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Field Monitoring of Suction Distribution Due to Grass Cover

Ong Choon Kian, Nazri Ali, Fauziah Kasim, Mohd Fakhrurrazi Ishak
ckong3@live.utm.my, nazriali@utm.my, fauziahkasim@utm.my, fakhrurrazi@ump.edu.my
Faculty of Civil Engineering, Universiti Teknologi Malaysia

***Abstract* – A field-monitoring program was conducted to investigate the suction induced by Axonopus Compressus in sandy silt under tropical climate. Matric suction data were recorded twice per day from August to December 2015, accounting for less than 10 periods of continuous drying of longer than 5 days over 5 months of measurement. The highest suction occurred on 3-Sept with 12 days of drying duration. However, the grasses failed to retain the soil suction, which dropped to a minimum magnitude at all depths after a rainfall event. This may due to the high infiltration rate of the dry soil after 12 days of drying. For comparison between Axonopus Compressus and Cynodon Dactylon, the data was obtained from two different sites. However, the rate of evapotranspiration for both studies was assumed similar because of the similar hot and sunny weather conditions in Malaysia and Hong Kong. The results from both studies showed similar suction profile during 6 days of the drying period with maximum difference of 10 kPa at 10 cm and 30 cm depths. This shows that these two grasses may produce similar suction profiles when monitored under similar conditions.**

***Keywords* – Evapotranspiration, Grass Water Uptake, Axonopus Compressus, Suction Profile.**

I. Introduction

Vegetation could be beneficial to a slope stability in terms of root reinforcement, soil moisture depletion, slope *buttressing and arching [1]. The use of conventional reinforcement can be very safe but bioengineering application is* inexpensive, environmentally friendly method and proven to be more cost-effective [2], [3]. Many researches had been done on mechanical reinforcement due to root system [4]-[9]. Studies on hydrological effect were also carried out previously [10]-[15] to investigate the response of water content changes in several conditions. In addition, suction would be increased in ground during root water uptake process resulting in changes of unsaturated properties of soil [16]. Therefore, the study on suction also received great attention at soil slope, riverbank, and ground [17]-[22].

Recently, [23] has done field and the laboratory investigation on grass-induced suction. The research shows the matric suction retention in soil after rainfall due to Cynodon Dactylon (Bermuda grass). Reference [20] investigated the magnitude and the distribution of induced suction in silty sand covered by Cynodon Dactylon under identical laboratory controlled atmosphere condition, and the grass samples produced different shoot lengths and different suction values. Reference [21] studied the influence of soil density and rainfall on grass-induced suction distributions. The result showed that the suction retained in vegetated-covered soil is 100% higher than that of the bare soil at 95% relative compaction (RC). Among the vegetated samples at various RCs, suction retained increases from 0 kPa (RC = 70%) to 40 kPa (95% RC) but the influence zone is reduced to less than half of the root depth (shallowest). A case study was published on grass evapotranspiration (ET) induced suction in slope [22]. The study investigated responses of suction in grass-covered slopes based on knowledge of soil, water, and root interaction. In three case sites, ET-induced suction in grassed slope is not always higher than that of the bare slope during insufficient soil aeration for wet soil. The grass-covered slope could retain higher suction for silty clay during rainfall but no discernible difference for sandy soil. However, the studies do not cover many types of common grasses. Thus, the field data of suction is still insufficient to understand, especially for design of slope cover with grasses.

In this study, a continuous field monitoring was carried out to obtain suction changes in grass-covered (Axonopus Compressus) residual soil. This could enhance the understanding on suction mechanism induced by grasses when subjected to raining and drying processes. The objectives of the study were to determine the mechanism of suction changes under wetting and drying process; and compare the suction induced by grass with findings of other similar research.

II. Research Methodology

Study Area

The study area is located at a grass field of grass Axonopus Compressus that is most common in this research campus, Universiti Teknologi Malaysia (UTM). It is located in front of Blok P18 at Faculty Electrical Engineering of UTM, Skudai. The location with respect to the global positioning system (GPS) is at latitude (1.5614) and longitude (103.6458). The study area is a flat ground contains only grasses and of least disturbance to prevent the effect of trees as shown in Fig. 1.

Fig. 1. The location of the field monitoring

Soil Characterization

The soil samples were collected to determine the characteristics of the soil of the field through laboratory experiments according to British Standard guideline [23]. The soil samples were collected from the field-monitoring site at ground surface to a depth of 40 cm. In general, the soils exist at the study area are classified as tropical residual soils. The physical index tests conducted were particle size distribution, Atterberg limits, specific gravity, and void ratio.

The liquid limit (LL) of soil was tested by cone penetrometer with five-second drops. The range penetration of 15 mm to 25 mm was obtained together with the increment of soil moisture content. The plastic limit (PL) was determined by obtaining the minimum moisture content when the soil start breaking at rolled thread of 3 mm diameter. The property of specific gravity was obtained by small pyknometer method.

From observation, the soil sample contain a little of sand and the soil is cohesive. According to the wet sieving result, the sedimentation analysis is required because more than 50% of soil passed through 63 µm sieve for two trials. About 40 g of dried soil passing 63 µm sieve was mixed with dispersion agent. Some distilled water was then stirred in high speed with machine to mix the soil into suspension. The soil suspension was then placed into 1000 ml measuring cylinder for the sedimentation test by hydrometer as shown in Fig. 2.

Fig. 2. Sedimentation test by hydrometer in water bath

Soil Water Characteristic Curve

It is an important relationship between soil suction and water content. A mathematical model [24] was used to obtain the soil water characteristic cure (SWCC). The important parameters required, saturated and residual water content was obtained through laboratory experiment. Residual water content was obtained by measured the minimum water content in several soil samples under sun drying. Meanwhile, saturated water content was obtained through soil properties calculation from the UD tube samples. Calibration between matric suction and water content was carried out to determine some points in SWCC. The coefficients (m & n) and α were tried until the curve matched with the calibration. The complete curve will be shown in following section.

Monitoring Setup

Tensiometer is a tool to measure the force with which water is held in the soil as soil suction, tension, or potential. The model of tensiometer used is jet-filled tensiometer 2725ARL; the unit Centibars shown in gauge is equal to unit Kilopascals (kPa). The limit of a tensiometer is about 85-90 kPa due to cavitation effect. The reservoir was filled when the water level started to drop below the service cap. The installation and the operation were done by following the instructions provided by Soil Moisture Equipment Corp. First, a hole with 2.2 cm diameter or smaller was created to a depth desired so that tensiometer fixed into soil with tight contact. The O-rings were inserted at connections to prevent leakage. The ceramic cup was locked by inverted the tensiometer and the gauge with face in upward direction. Then, the tensiometer was filled with water and located vertically until ceramic cup was fully saturated. Next, a vacuum was pulled inside the tensiometer 4-5 times by using the vacuum hand pump from service kit to ensure all air had been removed and there was no leakage at the connection. Installation was done immediately after locking the jet fill reservoir and the tube surface was backfilled tightly. The tensiometers were installed at five different depths: 10 cm, 15 cm, 20 cm, 30 cm and 40 cm (Fig. 3).

Fig. 3. Field monitoring at different depths by tensiometers at the study area

The reading was checked daily to ensure a reasonable data and no leakage of the connection. Maintenance was done in the first week and the readings showed reasonable response. Then, the reading was recorded twice per day for five months (August 2015 to December 2015) and the grass was cut to appropriate height twice per month to obtain the measurement data. Lastly, some samples of grasses were removed from ground carefully to obtain the rooting depth of grasses.

III. Result & Discussion

Soil Classification

The result of particle size distribution was plotted in Fig. 4. With results of liquid limit, plastic limit, and specific gravity of 56%, 36%, and 2.60, respectively, the soil samples were then classified using Unified Soil Classification System (USCS). With the liquid limit of over 50%, the plasticity index fall below ‘A’-line, and the percentage of sand is higher than that of gravel. The soil at field was classified as high plasticity silt with little gravel.

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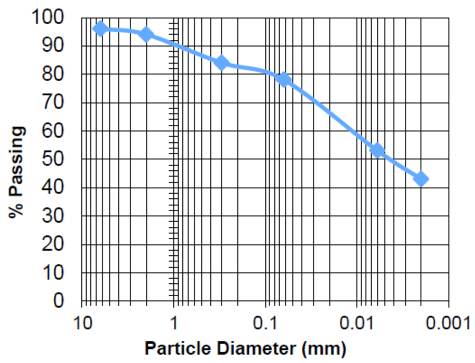

Fig. 4. Particle size distribution of soil at field at 20-40 cm depth

Soil Water Characteristic Curve

According to the experimental result, the residual and saturated volumetric water content is 0.577 and 0.032 cm^3/cm^3 respectively. The coefficient m and n was set as 0.75 and 4 with shape factor (α) of 0.15 to obtain a smooth curve which matched the calibration points as shown in Fig. 5.

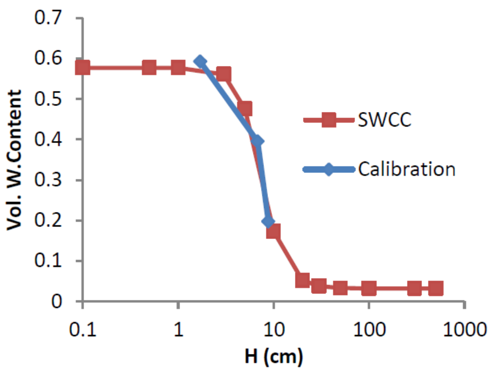

Fig. 5. Soil water characteristic curve of the study area

Soil Suction Profile

The measurements were taken at the end of July 2015, during a rainy period, with the matric suction at all measured depths under 10 kPa. Fig 6 shows the induced suction slightly increased from 1-Aug to 5-Aug when the soil started drying. The increment was not more than 5 kPa, the suction at depth 15 cm was 12 kPa and the rest were 7-8 kPa. The drying period was not long. There were frequent raining events in early August. The first obvious drying occurred from 12-Aug to 20-Aug; the suction induced reached 50 kPa at 10 cm depth but very low for the rest, 25 kPa at 15 cm, 15 kPa at 20cm, and 12 kPa at 30 cm and 40 cm. There was another drying curve after heavy raining (5 mm) on 21-Aug. The suction started from 2-4 kPa and increased to 91 kPa at 10 cm, 76 kPa at 15 cm, 56 kPa at 20 cm, 51 kPa at 30 cm, and 43 kPa at 40 cm on 3-Sep. Rains of 1 mm occurred several times but the suction continued to increase. This shows that light rain would not reach and affect the soil suction at depths of below 10 cm. However, the reading at 10 cm depth reached its limit of 87 kPa on 31-Aug due to cavitation and limit of tensiometer. Therefore, the suction at 10 cm depth could be more than 100 kPa between 1-Sep to 3-Sep.

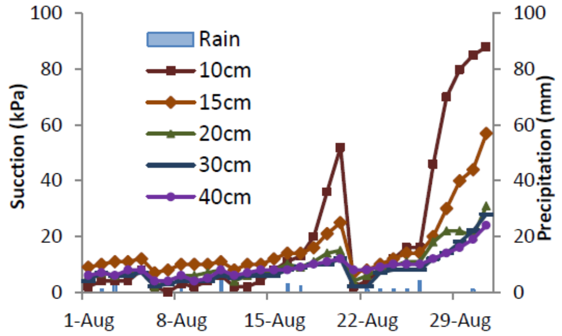

Fig. 6. Measured suction profiles at various depths in August 2015

On 4-Sep, a 7 mm rain wet all the soil profile down to 40 cm and the suction dropped to 1-4 kPa as shown in Fig. 7. There were 4 drying patterns in September. The suction remained under 10 kPa in first few days of the drying period. This indicates that it takes almost 4 days to start an obvious increment in suction. However, the water was still extracted or lost from soil every day, although the change of suction is small because it is mainly depends on the relationship between soil water content and suction, soil water characteristic curve (SWCC). The suction dropped to level below 10 kPa again after the end of September due to the rain. In short, month of September undergoes 4-5 periods of wetting which could reduce the suction to almost zero (saturated condition).

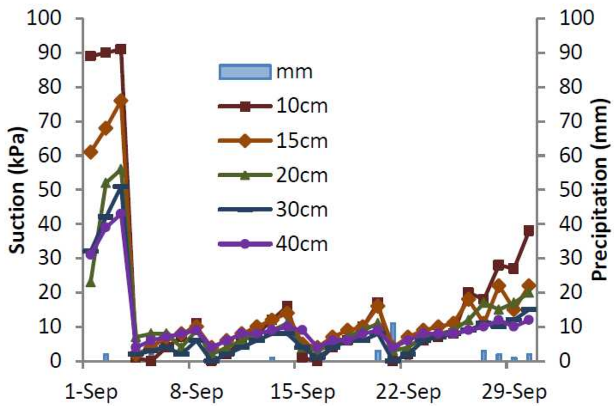

Fig. 7. Measured suction profiles at various depths in September 2015

There were two major drying periods in October; once early in the month and from 14-Oct to 23-Oct. During first drying period of October, suction at 10 cm depth reached 48 kPa but suction at depths below 15 cm was 16-22 kPa only. The suction produced was a bit small at lower depth; this might be because the evapotranspiration was not strong enough at that particular period to affect the lower level of soil. A heavy rainfall (>10 mm) on 15-Oct was followed by a drying period until 23-Oct. The suction started from under 10kPa, and took a few days to break 10 kPa on 19-Oct, 23 kPa at 10cm, 16 kPa at 15 cm, 14 kPa at 20cm, 10 kPa at 30cm, and 10 kPa at 40cm. It showed more obvious increment after 19-Oct and the gradient near to surface was higher. The gradient of suction increment decreased with depth as shown in Fig. 8; this indicated the rate of suction induced is higher near to soil surface (with grasses). The highest suction effect was 87 kPa at 10 cm, 56 kPa at 15 cm, 40 kPa at 20cm, 25 kPa at 30cm, and 18 kPa at 40 cm on 24-Oct. After that, heavy rain wet the soil profile, resulting in a low suction profile at the end of Oct. Despite the hot tropical climate, there was frequent rain in November and the suction was all under 10 kPa for all of November as shown in Fig. 9. In short, the suction effect is possible to be very low during raining season. However, the monitoring field is natural, without compaction, and void during tensiometer installation. Therefore, the suction induced and retained could be higher if it is constructed with certain percentage of relative compaction and density.

During December, it rained often until middle of month. The suction had increased quickly on 19-Dec, taking only 3 days to reach 10 kPa at lower level. It was raining on 24-Dec but the soil profile was able to retain suction with only a small drop, and continued increasing to 90 kPa at 10 cm, 60 kPa at 15 cm, 48 kPa at 20 cm, 26 kPa at 30 cm, and 24 kPa at 40 cm. After wetting, the suction dropped to minimum again, but the suction at 40 cm retained at 20 kPa, as the rain did not reach the lower elevation before 31-Dec (Fig. 10).

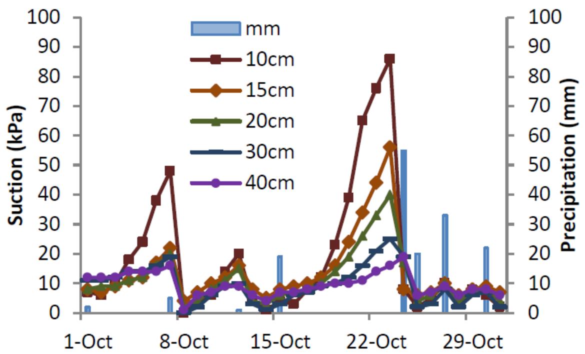

Fig. 8. Measured suction profiles at various depths in October 2015

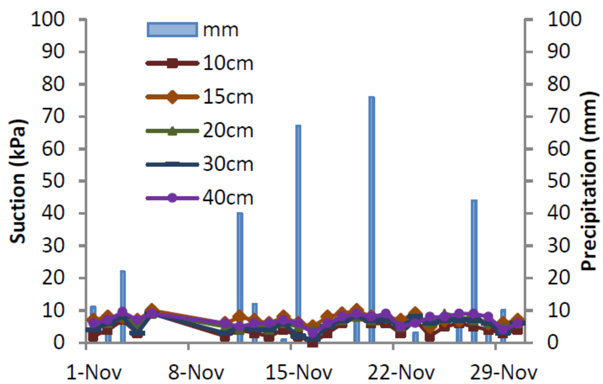

Fig. 9. Measured suction profiles at various depths in November 2015

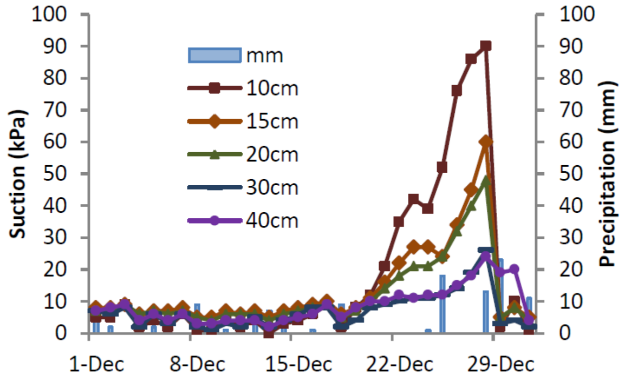

Fig. 10. Measured suction profiles at various depths in December 2015

Maximum & Minimum Drying Condition

Other than overall suction produced by evapotranspiration of Axonopus Compressus, the maximum suction induced is an important data which reveal the contribution of this grass in a specific drying period. The highest suction induced for each month was recorded in Table I.

Table I The highest suction (kPa) induced by evapotranspiration of Axonopus Compressus

Depth (cm)	AUG (31/8)	SEP (3/9)	OCT (24/10)	DEC (28/12)
10	88	91	87	90
15	57	76	56	60
20	31	56	40	48
30	28	51	25	26
40	24	43	18	24

There were two obvious suction increments in August, one in middle and another at the end. It took almost 9 days to achieve such suction from a wet condition but it did not stop and continued to increase to 3-Sept. The data showed suction at depth 10 cm increased from 88 kPa to 91 kPa, but the suctions increased at the lower level were almost 20 kPa. This means the tensiometer at depth 10 cm reached its limit on 31-Aug at morning (87 kPa) or maybe earlier because the increment became smaller. Therefore, the real suction at 3-Sept should break 100 kPa and be around 150 kPa. The estimated suction produced for 12 days of drying was 130-150 kPa at depth 10 cm and the rest as shown in column September. The maximum suction produced in October was located on (24/10), and was a 9 day drying result in which data did not touch the limit until last day. The suction at 10 cm depth increased from 77 to 87 kPa and 44 to 56 kPa at 15 cm depth. Based on the previous trend of increment, the suction at 10 cm increased higher than that of 15 cm depth. Thus, the suction 87 kPa could probably reach 95 kPa or higher. The continuous rain in November did not allow the suction in soil to raise over 10 kPa at the depth measured. This situation continued until middle of December and the suction was produced only after 18-Dec to 28-Dec. This was the last month of the suction profile measurement, and similar situation occurred where tensiometer at 10 cm reached its limit before 28-Dec. In short, tensiometer is not appropriate to measure the soil suction at depth less than 15 cm (shallow) when subjected to long drying period (more than 7 days).

Table II The lowest suction (kPa) retained by grass Axonopus Compressus

Depth (cm)	AUG (21/8)	SEP (9/9)	OCT (8/10)	DEC (13/12)
10	2	0	0	0
15	7	4	5	5
20	2	2	4	4
30	2	0	1	2
40	4	4	3	2

On top of that, the minimum suction could be retained in the grass field also a major consideration. Table II shows the lowest suction distribution recorded for each month. The suction came to a lowest point after some rainfall events which wetting the soil and reduced the suction. The suction was remained below 10 kPa in November due to rain as discussed previously. The minimum suction that retained was lower than 5 kPa as shown by the data obtained from August to December 2015. This indicates that the effect of grass in term of suction to soil enhancement is very low or no effect after the wetting of soil.

Comparison of Suction Induced with Another Study

Fig. 11 shows the responses of matric suction from two different sites and grass-covered measured during typical drying periods by jet-filled tensiometer (Table III).

Table III Details comparison between both studies

Author	Woon [25]	This study
Country	Hong Kong	Malaysia
Climate	Subtropical	Tropical rainforest
Soil type	Silty sand	Sandy silt
Grass	Cynodon Dactylon	Axonopus Compressus
Rooting depth (cm)	7-10	20-25
Depth of tensiometer (cm)	10, 30, 50	10, 30, 40
Solar irradiance ($kWh/m^2/d$)	JUN-4.52	AUG-4.27, OCT-4.51
Evapotrans-piration (mm/day)	2-5	2-6
Average temperature (^{o}c)	28-29	28-29
Average wind (m/s)	2	1
Relative humidity (%)	85-90	81-91

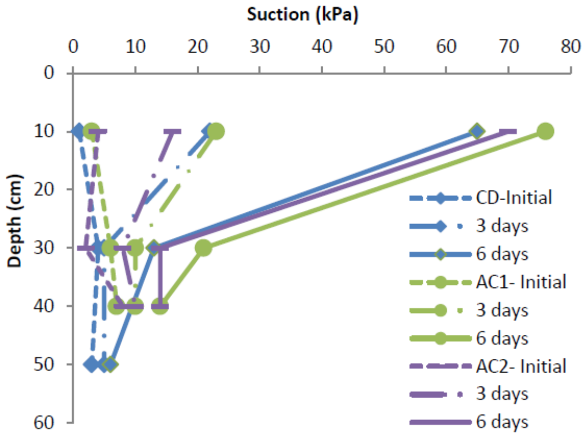

Fig. 11. Comparison of matric suction profiles between Cynodon Dactylon (CD) in Hong Kong and Axonopus Compressus (AC) in Johor, Malaysia for 6 days drying period

From the data measured, the initial suction after wetting is not similar most of the time. There were three drying profiles, one for Cynodon Dactylon (CD) from [25] and two for Axonopus Compressus (AC). The initial suction for AC was slightly higher than that of CD. After drying for 3 days in period 1, the suction induced at 10 cm for CD and AC1 was close but AC2 had lower increment of 12 kPa. For 30 cm depth, the suction increased only 1 kPa for CD, 4-6 kPa for AC. This could possibly because the rooting depth of CD tested was shorter or rate of evapotranspiration was low at that moment. The amount of suction increased at 40 cm and 50 cm depth was 2-3 kPa only. In period 2 (6 days drying), the suction increase at 10 cm was very obvious. It increased from 22 to 65 kPa for CD, 23 to 76 for AC1, and 16 to 70 kPa for AC2. For 30 cm depth, the amount increased was about 8 kPa for CD and AC. The increment of suction at 40 cm depth was 4 kPa for AC and 1 kPa for CD at 50 cm depth.

By comparing the suction induced by Axonopus Compressus and Cynodon Dactylon, the suction profiles during 6 days of drying indicated that both grasses would produce similar suction at depth of 10 cm, which were affected by both root water uptake and evapotranspiration. Rooting depth of grass Cynodon Dactylon at site in Hong Kong was only 7-10 cm, so it had little or no effect due to evaporation to the deeper depth, such as 50 cm depth. Meanwhile, the rooting depth of grass Axonopus Compressus at UTM campus reached 25 cm, and it has some effect to suction at 40 cm depth. The suction at 40 cm depth reached 24 kPa and 43 kPa after drying periods of 9 days and 12 days, respectively.

The suction induced depends on types of soils, i.e., the soil water characteristic curve, which means that same amount of water content loss from two soils would result in different suction, if the initial condition of both soils were not similar. Fig. 10 shows some slight differences in initial condition of the soil. By considering the initial condition of soil moisture or soil suction and the soil water characteristic for both sites, the grasses may give similar soil suction profile for 6 days of drying period when the grasses are monitored under identical or similar conditions.

IV. Conclusion

A monitoring program was carried out in order to obtain and investigate suction induced by Axonopus Compressus in sandy silt under climate of tropical rainforest. The suction profiles produced were showed and discussed in previous section.

The suction induced could reach up to 90 kPa during a long drying period, but the grasses fail to retain any suction induced and drop below 10 kPa with heavy rainfall event. Field monitoring of suction distribution due to Axonopus Compressus shows that suction profile is influenced by relative duration of drying and wetting period and antecedent moisture content.

From the comparison between suction induced due to Axonopus Compressus and Cynodon Dactylon at two sites, the results from both studies showed similar suction profile during 6 days of the drying period. Both of these grasses may lead to similar suction profile if they have the same rooting depths when monitored under similar or identical conditions.

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Authors' Profiles

Ong Choon kian received the B. Eng. (Civil) and M. Eng. (Civil-Geotechnic) Degree from Universiti Teknologi Malaysia (UTM), Skudai Johor, Malaysia in 2013 and 2014 respectively. He is currently a Ph.D. candidate in Faculty of Civil Engineering UTM since 2014. His research interests include soil mechanic, soil enhancement, computer simulation and slope stability.

Nazri Ali received B. Eng. (Civil) Degree from Universiti Teknologi Mara Malaysia, the M. Eng. (Civil-Geotechnic) Degree from Universiti Teknologi Malaysia (UTM) and Ph.D. (Geotechnical Engineering) Degree from Cardiff University, in 1998, 2002 and 2007 respectively. He has been a Design Engineer in 1998 to 1999 and became an academic staff since 1999. He is now Lecturer in Faculty of Civil Engineering UTM. His research include tree induced suction, soil moisture flow and slope stability. Associate Professor Dr. Nazri is a member of Board of Engineering Malaysia (BEM) and Malaysian Society Engineering & Technology (mSET). He has authored and co-authored 30 journal articles of which ten of them were indexed in ISI with impact factor and others indexed by Scopus and other database agencies.

Fauziah Kasim received B. Eng. (Civil) M. SC. (Eng. Science) Degree from University of Mississippi, USA in 1985 and 1990 respectively. She became an Assistant Lecturer during 1986 and appointed as Lecturer at 1990 in UTM. She is now Senior Lecturer in Faculty of Civil Engineering UTM at undergraduate and postgraduate level. She consults lots of report and analysis via Civil Engineering Testing Unit (CETU) and her research cover soil seepage flow, soil mineralogy, and unsaturated soil behaviour. Her specialization includes Geotechnical Engineering, Unsaturated Soil Mechanics, Seepage and Slope Stability. Madam Fauziah is a member of Institution of Engineers, Malaysia (IEM), Board of Engineers, Malaysia (IEM), American Society of Civil Engineers (ASCE) and Canadian Geotechnical Society (CGS).

Mohd Fakhrurrazi Ishak received B. SC. (Applied Geology) Degree from Universiti Malaya (UM), the M. Eng. (Civil-Geotechnic) Degree from Universiti Teknologi Malaysia (UTM) and Ph.D. (Civil Engineering) Degree from UTM. He is now Lecturer in Infrastructure Management University Malaysia Pahang (UMP). His expertise is eco-engineering slope stability. Dr. Mohd Fakhrurrazi has more than 5 years of experience in unsaturated soil mechanic, slope stability, engineering geology and rock mechanic.