figure 6 shows the photographs of test section 4.

### 3.2. INTEGRATED ONLINE SLOPE MONITORING SYSTEM

Figure 7 shows various screens of the RRD slope monitoring online interactive platform . Some highlights of the platforms consisted of the digital twins of the instrumentations and real-time readings on screen. The map indicated the location of the monitoring stations. On demand, the variation of factor of safety with rainfall could be also calculated in the real-time manner based on prescribed pore-water pressure monitoring results.

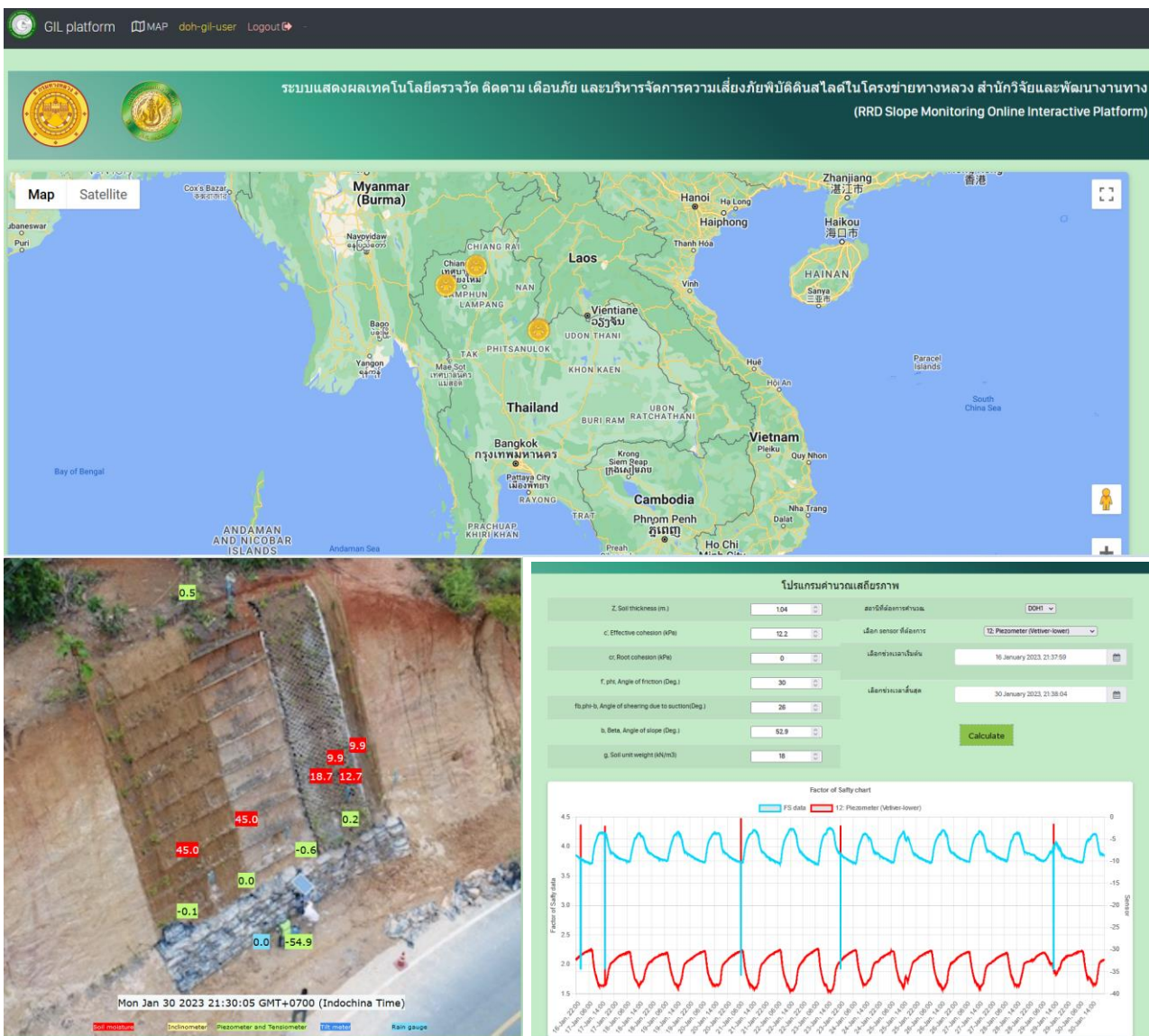


Figure 7 - Highlights of the RRD slope monitoring online interactive platform

## 4. RESULTS AND DISCUSSION

The performance and effectiveness of various vegetative and CBS slope cover installed at four experimental sites were investigated and compared based on the field monitoring results and the unsaturated soil mechanics principle. Pore-water pressure, soil moisture, and soil movement from the field measurements were simultaneously monitored after the site construction has been completed. Some typical performance and effectiveness of these test sections are discussed as follows.

Figure 8 shows the variation of moisture content and pore-water pressure as well as rainfall with time for the test section 1a (Highway no. 1192 at km post 11+500) which represents various bioengineering cover systems. Figure 9 shows the visual appearance of the different treatments of the section at various stages. It can be seen that CBS (e.g. geocell with biochar) could retain the soil moisture in the fine-grained layer while maintaining the soil suction in the soil underneath it well. The visual performance in Figure 9 supported this instrumentation results which clearly showed that CBS (with biochar top soil) clearly outperformed other systems, (e.g. erosion control blanket and vetiver).

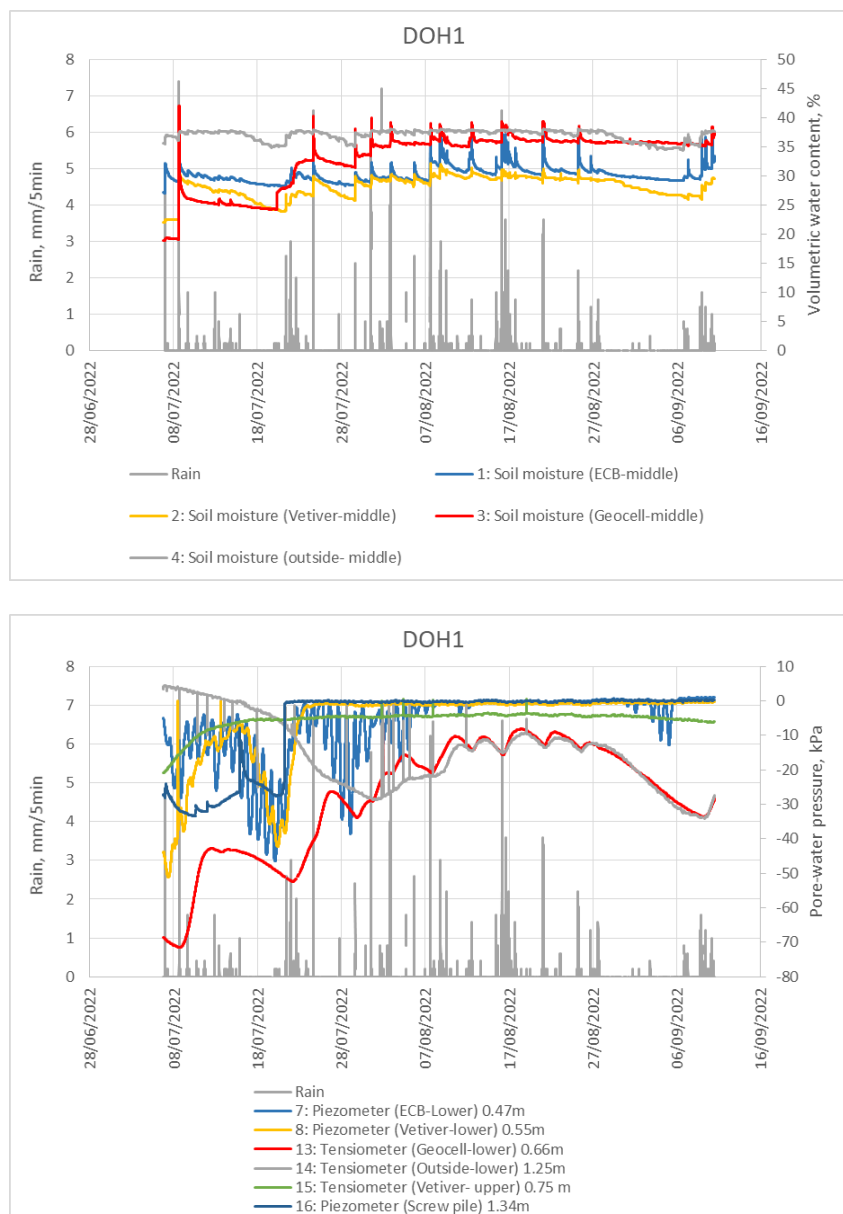


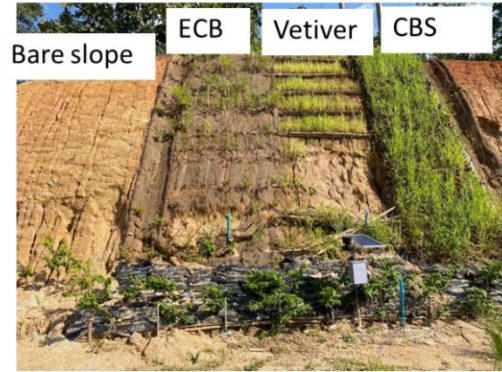
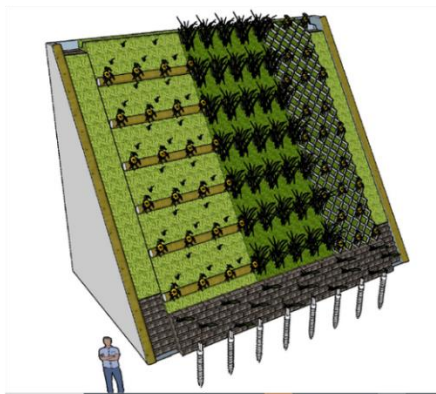
Figure 8 - Typical results of pore-water pressure, soil moisture and rainfall for test section 1a (Highway no. 1192 at km post 11+500)



Before 2020- July



After construction 2022- July



After first rainy season 2022- October

Figure 9 - Visual appearance of the different treatments of the section at various stages: test section 1a (Highway no. 1192 at km post 11+500)

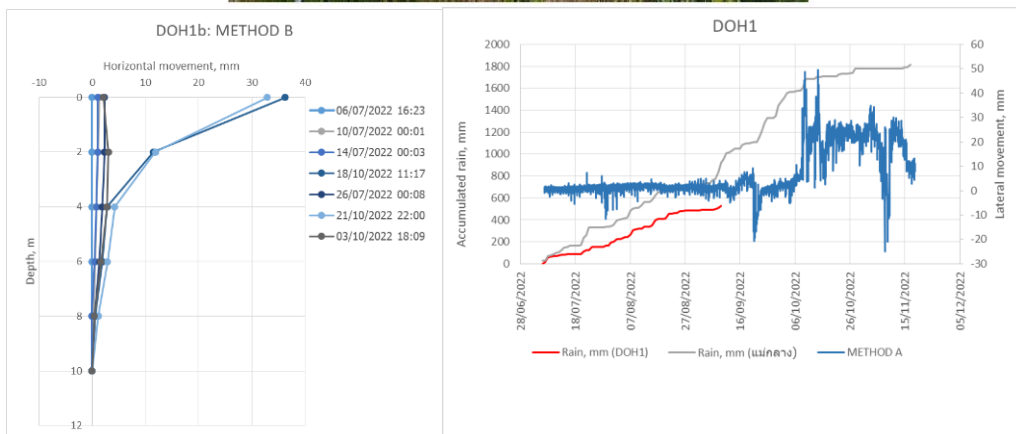


Figure 10 - In-place inclinometer results from section 1b (Highway no. 1192 at km post 11+500)

Some typical monitoring results of the in-place inclinometer are shown in Figure 10. The lateral movement of the slope crest agreed well with the damage found on the pavement surface and the rate of movement corresponded well with the accumulated rainfall. The total thickness of the moving soil was about 3-4 meter which corresponded to the thickness of the road fill. This kind of slope movement can be monitored real-time and thus aided in management of road safety during prolonged rainfall or monsoon season.

## 5. CONCLUSIONS AND RECOMMENDATIONS

Highway slope failure and erosion are becoming more severe due to climate change and increasing infrastructure development. The online sensor platform was developed for early warning and evaluating performance of bioengineered slopes in this study. A series of online monitoring sensor and field instrumentation consisting of soil moisture sensors, piezometers, tensiometers, inclinometer, tiltmeters, rain gauge, settlement points, data acquisition system, and IoT slope monitoring system were deployed at four test sections along the national highways' cut and fill slopes in the Northern Thailand in order to simultaneously collect the field measurement data under Thailand's tropical climatic conditions. The following conclusions and recommendations can be drawn as follows:

- An implementation of nature-based solution such as vegetative cover, capillary barrier system, bio-engineering stabilization represented the state-of-the-art solution in terms of cost, resiliency, sustainability, environmental-friendly, and aesthetics for future green growth development of highway network.
- Bio-engineering stabilization provided sound engineering practices in conjunction with integrated ecological principles for slope resiliency and sustainability. It helped reducing land sliding hazard risk, enhancing the resiliency of infrastructure, promoting effective maintenance scheduling, and improving emergency and recovery plans. It was also beneficial for community engagement and social awareness through workshop, knowledge transfer, and capacity building.
- Real-time data-driven decision making through the online sensor platform provided good supportive and advantageous evidence for the advancement in slope resilience and sustainable mitigation with respect to the increase and the faster recovery of factor of safety during prolonged and/or intense rainfall during the extreme events.
- There existed a need for the real-time monitoring and evaluation tools in making critical decision by the road transportation agencies both management and operational levels regarding to the traffic management during the construction and rehabilitation works of existing road infrastructure.
- Public and private sectors' interest for the project-based investment of field instrumentation and IoT technology as well as business development for the online sensor platform and further implementation were required in a larger scale.
- Understanding resilient design, adaptation strategies, evaluation methods, accessing the vulnerability of infrastructures, and monitoring performance parameters are key success factors for building nature-based solution for climate-resilient-sustainable infrastructures.

## REFERENCES

1. 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 & AGSSEA* Vol. 46 No.1 March 2015 ISSN 0046-5828. pp. 45-54.
2. Iverson, R.M. (2000). Landslide triggering by rain infiltration. *Water Resources Research*, Vol. 36, No. 7, pp. 1897-1910.
3. Polemio, M. and Petrucci, O. (2000). Rainfall as a landslide triggering factor: an overview of recent international research. *Landslides in Research, Theory and Practice, Proceedings of the 8th International Symposium on Landslides*, Cardiff, UK.
4. Mahannopkul, K. and Jotisankasa, A. (2019). Influences of root concentration and suction on *Chrysopogon zizanioides* reinforcement of soil. *Soils and Foundations*. 59(2), 500–516. doi.org/10.1016/j.sandf.2018.12.014
5. Jotisankasa, A, Mairiang W., Mahannopkul, K., Hunsachainan, N., Chaingphan, D., and Palangtanasukit, J. (2019) Field performance of vegetated flapped soil-bag retaining structure along a stream bank. *Proceedings of the 16th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering*, October 14-18, 2019, Taipei, Taiwan
6. 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 GSP, March 2013, pp 1912-1921
7. Rahardjo, H., Hua, C.J., Leong, E.C.& Santoso, V.A. (2010) Performance of an instrumented slope under a capillary barrier system. *Proc. 5th International conference on unsaturated soils*, Barcelona, Spain, 6-8 September 2010. CRC Press.
8. Jotisankasa, A. & Hunsachainan, N., Kwankeo, N., Chunrod, P. & Mancharoen, J. (2010). Development of a wireless landslide monitoring system. *Proc. International conference on Slope*. Thailand 2010. *Geotechnique and Geosynthetics for Slope*. Chiangmai, Thailand
9. Jotisankasa, A., Porlila, W., Soralump, S., Mairiang W. (2007). Development of a low cost miniature tensiometer and its applications. *Proc. 3rd Asian Conference on Unsaturated Soils (Unsat-Asia 2007)*, Organized by Geotechnical Research Institute, Hohai University, Nanjing, China, April 21-23, 475-480