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Live Poles for Slope Stabilization in the Tropical Environment

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ABSTRACT

Slope instability causing landslides, a major geologic hazard, is a risk common to most regions. Among all categories of landslides, *shallow slope failures* which affect many hill slopes and earthwork projects are the most wide spread and pose the most costly maintenance problem. One of the soil improvement methods that seem suitable for shallow slope failures is the *Live Pole* technique. The potential value of this bioengineering technique is that it offers an effective, economical and environmentally favorable means of combating the predicted future increase in shallow slope instability by reinforcing slope shoulders, conducting drainage of horizontal groundwater and acting as surface flow retardation or energy dissipaters, to control slope erosion. Moreover the growth of live pole roots provides shear strength enhancement and modifies the saturated soil water regime. Due to the geographical variability in the application of this technique in different regions this study was carried out for a tropical environment.

This paper initially describes the bioengineering technique for slope stabilization and the requirement for selecting suitable live poles in tropical regions utilizing indigenous woody species. These plants put through screening tests trials for the potential of the species to propagate from large live cuttings obtained from branches of small trees and shrubs tests, viz., tests for root and stem growth in a controlled medium under controlled shade-house conditions with irrigation, mechanical tests and then gauge their suitability for field trails by replanting in selected natural soils. Then results of these screening tests found two species, namely, *Hibiscus tiliaceus (Ht)* and *Dillenia suffructicosa (Ds)* which met the requirements for field test trials. For field tests they were installed using a two-man auger in a close center array on selected trial slopes in the University Putra Malaysia (UPM) campus and monitored for about 1 year. Some of these planted poles were studied and tested after exhumation at the end of this period and the results are discussed. This research shows that live poles are a practical and economical alternative method to conventional techniques for shallow-seated hill slope stabilization.

KEYWORDS: shallow failure; slope stabilization; tropical region; live poles

INTRODUCTION

Slope instability causing landslides is a serious geologic hazard in the tropics. Globally, landslides annually cause billions of dollars in property damage and thousands of casualties. Slope failures are typically associated with periods of heavy rainfall usually observed in tropical regions therefore it is imperative to find effective and economical methods to reduce these soil mass movements.

The reinforcement of soil by the bioengineering method (vegetation) is a highly promising solution with regard to reducing superficial landslide risk and erosion on natural and man-made slopes (Gray & Leiser, 1982; Barker, 2004). An increased adoption of the vegetation approach in the design of slope covers, to increase the benefits from grass and woody slope covers with respect to erosion and stabilization, optimize slope drainage (together with land-forming (Schor & Gray, 2007)) and improve slope maintenance would appear to be the best way forward.

The bio-engineering (*a.k.a.* vegetative engineering or eco-engineering) approach for slope cover would benefit the slope in the following manner:

i) Prevention of soil erosion and mass movement: The control of soil erosion is primarily affected by herbaceous plants although woody vegetation also plays a role. The role of woody plants is greater in preventing mass movement.

ii) Root reinforcement: Roots embedded in the soil form a composite material which increases the overall shear strength of the soil. The increase in strength is dependent upon the root geometry and strength.

iii) Slope buttressing and arching: Buttressing and arching is affected by the tree trunks and by the volume of soil reinforced and anchored by these roots. Trunks and large roots act as cantilever piles to restrain the soil from moving down-slope.

iv) Soil moisture modification: The presence of vegetation influences the proportion of precipitation that reaches the soil and affects the behavior of water within a soil mass.

Moreover, soil slopes reinforced using the bioengineering technique appears to offer significant benefits in term of ecology, aesthetics, sustainability and finance; it, however, still requires validation for use on highway slopes, riverbanks and other cases of earth slope.

Figure 1 below illustrates the reinforcing action of tree stems, planted deep (some 1.5-2.0m) below the ground surface, and roots in preventing surface soil erosion and slope failure. The woody stems initially act as short piles in reinforcing the slope. In the medium to long term roots start to grow all along the woody stems, thus further reinforcing the soil in addition to increasing the woody mass and soil suction due to water uptake. This particular technique is referred to as the *live pole array stabilization*. Field trials have been carried out in temperate zones in the UK and USA using willow shrub and small tree species with promising results (Wu *et al.*, 2008; Steele *et al.*, 2004).

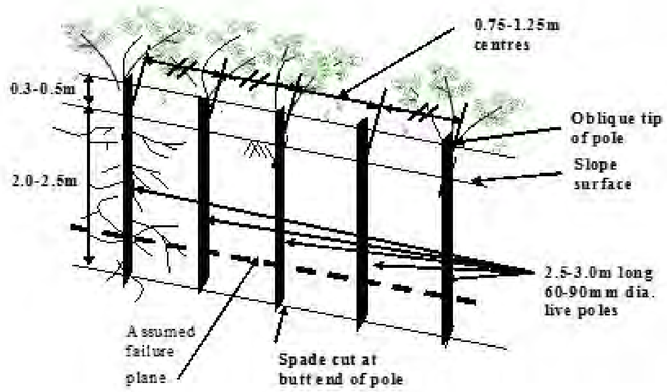


Figure 1: Section through a live pole array

Slope stabilizing by using vegetation on natural or benched terraces of hill ranges is an ancient method, probably introduced by the Romans and Byzantines about 2000 years ago. The historical evidence of the utilization of this technology are seen in many places of the world, such as the Middle East, South America and even in humid and tropical climate of South East of Asia (Figure 2).

Figure 2: Banaue rice terrace, Ifugao Province, Philippines (McCouch, 2004)

Literature review revealed the use of live pole as an engineering method for slope stabilization was adapted during 1950s and 1960s in the high seasonal rainfall area of New Zealand natural forests, to counter slope creep and more rapid down-slope mass movement (Barker, 2004). The technique using Willow (*Salix*) shrub and small tree species has been found to be effective in the temperate zones (Wu, 1995) such as in central Europe (Switzerland and Austria), UK and USA (Steele *et al.*, 2004; Wu *et al.* 2008). Practically three more common species of Willow i.e. *Salix alba*, *Salix dasyclados* and *Salix spaethi* are used exclusively as live poles in UK. Poplar (*Populus*) species have also been proposed for temperate regions of the western United State and some experimental work for assessing the potential for slope reinforcement by planting Casuarinas glauca trees was conducted in south west of Sydney, Australia (Docker & Hubble, 2001).

However, previous workers examining the soil reinforcing effects of vegetation have also found fairly significant geographical discrepancies which indicate that results for a certain region are pertinent to those with different environmental characteristics. This study was carried out to investigate the application of the live pole technique in a tropical environment as data for this geographical region was very limited.

In describing the bioengineering technique for slope stabilization studied this paper first describes the requirement for selecting suitable live pole in tropical regions and presents the results of screening trials of potential tropical plant species in their ability to propagate from large live cuttings. Then the laboratory tests, further growth under control conditions and, finally, the results of the field trails are presented. At the end the effect of these live poles roots on soil suction is also discussed.

The testing of various candidate species for root and stem growth in containers, filled with a control medium under shade-house conditions with irrigation, yielded three suitable species, namely, *Hibiscus tiliaceus* (*Ht*), *Dillenia indica* (*Di*) and *Dillenia suffruticosa* (*Ds*). These were then subjected to laboratory strength testing of stems and roots and planted again in selected natural soils under controlled shade-house conditions for highlighting the influence of soil type on their growth/survivor rate. Only two, namely, *Hibiscus tiliaceus* (*Ht*) and *Dillenia suffruticosa* (*Ds*) were found to be suitable and were The used as live poles for the field trials. They were installed using a two-man auger in a close center array on selected trial slopes in the University Putra Malaysia (UPM) campus and monitored for about 1 year for their growth/survivor rate. At the end of this period, some of the live poles were exhumed, studied and compared were compared for their effectiveness to serve as live poles.

REQUIREMENTS FOR PLANT SPECIES FOR USE AS LIVE POLES

Many conditions can be considered in selecting a species as a potential live pole for slope stabilization; however, the specifications which appear more significant are as follows (Barker, 2004):

i) Ability to propagate from large-selection hardwood cuttings.
ii) Ability to grow rapidly.
iii) Ability to root at depth.
iv) Ability to coppice.

v) Ability to grow in waterlogged conditions.
vi) Ability to withstand desiccations.
vii) Ability to resist impacts imported by driving.
viii) Ability to grow long straight branches needed for ease of installation.
ix) Ability to withstand burial and impact by moving slope debris.

However, the selection of plant species for testing as life poles is based on their meeting the following requirements:

- Root growing quality;
- Growing rate of the plant and root;
- Potential of preparing bigger size and straighter fresh cutting with enough length (up to 2.00m);
- Mechanical properties

SPECIES SCREENING (1): GROWTH INVESTIGATIONS FOR POSSIBLE LIVE POLE SPECIES

Literature review showed that based on these conditions some of tropical indigenous species which stood as potential live poles are: *Acacia mangium*, *Andria surinamensis*, *Casia siamea*, *Cerbera* manghas, *Dillenia suffruticosa*, *Erythrina orientalis*, *Erythrina variegate*, *Gliricidia sepium*, *Hibiscus tiliaceus*, *Perrocarpus indica*, *Macaranga gigantean* (Barker, 2004).

Ten of these potential species, listed in Table 1, were identified for screening trials for their ability to propagate from large live cuttings obtained from branches of trees. These were tested for root and stem growth in irrigated containers under shade-house conditions. They were planted in four replicates in a standard medium consisting of crushed well-graded sand and *10*% organic matter for about *8* weeks in the shade-house.

Table 1: Potential tropical plant species as live pole

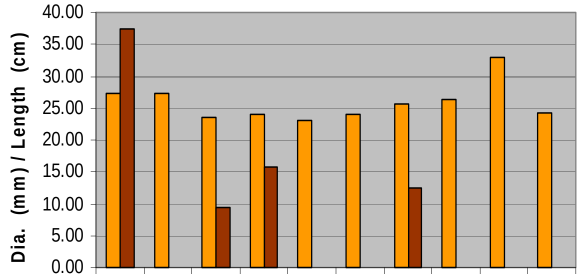
No.	Species	Symbol
1	*Hibiscus tiliaceus*	*Ht*
2	*Cassia fistula*	*Cf*
3	*Dillenia indica*	*Di*
4	*Pterocarpus indicus*	*Pi*
5	*Macaranga*	*M*
6	*Ficus benjamina*	*Fb*
7	*Dillenia suffruticosa*	*Ds*
8	*Glyricidia sepium*	*Gs*
9	*Pajanella longifolia*	*Pl*
10	*Erythrina fusca*	*Ef*

After opening the containers, the roots were scanned and the results are summarized in Table 2 and Figure 3. Six species did not show any significant progress while four species, namely, *Hibiscus tiliaceus* (*Ht*), *Dillenia indica* (*Di*), *Pterocarpus indicus* (*Pi*) and *Dillenia suffruticosa* (*Ds*) seemed to indicate a potential for use as live poles. The survivor rates of these four species were 50%, 50%, 50% and 75% respectively.

Table 2: Lab trial screening of potential tropical plant species as live pole

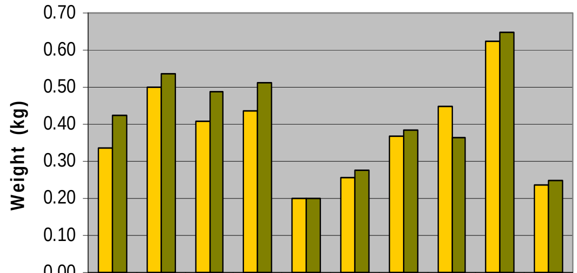
Name*	Prelim Dia. (mm)	Week 2		Week 4		Week 6		Week 8		Dry weight (kg)	Green weight (kg)		Average No. of Root**	Average Root Size (mm)	Longest Root Length (mm)
		Bud / Shoot	1st Leaf Size(cm)	Bud / Shoot	1st Leaf Size(cm)	Bud / Shoot	1st Leaf Size(cm)	Bud / Shoot	1st Leaf Size(cm)		With Leaf	Without Leaf			
Ht 1	29.00	0		2		3	6.5	5	11.6	0.30	0.45	0.35	27	2.5 to 5.0	195
Ht 2	26.00	0		2		0	0.0	0	0.0	0.30	0.30	0.30	50	2.5 to 4.5	420
Ht 3	24.00	0		3		6	3.0	6	9.5	0.30	0.35	0.30	43	4.0 to 5.0	485
Ht 4	30.00	0		4		0	0.0	0	0.0	0.45	0.60	0.45	52	5.0 to 8.5	400
Cf 1	30.00	0		2		3	8.5	5	11.5	0.40	0.45	0.40			
Cf 2	30.00	0		4		10	14.2	12	16.1	0.65	0.65	0.65			
Cf 3	20.00	0		2		2	4.5	2	6.7	0.40	0.45	0.40			
Cf 4	29.00	6		3		4	5.0	6	12.9	0.55	0.60	0.55			
Di 1	25.00	0		4		6	10.5	6	15.5	0.50	0.60	0.55	24	3.0 to 5.5	80
Di 2	22.00	0		2		7	9.2	7	15.0	0.45	0.60	0.50	35	2.0 to 5.5	110
Di3	25.00	0		3		0	0.0	0	0.0	0.33	0.35	0.35	-	-	-
Di4	22.00	0		4		5	4.5	0	0.0	0.35	0.40	0.40	22	3.0 to 5.0	150
Pi 1	26.00	0		3		7	7.5	10	10.5	0.50	0.45	0.35			
Pi 2	24.00	0		2		4	4.5	5	7.5	0.40	0.45	0.35	28	0.3 to 6.0	115
Pi 3	23.00	0		2		4	7.6	5	13.2	0.35	0.60	0.50			
Pi 4	23.00	0		1		5	4.5	4	9.5	0.50	0.55	0.50	36	0.3 to 6.0	200
Mg 1	22.00	0		0		0	0.0	0	0.0	0.20	0.20	0.20			
Mg 2	25.00	0		0		0		0	0.0	0.20	0.20	0.20			
Mg 3	20.00	0		0		2	3.0	0	0.0	0.15	0.15	0.15			
Mg 4	25.00	0		1		3	3.5	0	0.0	0.25	0.25	0.25			
Fb1	27.12	0		0		0		0		0.25		0.25			
Fb2	18.45	0		0		0		0		0.20		0.20			
Fb3	23.30	0		0		0		0		0.23		0.30			
Fb4	27.10	0		0		0		0		0.35		0.35			
Ds1	26.21	0		1		3	4.5	4	8.5	0.35	0.45	0.40		4.0 to 6.5	200
Ds2	29.64	0		2		3	5.5	5	7.5	0.50	0.60	0.55		3.5 to 5.5	350
Ds3	21.13	0		2		0	0.0	0	0.0	0.25	0.25	0.25		2.5 to 3.5	120
Ds4	28.70	6		4		6	3.5	8	5.5	0.30	0.25	0.25		4.0 to 5.5	280
Gs1	22.99	0		0		0		0		0.35		0.30			
Gs2	32.64	0		0		0		0		0.55		0.55			
Gs3	22.92	0		0		0		0		0.30		0.30			
Gs4	26.47	0		0		0		0		0.60		0.30			
Pl1	31.15	0		0		0		0		0.55		0.55			
Pl2	29.40	0		0		0		0		0.45		0.50			
Pl3	31.86	0		0		0		0		0.55		0.55			
Pl4	39.34	0		0		0		0		0.95		1.00			
Ef1	26.07	0		0		0		0		0.25		0.30			
Ef2	22.50	0		0		0		0		0.20		0.20			
Ef3	21.02	0		0		0		0		0.25		0.25			
Ef4	27.05	0		0		0		0		0.25		0.25			

* Refer to table 1 for species name.
** Root counted only that appear from the main stem.
*** 0 : No any growth is seen.



Species	Ht	cf	Di	Pi	Mg	Fb	Ds	Gs	Pl	Ef
Pelim Dia. (mm)	27.25	27.25	23.50	24.00	23.00	23.99	25.66	26.26	32.94	24.16
Longest Root Length (cm)	37.50	0.00	9.50	15.75	0.00	0.00	12.50	0.00	0.00	0.00

(a) Length of roots



Species	Ht	cf	Di	Pi	Mg	Fb	Ds	Gs	Pl	Ef
Dry weight (kg)	0.34	0.50	0.41	0.44	0.20	0.26	0.37	0.45	0.63	0.24
Green weight (kg)	0.43	0.54	0.49	0.51	0.20	0.28	0.38	0.36	0.65	0.25

(b) Dry/Green Weight

Figure 3: Comparison of species growth

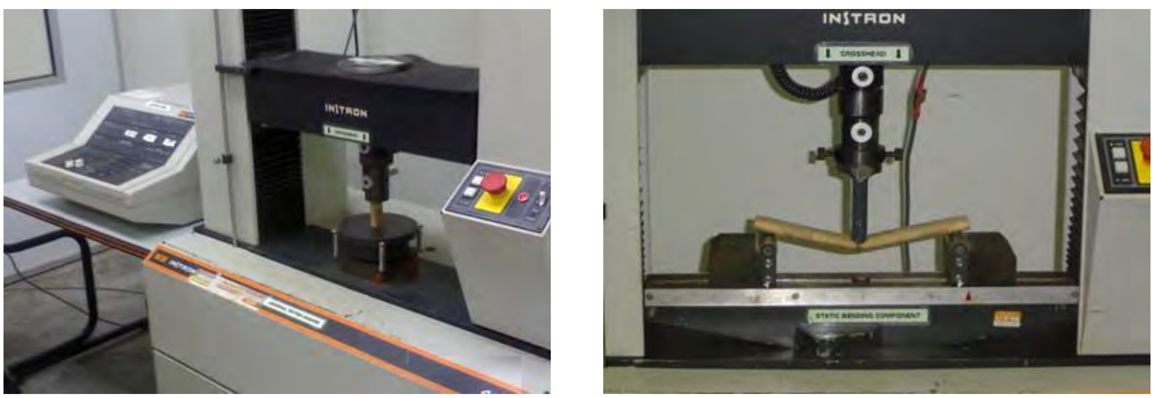
From the observations of the distribution/location and shape of the root growth (Figure 4) as *Pterocarpus indicus* had shown only end roots the other three species, namely, *Hibiscus tiliaceus* (*Ht*), *Dillenia indica* (*Di*) and *Dillenia suffruticosa* (*Ds*) were selected as the primary candidates to be used as live poles. The mechanical properties of these plant species were tested in the laboratory and these were replanted in selected natural soils to determine their ability to withstand field trials as described below.

SPECIES SCREENING (2): CHARACTERIZATION OF THE MECHANICAL PROPERTIES OF SELECTED POTENTIAL LIVE POLE SPECIES

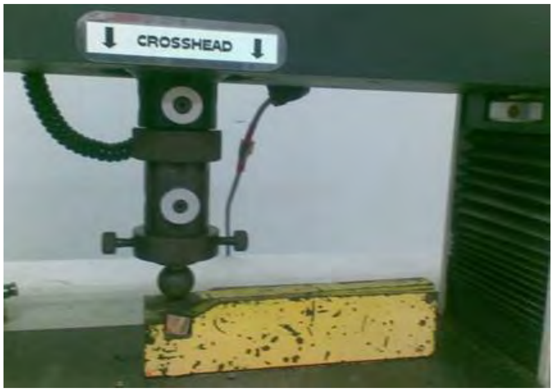
This study consisted of two series of tests on the stems and roots of the selected potential live pole species. The first series determined the mechanical properties of the stems by testing for the compression, shear and bending strength of the fresh woody stems from four age categories (Young, Juvenile, Mid-age, and Mature) according to the BS 373 (1957) testing methods. The second series investigated the tensile strength of the roots based on the ASTM D1037-99. These laboratory tests were conducted by using the Universal Testing Machine (Instron, Model 4204, United Kingdom). Figure 5 shows the samples under testing conditions.

(a) Hibiscus tiliaceus (Ht) **(b)** Dillenia indica (Di) **(c)** Dillenia suffruticosa (Ds)

Figure 4: Selected species of first stage.



(a) Compression test of the stem **(b)** Bending test of the stem



(c) Shear test of the stem

(d) Tension test of the root

Figure 5: Methods of live pole mechanical testing

To obtain the root samples for the tensile tests the selected species were first planted in cylindrical containers filed with two types of soil [one each from Jalan (road) MARDI and Jalan (road) Alumni field trial sites respectively] and kept in the shade-house for 8 months after which they were exhumed and roots specimens were cut from the upper and lower part of the portion of the root zone.

The results of the strength tests on stems are summarized in Figures 6. As is obvious from Figure 6 *Ds* has on the whole the highest average mechanical properties as compared to *Ht* and *Di* (38% to 40% more average compression strength than *Ht* and *Di* respectively, 20% and 60% greater average bending strength than *Ht* and *Di* respectively and is more than 27% stronger than *Ht* in its average shear strength) and only in its shear strength is *Di* about less than 10% and 40% stronger than *Ds* and *Ht* respectively.

As seen in Figure 7, the average tensile strength of both the *Ds* and *Ht* roots from the Jln. MARDI soils is almost the same. However, the *Ds* roots are seen to be nearly 40% stronger than the *Ht* roots in the Jln. Alumni soil. Moreover, it is observed that the average tensile strength of the upper roots of both plants is about 35% more than the average strength of their lower roots.

SPECIES SCREENING (3): INFLUENCE OF SOIL TYPES ON THE GROWTH OF SELECTED LIVE POLE SPECIES

Soil absolutely dictates the success of all plant growth as it is the source of water and minerals and the medium for anchorage. The most effective soil mechanical parameters on root development are: soil composition and texture, structure, profile and moisture availability. In fact the water and mineral storage capacity is a function of soil composition and texture.

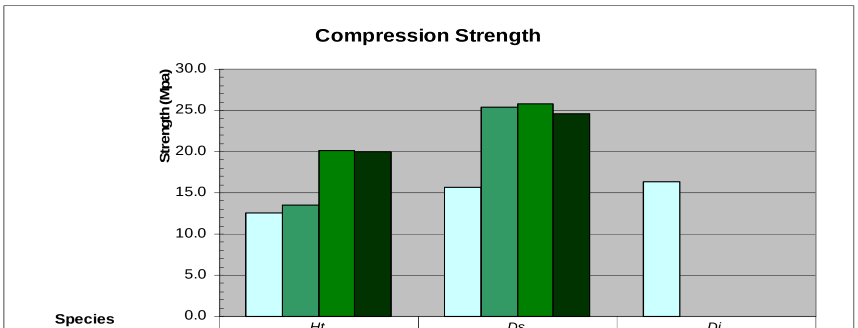
The selected live pole plant species were planted in five types of common soils found in Malaysia, taken from the locations mentioned in Table 3 with an analysis of their nutrients, under shade-house conditions. In terms of the three elements Carbon, Nitrogen and Potassium, only

Serdang soil can be considered as rich agricultural soil. Table 4 shows the result of the shade-house planting after 2 months and it was again observed that *Ht* and *Ds* had not only the fastest growing rates but were also the most adaptable to the different soil types.

The performance of *Dillenia indica (Di)* did not match that of the other two species, *Hibiscus tiliaceus* (*Ht*) and *Dillenia suffruticosa* (*Ds*)

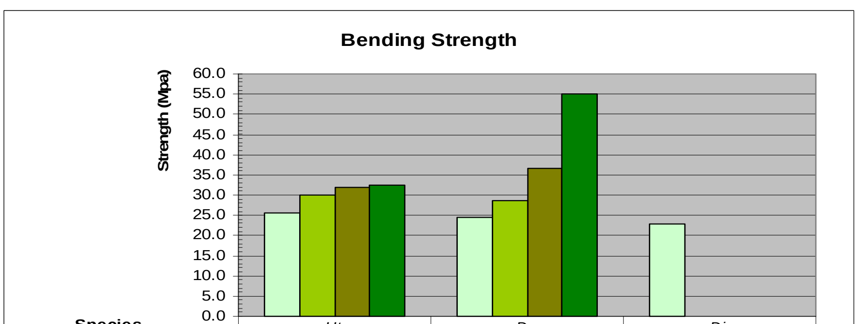
SELECTION OF PLANT SPECIES AS LIVE POLES

After considering the results of the above mentioned investigations it was found that as *Dillenia indica (Di)* could not meet all the conditions, *Hibiscus tiliaceus* (*Ht*) and *Dillenia suffruticosa (Ds)* were considered as the most suitable candidates and were utilized for the next two stages of this research as described below.



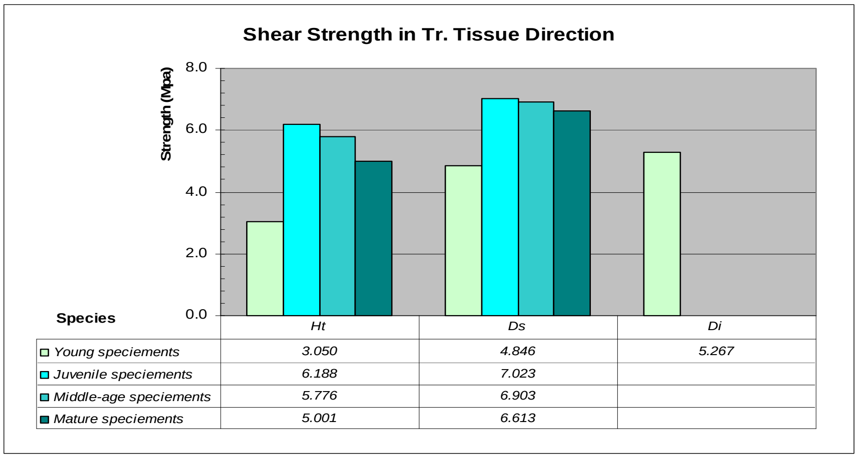
Species	Ht	Ds	Di
Young speciements	12.600	15.696	16.361
Juvenile speciements	13.532	25.359	
Middle-age speciements	20.112	25.841	
Mature speciements	20.036	24.587	

(a) Compression strength



Species	Ht	Ds	Di
Young speciements	25.493	24.598	22.951
Juvenile speciements	30.095	28.748	
Middle-age speciements	31.930	36.689	
Mature speciements	32.421	55.067	

(b) Bending strength



(c) Shear strength

Figure 6: Comparing mechanical properties of selected live pole

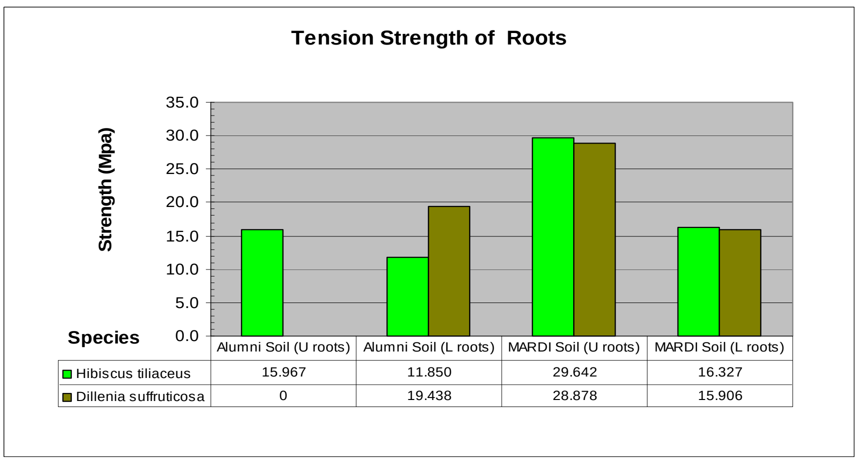


Figure 7: Comparison of the tensile strength of the roots of the selected live pole species

Table 3: Nutrient level of the various soils

No.	Location	Plants Nutrition Analysis											
		N %	C %	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Cu (ppm)	Zn (ppm)	Mn (ppm)	Fe (ppm)	PH	CEC (kM/Kg)
1	Jln Alumni, UPM (trial site 2)	0.07	1.67	0	33	60	1.5	6	58	5	58	4	10.3
2	Jln MARDI, UPM (trial site 1)	0.01	0.05	0	12	46	0	TR	11	TR	11	4	5.5
3	Balakong	0.04	0.19	121	14	46	0	1	3	TR	3	5	4.0
4	Bangi	0.01	0.07	0	4	58	0	3	2	TR	2	5	5.4
5	Bkt Saujana, UPM	0.19	2.07	52.8	80.3	697	85	1.48	2.35	7.54	114.4	6	5.2

Table 4: Selected live pole growth-ability in various soils

No.	Location	Agricultural Series	Soil Description	Date of Planting	Species	No. of Replicate	Plant Screening (after 2 months)
1	Jln Alumni, UPM (trial site 2)	Melaka (Malacca)	Yellow well grd Sand with gravel	01-Feb-08	*Ht ,Ds, Di*	8	*Ht*: 80% survived *Ds:* 50% survived *Di:* 25% survived
2	Jln MARDI, UPM (trial site 1)	Muchong	White poorly grd Sand with gravel	11-Apr-08	*Ht, Ds, Di*	2	*Ht*: 100% survived *Ds:* 100% survived *Di:* 100% survived
3	Balakong	Masai	Yellowish red poorly grd gravely Sand with silt	14-May-08	*Ht, Ds*	3	*Ht*: 67% survived *Ds:* 100% survived
4	Bangi	Prang	Red clayey Sand with gravel	09-May-08 13-Jun-08	*Ht, Ds*	4, 1	*Ht*:75% survived *Ds:*100% survived
5	Bkt Saujana, UPM	Serdang	Brown clayey Sand with gravel	13-Jun-08	*Ht*	3	*Ht*:100% survived

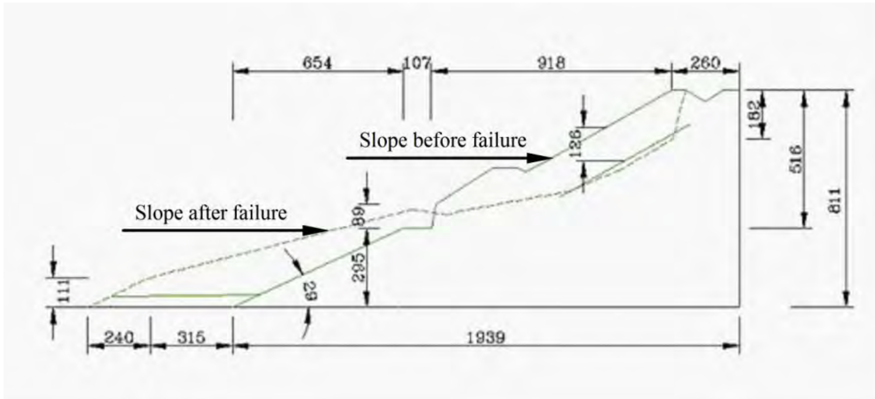
FIELD TRIAL ON SLOPES

The field trials were carried out on one meta-stable at Jalan MARDI and stable slope at Jalan Alumni respectively in the vicinity of the UPM campus. These sites have a reasonable slope angle of nearly 30 degrees, are wide enough for planting and also are easy to access.

First Trial Site (Jalan MARDI): Meta-stable Slope

This slope had a general angle of inclination of about 29^o, with shallow failures (*0.95 - 1.5* m deep) at several locations. Most of the failures were rotational failures, but a translational failure was also evident in this slope. The slopes were quite wet, with softer sandy soils of shale origin (weathering grade *VI*). Figure 8 shows a general view and surveying section of this trial site as in July 2007.

(a) General view



(b) Surveying section

Figure 8: 1st trial site as in July 2007

Live poles of *Ht* and *Ds* were used on this slope. Two trial strips were installed with a grid of live poles at *0.5* by *0.75* meter staggered centers across and down the slope with alternative rows of *Ht* and *Ds* (Figure 9). They were planted as stem cuttings to a depth of *1.5* m below the ground surface. The first strip as shown in Figure 10(a) was a re-graded section of an already failed slope shown Figure 8(a). The next trial strip was about 50 m away to the south along the slope as shown in Figure 10(b).

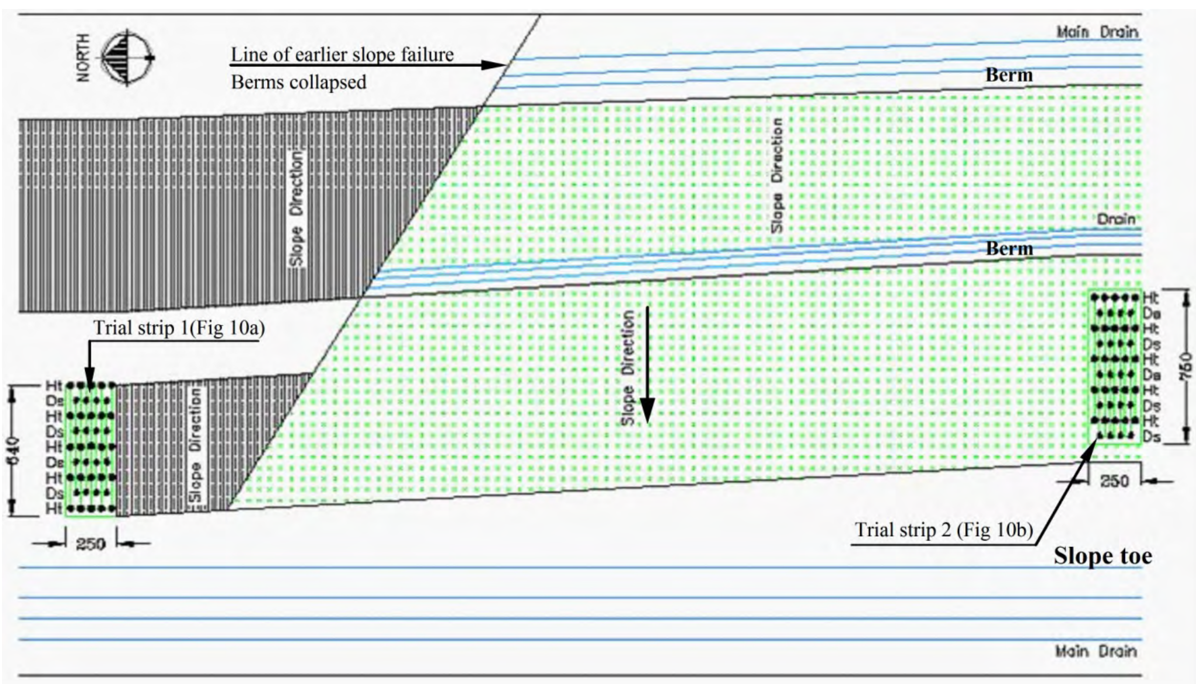


Figure 9: Live pole installation layout plan at the 1st trial site

(a) Trial strip 1

(b) Trial strip 2

Figure 10: 1st trial site as in April 2008

Second Trial Site (Jalan Alumni): Stable Slope

This slope had an angle of inclination of about *28*^{o} and it seemed stable. It was apparently drier than the first slope with a harder (gravelly) soil (i.e. of weathering grade *V*) of sandstone origin. Again *Hibiscus tiliaceus* (*Ht*) and *Dillenia suffruticosa* (*Ds*) were selected for the live poles in this site, as they were proven to be more versatile and adaptable. An area of about *9.0* m by *10.5* m along and down the slope was installed with a grid of live poles at 1.0 by 0.75 m staggered centers across and down the slope (Figure 11). The stem cuttings were planted in alternate rows to a depth of *0.75* to *1.0* m respectively below the ground surface (Figure 12).

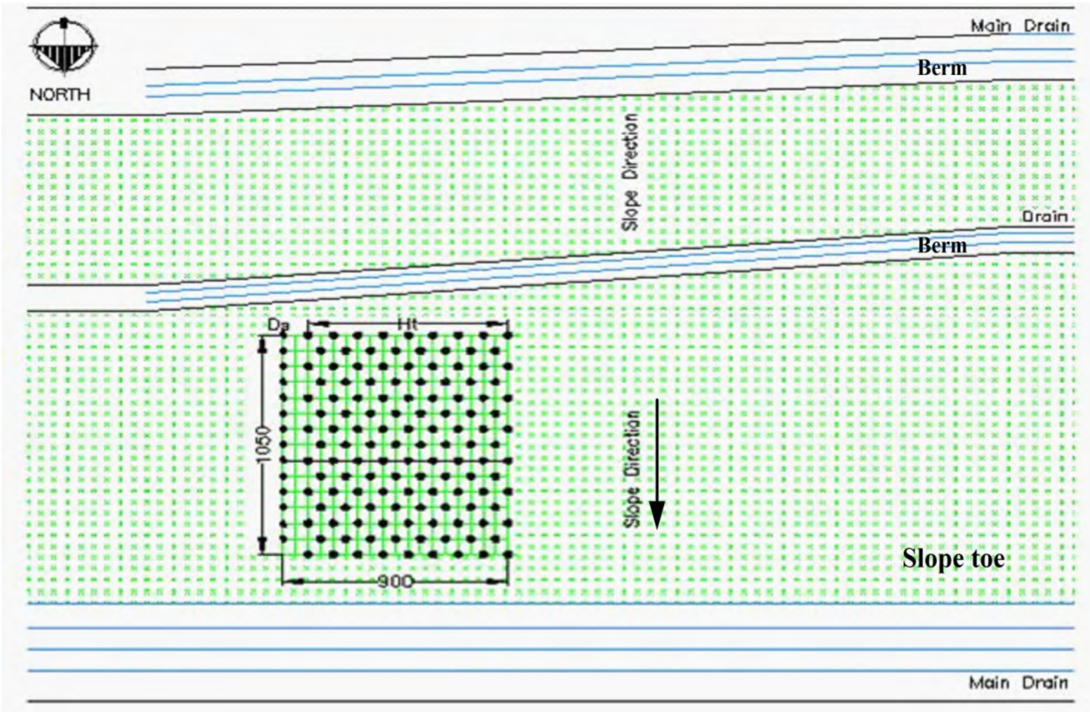


Figure 11: Live pole installation layout plan at the 2nd trial site (Ht and Ds are shown)

Figure 12: 2nd trial site during planting on May 2008

The Live Pole Installation Procedure

The planting operation was done over two/three days during the 3rd week of April and 4th week of May 2008 at the sites 1 and 2 respectively. All live poles were freshly harvested, directly transported to the site on the first day of planting and kept cool and moist with wet gunny sacks covers during the planting days.

All the fresh cuttings of *Ht* and *Ds* had initial lengths of *2.10* to *2.30* m for the 1st trial site and *1.25* to *1.40* m for the 2nd trial site, diameters between *50* to *70* mm at the upper end and *50* to *80* mm at the butt end, were almost straight, smoothly tapered with no bends or branch points forming large bifurcations.

The live poles were removed from a forest near the campus and installed in batch after holes (of about *100* mm in diameter) had been pre-bored into the ground for their installation using a two-man powered auger as shown in Figure 13.

Figure 13: A two- man powered auger team preparing the pre-formed hole

Prior to being installed the length to be buried and the upper *300* mm were marked off on the poles. The *200* to *250* mm of the butt ends of the live poles were shaped into a point while the upper end of each pole was protected from splitting by wrapping about *25* mm from the end with at least two turns of *1* mm diameter galvanized wire. Each pole was placed with the pointed butt end first into a pre-formed hole and driven in using a *14* lb hammer to about *1.5* m or *0.75/1.0* m of its length.

After installation the annulus between the pole and the pre-formed hole was backfilled with fine dry sand to within *250* mm of the ground surface. The final *250* mm was backfilled with the previously removed topsoil. On completion of the driving, the exposed end of each live pole was trimmed cleanly at an angle about *60*° to the longitudinal axis of the pole. Any splintered portion at the end of the pole was trimmed off neatly and the end re-wrapped as mentioned above to avoid splitting. Each live pole was labeled using a durable label with an identification number and date of installation.

In addition, an irrigation system and a temporary shading cover of a plastic net were installed at each of the trial sites (Figures 14).

Monitoring

The trial sites were monitored after the completion of installation for the next *10* months. Monitoring was done daily for the first two weeks, two times a week for the next month and weekly after that. The progress and growth/survivor rate of live poles at both sites were the most important items for monitored.

(a) 1st trial site (strip 1)

(b) 2nd trial site

Figure 14: Completed installation of live poles
(with irrigation system and temporary shades)

The observed growth/survival rates of the live poles are given in Table 5. Figure 15 and 16 show the progress of the live poles at the two trial sites after 10 months. The survival rate at the 1st trail at Jalan MARDI site seems low, with little difference between the North and South trial strips. However, the rate at the 2nd trail site at Jalan Alumni was more satisfactory.

Exhumation of Live Poles from the 1st Trial Site (Jalan MARDI)

At the end of the monitoring period 2 *Ht* and 2 *Ds* live poles were exhumed from the 1st trial site at Jalan MARDI in order to study the specification and properties of the live poles in a field condition (Figure 17). The geometry and topology of the roots and the live pole strength parameters were determined.

A visual comparative study of *Ht* and *Ds* live poles (Figures 18 and 19) showed that (on average) 1625mm of the total 1850mm length of the *Ht* poles were under the ground whereas for the *DS* poles it was 1635 mm (on average) of about a total length of 1950 mm.

Table 5: Growth/Survival rates of the live poles

Trial Site	Jln. MARDI		Jln Alumni	Remarks
	Strip 1 (North)	Strip 2(South)		
Installation	21 to 24 Apr 08		21 to 24 Apr 08	
After 1 months	95% [a]	85% [a]	75%	[a] Regarding to dieback plants
After 2 months	89%	71%	92%	
After 3 months	77%	63%	88% [b]	[b] Regarding to dieback plants
After 6 months	56%	45%	83%	
After 9 months	56%	45%	79%	
After 10 months	56%	45%	79%	


(a) Trial strip 1


(b) Trial strip 2

Figure 15: Live poles at the 1st trial site 10 months after planting

Figure 16: A *Ht* Live pole at the 2nd trial site 10 months after planting.

(a) An *Ht* pole during excavation

(b) Live poles after removing

Figure 17: Exhumation of live poles at the 1st trial site at Jalan MARDI

Figure 18: An exhumed *Ht* live pole

Figure 19: An exhumed *Ds* live pole

The roots of *Ht* had grown only on 25% of the length under the ground but for the *Ds* roots could be seen along 31% of its embedded length. On the other hand, roots of *Ht* seemed longer (length: 230mm to 1230mm) and thicker (diameters: 0.5mm to 5.7 mm) than the roots of *Ds* (length: 350mm to 1060mm and diameters: 0.5mm to 2.5mm).

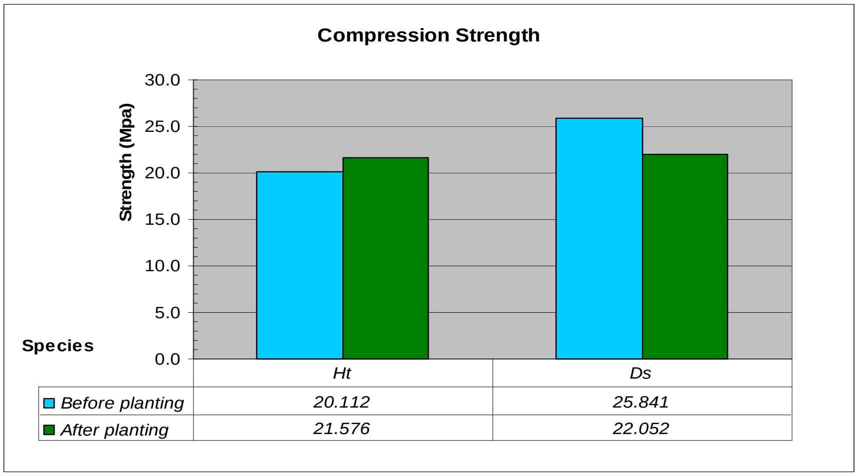
The strength of the live pole stems before and after planting are compared in Figure 20. It is obvious that the difference between the mechanical properties of *Ht* poles at about ±1% to 8% is not very considerable while for the *Ds* poles the compression and shear strengths decreased by 15% and the bending strength increased by 25% after planting.

EFFECT OF THE SELECTED LIVE POLES ON SOIL SUCTION

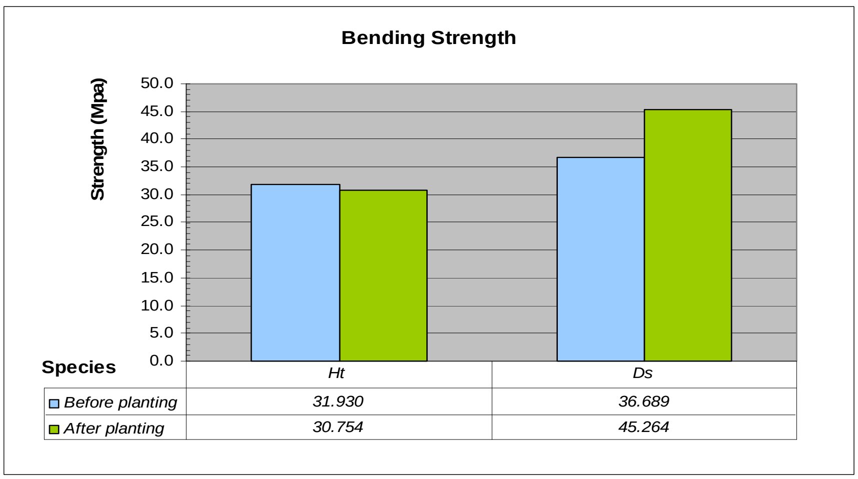
The last test on the selected live poles was the observation of their effect on soil suction. Four specimens were prepared for suction testing. Four small prospect containers were filled with the 2nd test site (Jalan Alumni) reddish yellow SW which was naturally compacted to an approximate 80% field density. One of the containers was not planted with a live pole for measuring the control condition while the remaining three were planted with the selected live pole species, namely, *Ht* and *Ds*. Adequate drainage was provided to each container by five 10mm holes at their bottom sides as well as a 20mm thick bottom layer comprising of a mixture of different grain size gravel. These samples were placed outside the shade-house to simulate natural conditions. However, an irrigation system was erected for controlled watering.

The testing commenced just after the samples were planted. Four micro-tensiometers 100 HPa capacities connected to a data logger system were install at depths of 200 mm or 400 mm in each container (Figure 21 and 22).

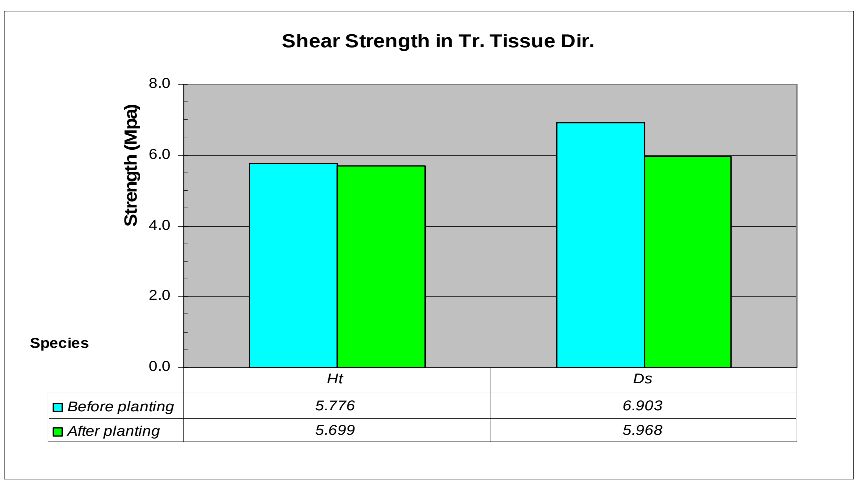
Figure 24 depicts the result of the suction measurements during an approximately 5 month period. It is observed that the suction of the soil with *Ht* roots is 2 to 10 times greater than he control (unplanted) soil during dry and wet soil conditions respectively. Also soil suction at 400 mm depth is obviously 50% to 60% of the suction at 200 mm depth (in dry and wet soil conditions respectively). Comparing the effect of *Ht* and *Ds* roots shows that the suction created by the *Ds* roots is 100% to 70% that of the *Ht* roots (in dry and wet soil conditions respectively).



(a) Compression strength



(b) Bending strength



(c) Shear strength

Figure 20: Comparison of the mechanical properties of the live pole stems after planting

Figure 21: Samples for soil suction testing beside the shade-house

(a) Date logger box **(b)** Connection of tensiometers to logger

Figure 22: Method of live pole testing

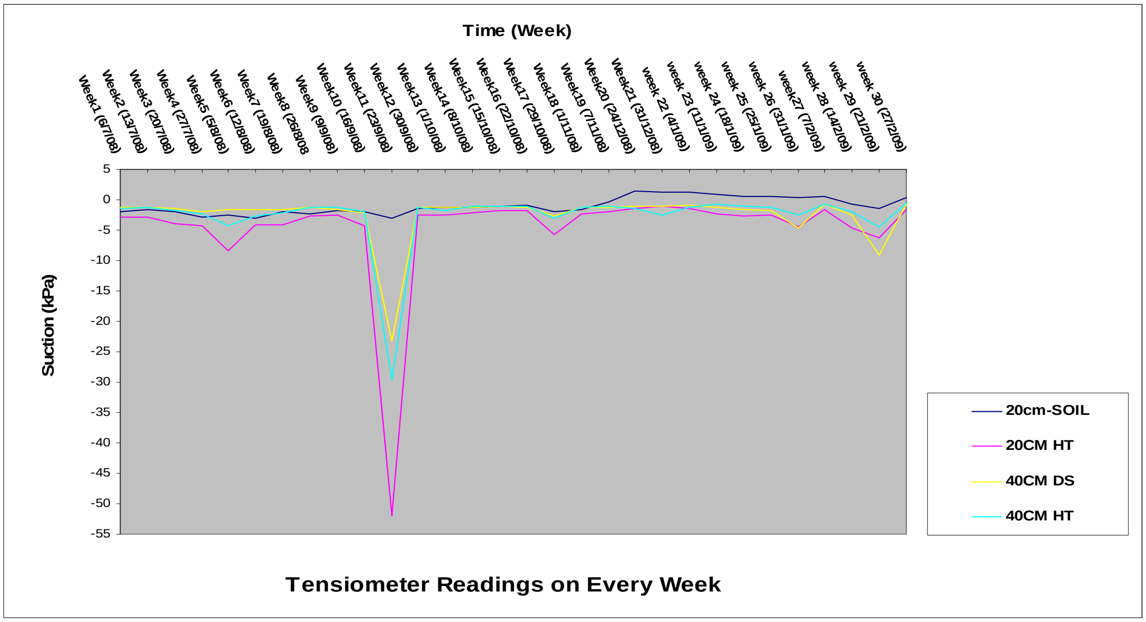


Figure 23: Comparing suctions in the 2nd testing site (Jalan Alumni) soil planted with Ds/Ht and the control (unplanted) soils.

CONCLUSIONS

The presented research is planned in tropics to provide more practical and theoretical knowledge about the live pole technique and ways of optimizing its effectiveness. Results obtained to date indicate that *Hibiscus tiliaceus* and *Dillenia suffruticosa* poles may be effective for stabilization of shallow slides in clayey Sand to Sand soils. The principle limitations are constraints on construction time and the procedure for installing plant materials, which are critical but unfamiliar to many civil engineers and contractors. Also the pole stand can die and thus requires additional monitoring and maintenance beyond what is typically necessary for conventional stabilization repairs. And at last, it seems remarkable that *the live pole technique* is only effective for shallow slop failure at depth of approximately less than 1.5 m.

The results of this study so far show that the selected live poles were above to be sub-planted in to the slopes where after ten months some were seen to have begun to grow and the growth had shown good progress by some species. The continued growth of these live pole species provide a form of vegetated soil nailing or dowelling which offers immediate improved slope stability. The continued growth would be beneficial for the slope as its stability would be subsequently increased over time through the development of a root system, increase in soil suction and a reduction in the soil moisture. As is being attempted in this study live poles can be used in close-spaced arrays on suspect or failure slopes to provide low-cost and environmentally suitable alternatives to conventional methods of slope stabilization.

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