Chapter 5

Chapter 5

Survey on Soil Water and Root Profiles of Slopes Along the North-South Expressway

5.1 Introduction

Vegetation effect on slope stabilisation, *inter alia*, is always be related to soil conditions (wetness, etc.), vegetation characteristics (root profile, etc.) and the external conditions, including wind direction (Viles, 1990). Previous studies revealed the important attributes of plant cover on slope stability such as community compositions, plant densities and plant shape including plant height and foliage density (e.g. Thomas and Tsoar, 1990). In terms of plant densities, higher values are likely to provide greater surface of stabilisation through larger canopy area for transpiration and binding effects of roots (e.g. Hesp, 1981).

In order to understand the effects of vegetation on slope stabilisation, a survey of soil water and root profile will be done on five types of slopes, ranging from slope with dense shrubs to those which are near barren. In the survey, the relationship between these parameters with soil strength factors including penetrability and shear forces will be measured and established. In addition, the *in situ* values of these parameters in slopes of different stabilities will be classified for comparison to the values of an experimental slope (Chapter 6).

5.2. Materials and Methods

5.2.1 Description of the Sites

Slope of five different locations were chosen based on bush densities along the North-South Expressway, arbitrarily called type A, B, C, D and E. The range of slope angle was $30 - 40^0$. The details of the slope is tabulated in table 5.1.

Table 5.1: Description of the slopes

Type	LOCATION North-Bound (NB) /South-Bound (SB)	Description	Vegetation cover (%) ($\approx 30\ m^2$)	Cover type (prominent species)	Slope angle (°)
A	KM 386.6 NB	Bushy	100	Diverse species (< 3m height)	40
B	KM 436.6 NB	Moderate Bushy	100	Diverse species (< 1m height)	35
C	KM 404.0 NB	Moderate Vegetated	100	Fern, Melastoma sp.	40
D	KM 423.4 SB	Moderate Failed	80	Melastoma, grass sp.	38
E	KM 397.8 SB	Failed	30	Grass sp.	32
Average					**37.2 ± 3.3**

5.2.2 Measurements

(a) Root and Soil Water Profile

Soil coring machine was used to sample the soil cores on slopes down to 1m. Each core was cylindrical with 11 cm diameter. In the laboratory, the soil core was divided into five equal divisions, 20 cm each, and three subsample replicates were taken and weighed (fresh weight). The samples were placed in oven at 80°C to constant the dry weight. Soil water content was calculated in a traditional method as follows :

$$\frac{FW - DW}{\text{Soil sample}} \times 100\,\%$$

The remaining soil in the cylindrical cores was washed manually to clean the roots from the soil particles. The roots were cut into 10 cm long and stained with methyl violet in the laboratory. The root length density was measured as described earlier (2.2.2b) with soil volume of 950 cm^3.

(b) Soil Penetrability

This was measured by using penetrologger (Eijkelkamp Agrisearch Equipment, model 06.15, The Netherlands), an electronic penetrometer for determination of the resistance to penetration of a soil. The equipment can penetrate to 80 cm deep using a cone type of 60^0 with the basal area of 1 cm^2. The speed of the penetration was maintained at 2 cm/s. During the coarse of measurements, the penetration was done steadily. The apparatus automatically log the penetrability data.

(c) Shear Strength

Shear strength was measured by using field inspection vane tester (Eijkelkamp Agrisearch Equipment, model 14.05, The Netherlands). This equipment was used to measure the *in situ* undrained shear strength. The measurement range of the instrument was 0 to 260 kPa. The accuracy of the instrument was within 10 % of the readings. The readings were taken manually.

All measurements on each slope have been summarised in table 5.2.

5.3 Results and Discussion

5.3.1 Root Length Density (RLD)

The RLD of slope soil decreased with depth (Fig. 5.1). The slope type A had the highest total RLD and the slope type E had the lowest (Table 5.3). The trend of root profile is as follows:

RLD :	A	>	C	>	B	>	D	>	E
(km m^{-3})	**(55.7)**		**(26.3)**		**(24.6)**		**(22.1)**		**(11.0)**

RLD of bushy slopes was about twice of moderate slopes and five times higher than the failed slope. The result is expected as the bushy slopes had various type and number of species compared to other type of slopes. The combined effects of vertical root anchorage and a traction effect of lateral roots (Sidle, 1991; Zhou, 1997) are significant in mitigating against instability. Thus, high RLD would be one of the characteristics of sustainable slopes. Even though the moderate bushy slope (type B) had more species than moderately vegetated slope (type C), its root systems was not as high as that in

Table 5.2 : Information of the measurements on slopes

Equipment	*Measurements*	*Method*	*Replicates*
Soil core	RLD and SWC	Random	4 *
Penetrologger	Penetrability	Diagonally across the slope	8
Vane tester	Shear strength	Diagonally across the slope	8

* The mechanical difficulty and physical constraints limit replication of soil coring measurements.

Fig. 5.1 : RLD of 5 type of slopes studied along the NSE. Each point represents the mean of 4 determinations. (□ type A, Δ type B, ◊ type C, O type D and ✕ type E).

Fig.5.1: Root length density of the NSE slopes

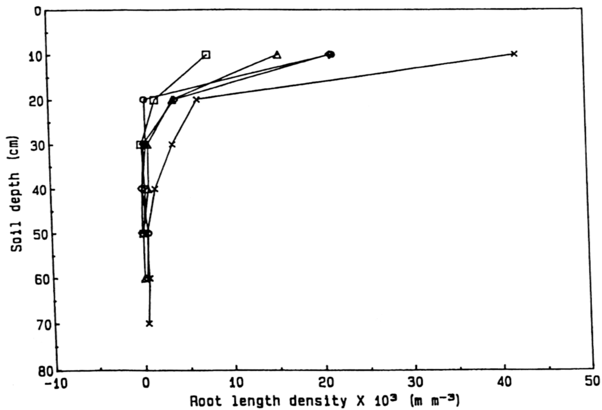


Table 5.3 : Root profile of 5 type of slopes

Soil depth (cm)	Bushy		Moderate bushy		Moderate		Moderate failure		Failure	
	m m^{-3}	%	m m^{-3}	%	m m^{-3}	%	m m^{-3}	%	m m^{-3}	%
10	42191	75.8	21707	88.4	21460	81.7	15790	71.6	7937	71.9
20	6635	11.9	717	2.9	4062	15.4	3871	17.5	1868	16.9
30	3723	6.7	755	3.1	505	1.9	1005	4.6	326	3.0
40	1546	2.8	198	0.8	185	0.7	896	4.1	633	5.7
50	587	1.0	737	3.0	68	0.3	243	1.1	273	2.5
60	658	1.2	436	1.8	-		252	1.1	-	
70	353	0.6	-		-		-		-	
80	-		-		-		-		-	
Total	**55693**		**24550**		**26280**		**22057**		**11037**	

slope C (Table 5.1). This is because the species might have had shorter root system or root are laterally distributed and thus were largely not sampled during the coring process. The results also show that in the sampling technique used, the highest RLD occurred at the first 10 cm in all types of slopes (Table 5.3) which contributed 71.6 - 88.4 % of the total RLD. The vigorous root at this depth would extensively reinforce the soil at upper soil level, and protect the soil mass below as well. Therefore, the bushy (type A), moderate bushy (type B) and moderate vegetated (type C) slopes which were observed to have good root system are expected to have significant soil reinforcement compared to other slopes.

5.3.2 Soil Water Content (SWC)

The results show that failed slope (type E) had the highest SWC at all soil depths in which its value was more than twice of that type A slope (Fig. 5.2). The type E slope at 60 and 100 cm soil depth were super saturated and virtually saturated at the other soil depths (compare Fig. 5.2 and Appendix 1). The little root of the failed slope presumably absorbed less amount of water which ultimately, the slope remained virtually saturated (mean FC, Table 5.4) and unstable. This phenomenon is due to higher ground water flow which in turn exerts weight and pressure on soil particles, ultimately impairing the stability of slopes. Moreover, the moving water washes out sand and silt particles from the slope and the underground cavities thus formed weaken the stability (Zaruba, 1969). Conversely, the type A slope had dense vegetation cover at the upper ground and also extensive root systems below the ground. Thus, this type of slope might have higher level of water absorption and also higher leaf area for transpiration (Russell,1977). In term of SWC profile, the slopes studied showed three patterns of relationship between SWC and soil depth: constant, increase or decrease. Two of the slopes studied; type A and type B tend to have their SWC decreased at 40 cm of the soil depth. Whilst, slopes type D and E remained constant and SWC of slope type C increased at 40 – 80 cm (Fig. 5.2). All the observation described are possibly be due to the capacity of RLD to absorb

Fig. 5.2 : SWC of 5 type of slopes studied along the NSE. Each point represents the mean of 4 determinations. (□ type A, Δ type B, ◊ type C, O type D and × type E).

Fig.5.2: Soil water content of the NSE slopes

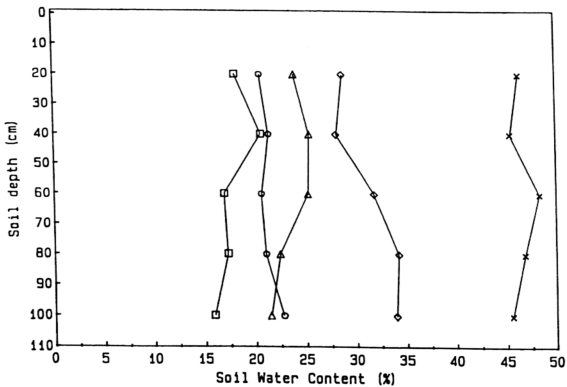


Table 5.4 : Soil water content and field capacity ( )* of the slopes studied.

Slope type	Range	Mean	Median
A	15.9 - 20.7 % (27.7 – 35.3)	17.8 % (32)	18.3 % (31.5)
B	21.5 - 25.5 % (29.2 – 31.4)	23.8 % (30.5)	23.5 % (30.3)
C	28.2 - 34.3 % (33.6 – 36.8)	31.5 % (35.4)	31.3 % (35.2)
D	20.7 - 22.8 % (25.1 – 30.9)	21.4 % (27.6)	21.8 % (28.0)
E	45.4 - 48.3 % (44.0 – 49.4)	46.5 % (46.6)	46.9 % (46.7)

* Value of FC

water as mentioned earlier (5.3.1). In general, all type of slopes, except type E, are unlikely to fail as the value of SWC are lesser than the field capacity (Table 5.4).

5.3.3 Penetrability

Most of the slopes studied show typical relationship of penetrability and soil depth : hyperbolic rectangular for slopes type A, B, D and E (Fig. 5.3). The penetrability of these slopes increased up to certain soil depth and decreased beyond that, except for type A which remained constant. The increased penetrability is presumably brought by the higher roots tensile property and the increase in root-soil bond (Zhou, 1997). The lateral roots from neighbouring plants which include in the core might create maximum bonding force per unit area on the soil-root interface to balance the stronger sliding or pulling force. Thus, this binding effects create maximum resistance by the root which attribute to increase penetrability. On the other hand, the failed slope (type E) had the lowest range of penetrability which is 0.71-1.64 MPa. This observation is possibly due to its lower RLD and higher SWC, thus decreasing its soil reinforcement and asserting the greater mass, a common characteristic of failed slopes. Unlike other slopes, for some reasons, type C slope had linear relationship between its penetrability and soil depth.

5.3.4 Shear Strength

Shear strength of the slopes studied varied from 25.7 – 182.8 kPa (Table 5.5). The failed slope showed the lowest value. Previous studies (Schroeder, 1985; Zhou, 1997) concluded that soil is reinforced when its shear strength is increased. And this happens when there are more vertical root reinforcement. Moreover, soil water content of nearly 50% in the failed slope was high compared to that in other slopes (Fig. 5.2). Study by Head (1980) showed that increase in SWC results in decrease of shear strength. The type A slope was expected to have higher shear strength due to higher root density. Surprisingly, this slope was observed to have low shear strength which may not represent the values at depth beyond 4 inches. No measurement was done beyond 4

Fig.5.3: Penetrability of the NSE slopes

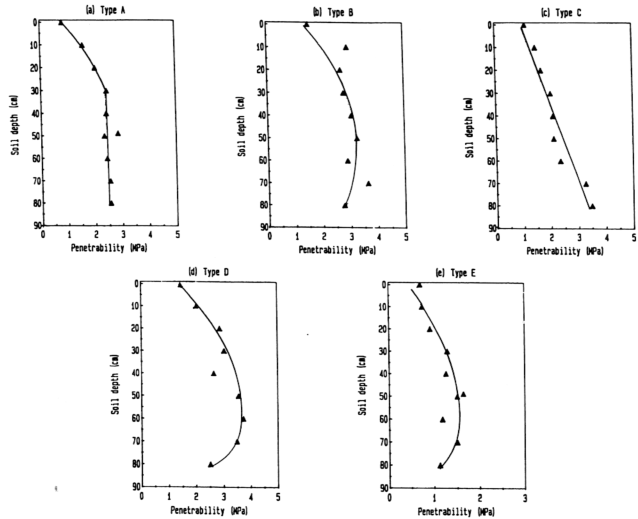


Table 5.5 : Shear strength value (kPa) at 4 inches of soil depth of the NSE slopes (n = 8).

Type of slopes	Shear Strength (kPa)
A	46.11 ± 3.4
B	182.8 ±12.5
C	132.5 ± 9.6
D	100.7 ± 11.5
E	25.71 ± 3.5

inches because in some slopes the soil become increasingly hard which is beyond the measuring range of the instrument used. The shear force was expected to be higher as the root went deeper below the ground and played a pivotal role in soil reinforcement. The type B slope had the highest shear strength as roots help to reinforce the soil. This slope might have shorter root compared to the type A slope. Similar to type B slope, shear strength of the type C slope was quite high which may be due to the same reason as above. In the case of type D slope which had lower soil water content, its higher value of shear strength may be due to the formation of hard crust due to exposure after a failure. Furthermore, with lesser root system, the soil may become more compact and hardier to shear off.

5.4 General Discussion

Similar to most other studies (e.g. Materechera and Mloza-Banda, 1997), penetrability of all slopes are strongly and negatively related to SWC (Fig. 5.4). The penetrability increases as SWC decreases. This relationship provides some useful information about the range of penetrability and SWC, and could serve as one of the slope stability indicators. However, no relationship was observed between penetrability and RLD (Fig. 5.5). The root characteristics including type, shape and distribution might also influence the root effects on penetrability (Schiechtl and Stern, 1996).

There are some correlations between SWC and shear strength (Fig. 5.6). The negative relationship was observed up to the value of 50 kPa. At this range, the SWC decreases as shear strength increases (e.g. Head, 1980). However, beyond this point, the shear strength was constant. There is a positive relationship between shear strength and RLD (Fig. 5.7), implying that dense root density at the first 10 cm depth could help reinforce the soil by increasing its shear strength. This would help in soil reinforcement at surface level, thus reducing surface erosion.

Fig. 5.4: Relationship between penetrability (MPa) and SWC (%)

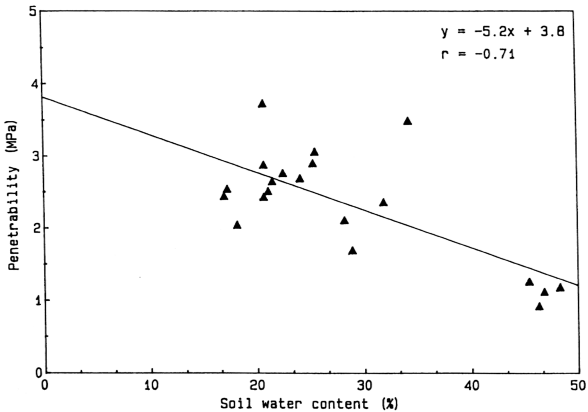
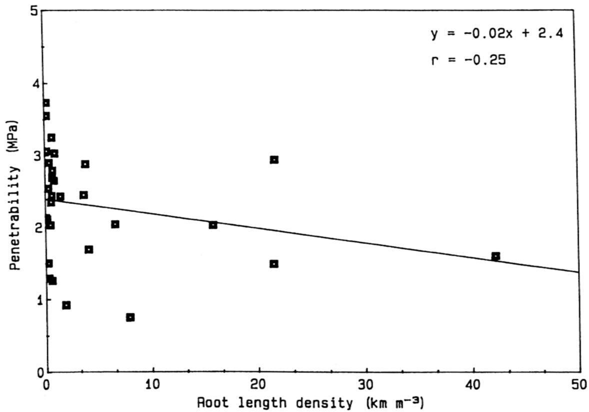


Fig.5.5: Relationship between penetrability (MPa) and RLD (km m^{-3})



Overall results show that it is not possible to link the qualitative characteristics of the slopes to values of the parameters studied in all five slopes. It is however possible to achieve this in the two extremes, type A and type E slopes representing bushy and failed slopes, respectively. The penetrability and shear strength of type A slope were 0.84 – 2.85 MPa and 46.1 kPa, respectively, as against 0.71 – 1.64 MPa and 25.7 kPa of type E. Type B, C and D slopes are perhaps difficult to delineate as they overlap in characteristics and their choice was subjective.

Fig.5.6: Relationship between SWC (%) and shear strength (kPa)

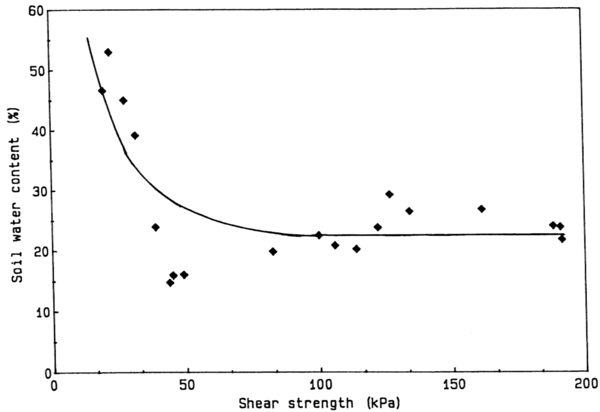


Fig.5.7: Relationship between shear strength (kPa) and RLD (km m^{-3})