Ceylon Journal of Science: Physical Sciences, 9(1), 23-36 (2002)

ROLE OF WEAK SOILS AND RELICT GEOLOGICAL DISCONTINUITIES IN CREEPING SLOPE FAILURE AT POOLIYADDA, SRI LANKA.

UDENI B.AMARASINGHE[a*], KAPILA DAHANAYAKE[a] AND NIMAL SENEVIRATNE[b]

a. Department of Geology, University of Peradeniya, Peradeniya, Sri Lanka
b. Department of Civil Engineering, University of Peradeniya, Peradeniya, Sri Lanka

ABSTRACT

The key to understanding the stability of slopes in residual soils lies in recognizing the behavior of weak soil layers and underlying relict geological structures inherited from the parent bed rocks. It is necessary to have a clear understanding of the geological origin of such weak zones in the sub surface of a particular slope. Such information would help to assess stability of slopes with much more confidence and predict the depth of the potential slip surface material.
Detailed studies of the weathering profile of a creeping slope failure at Pooliyadda, Kandy indicate that the sub surface of the slope mass had developed due to the breakdown of quartzite, pegmatite and marble - metasedimentary/ metaigneous rocks of Precambrian age. The slip surface had developed in a kaolin and mica - rich material formed due to the complete weathering of pegmatite. The slip surface material is inorganic silt with low shear strength characteristics under saturated condition. A highly permeable soil of parent quartzite overlies the slip surface material and supports heavy surface water infiltration to produce a shallow perched water table above the slip surface area. Further, it was noted that the two main joint sets existing in the underlying parent bed rocks controlled the development and distribution of tension cracks in the overlying completely weathered rock and residual soil horizons. The study highlights the role of weak soils in the development of the slip surface and the soil weakening character of relict discontinuities of the underlying rocks.

1. INTRODUCTION

Landslides are frequently observed during the rainy periods on hill slopes of the Central Highlands of Sri Lanka underlain by Precambrian metasedimentary/metaigneous sequences of quartzite, charnockites, gneisses, pegmatites and marble. Some of the slope failures are rapid while others are creep type slow movements. The landslide that began to occur in the hill slope underlying Weldambala School, at Pooliyadda near Kandy, Sri Lanka (Fig.1) and [1] in 1996 can be classified as a creep type slope failure. The failure caused the complete destruction of two school buildings and about 40 houses in the Pallegama village located in the lower reaches of the slope that had buttressed against a stream. Pooliyadda is an area, which had not been subjected to any significant human disturbances, and the determination of causative factors for slope failure could be extremely interesting.

* udenia@pdn.ac.lk

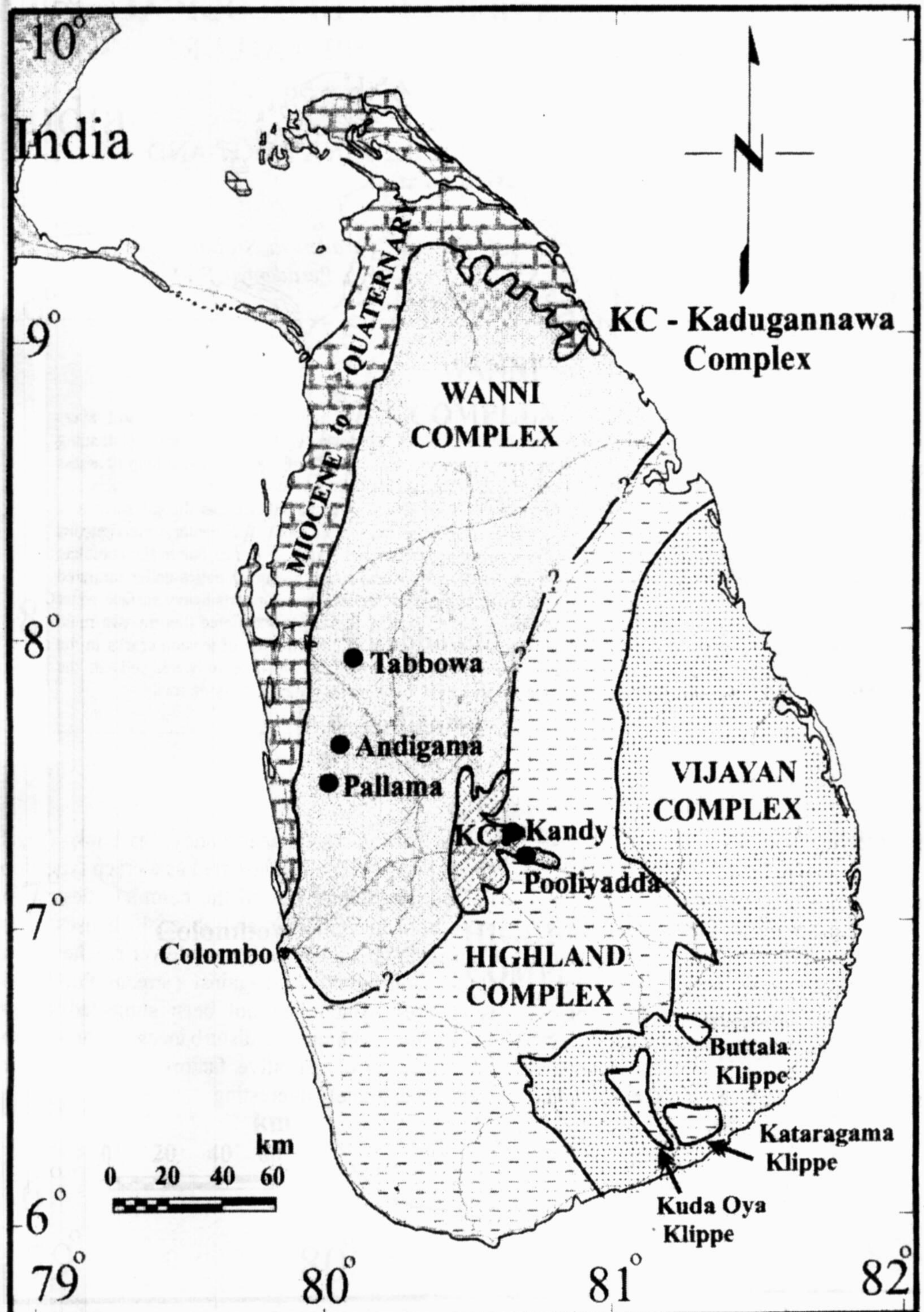


Fig.1 Geological Map showing the location of the creeping slope failure at Pooliyadda near Kandy (modified after Cooray,1994).

This paper attempts to highlight geological factors that yield slip surfaces in weak soil materials on residual shear planes developed on relict discontinuities. Once the causative factors are understood, finding engineering geological solutions for the control of the movement is a possibility. Continuous rainfall is the main triggering factor of Sri Lankan slope failures but there are significant geological factors as well. In Sri Lanka, the creeping slope failures have attracted the special attention of engineering geologists, as they seem to be controlled mainly by geological causes. This paper attempts to highlight geological factors that yield slip surfaces in weak soil materials on residual shear planes developed on relict discontinuities. The slip surface material would depend on the ability of bed rock material to produce weak soil layers with lower shear strength planar features. Deer and Patten [2] stated that the profile of weathering developed on a rock slope over a long period of geologic time has altered the strength and permeability characteristics of the slope so as to increase its susceptibility to failure. Relict geological structural features- joints, bedding planes, foliation planes and faults which have been inherited from the original rock mass further reduces the stability of the slope. Beetham et al [3] showed that the development of the landslides is controlled by the main defects, groundwater and rock mass properties with respect to discontinuities. The Pooliyadda creeping slope failure is found to be a first time shear failure and occurred in the weathered materials and residual soils overlying the bed rock Lumb [4] described residual soils produced by in-situ decomposition of the underlying rock owing to percolation of water through the rock fissures and into the rock pores, thus breaking down the more unstable rocks. Fang, Hsai-Yang [5] also reported that the physical structure and engineering properties of residual soils are unique. The texture and mineralogy may still reflect the original structure with added complication of decreased weathering with increasing depth below the ground surface. The creeping slope failures have attracted the special attention of engineering geologists, as they seem to be controlled mainly by geological causes with emphasis on the weathering profile of a creeping slope failure at Pooliyadda, Kandy.

2. METHODS AND MATERIALS

The slope failure was studied systematically using aerial photograph and topographic map interpretation subsequent to a literature survey, reconnaissance and detailed field engineering geological investigations, together with excavation of three test pits to detect the slip surface area and collection of disturbed and undisturbed box soil samples. Each horizon of the weathering profile was sampled. On the basis of the field mapping and subsurface exploration programme a detailed engineering geological map was produced. A cross section was drawn to understand subsurface engineering geological condition and the mechanism of the failure. The samples were tested in the soil engineering laboratory. The tests include particle size analysis, liquid limit and plastic limit determination, direct shear testing on undisturbed box samples for determination of shear strength parameters, X-ray diffraction analysis of soil horizons of the weathering profile to identify their soil constituents.

3. RESULTS

3.1 Engineering geological observations

As shown in the Figs 2 and 3 Pooliyadda slope failure occurred on an area underlying two school buildings and about 40 houses in 1996. Land subsidence occurred due to a slow creeping vertical downward movement of 6m observed on the scarp surface of the slide (Fig.3). The slope is underlain by an upper layer of highly weathered quartzite associated with a lower lying conformable layer of completely weathered pegmatite. Both these layers are characterized by the presence of relict mineral bands. The weathered quartzite rock shows gravel size quartz bands in a reddish silty clay medium and the weathered pegmatite shows whitish secondary kaolin type clay mineral material together with greenish chlorite mica formed due to chemical weathering of primary minerals such as feldspar and biotite. This soil layer is the 1C horizon of a typical weathering profile and it is recognized by evidence of the "saprolite" original rock structure in the soil material. It is significant to note that relict residual shear planes were observed in the completely weathered pegmatitic parent rock. The strike and dip of rock foliation is found to be 35° NW and 32° NE respectively. Figs. 4, 5, and, 6 show the cross section of the rock weathering profile. The upper layer is found to be highly permeable clayey sand with gravel (SC). The second layer from the surface is a pinkish to white clayey silt (MH) and the third layer is the whitish to greenish clayey silt (MH) layer (Fig.4). These silty layers are composed of kaolin clay and chlorite mica flakes. The clayey sand layer is the weathering product of the quartzite layer and second, third silt layers have formed from the decomposed conformable pegmatite horizon. Iron oxide enrichment is noted in the second silt layer. It is important to note that the surface sand layer covers about the 95% of the landslide slope. The toe area of the slope is found to be underlain by marble.

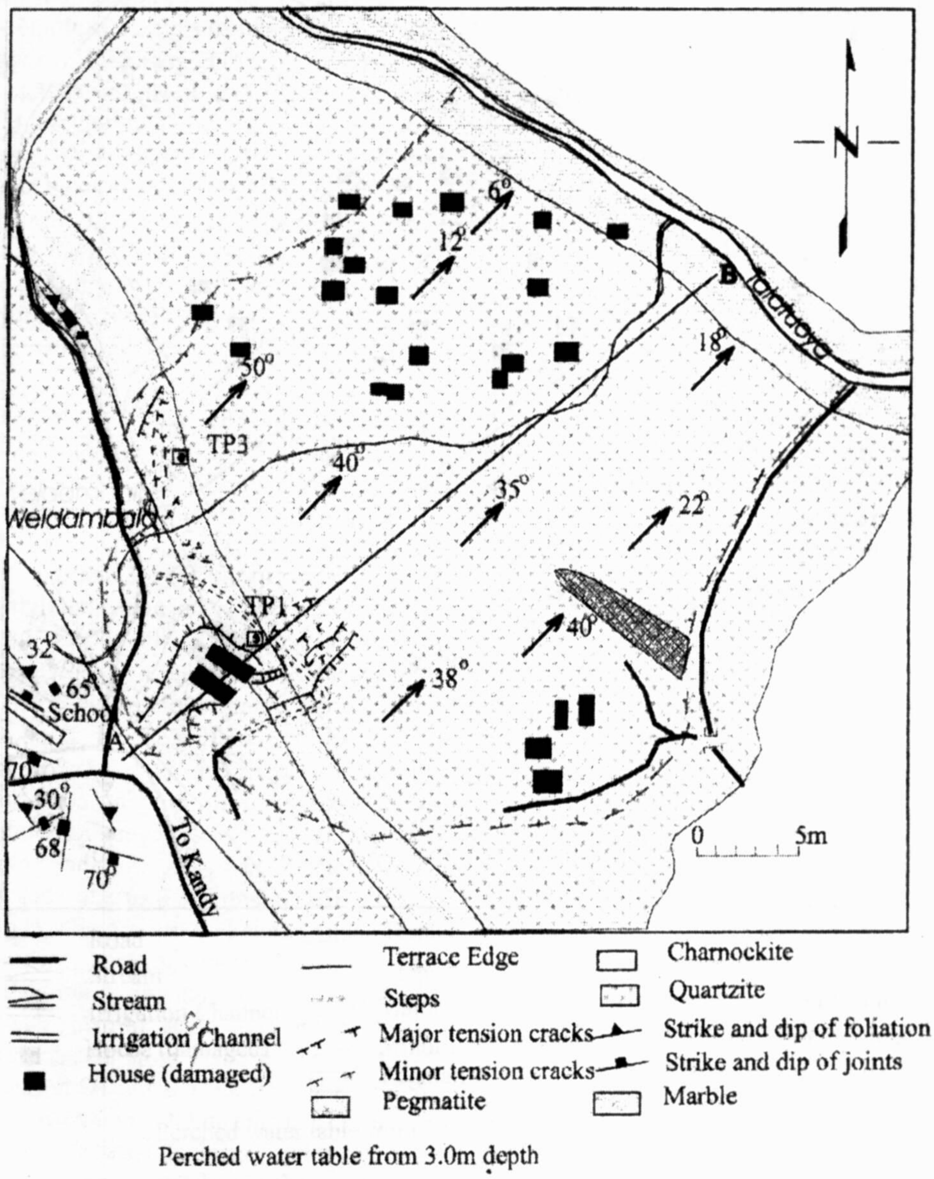


Fig.2 Engineering Geological Map of the Study Area

Fig. 3 Pooliyadda Creeping Slope Failure with Damaged Buildings of Weldambala School in the background.

Fig. 4 Weathering Profile at the head scarp of the slope failure.

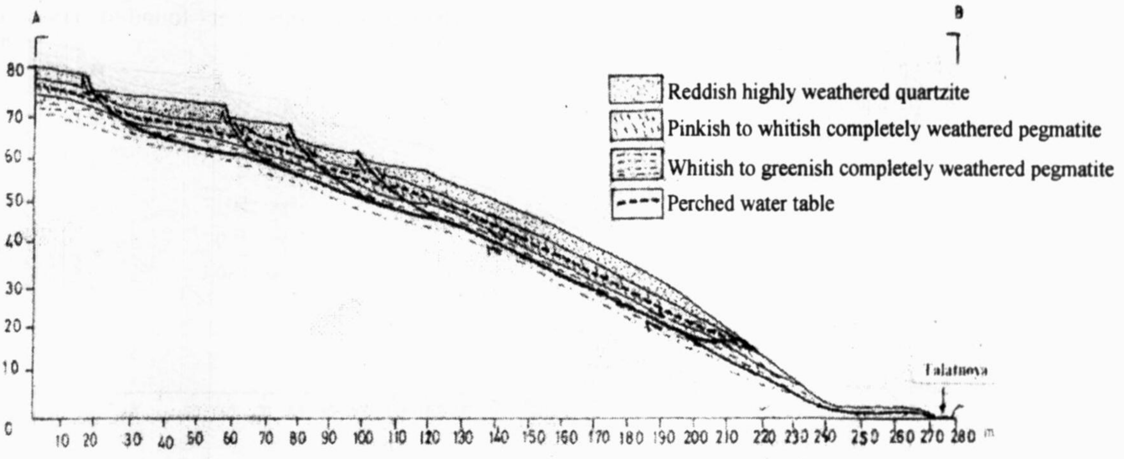


Fig. 5 A Longitudinal Section Between Points A and B as indicated in Fig.2.

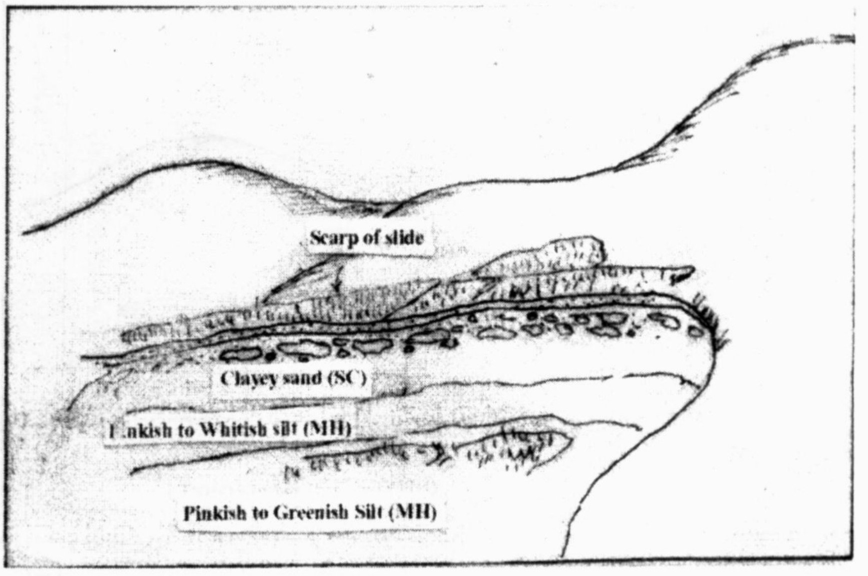
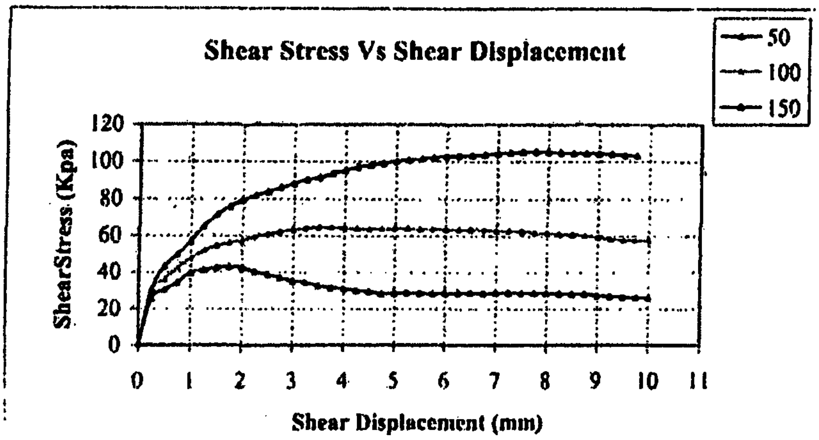
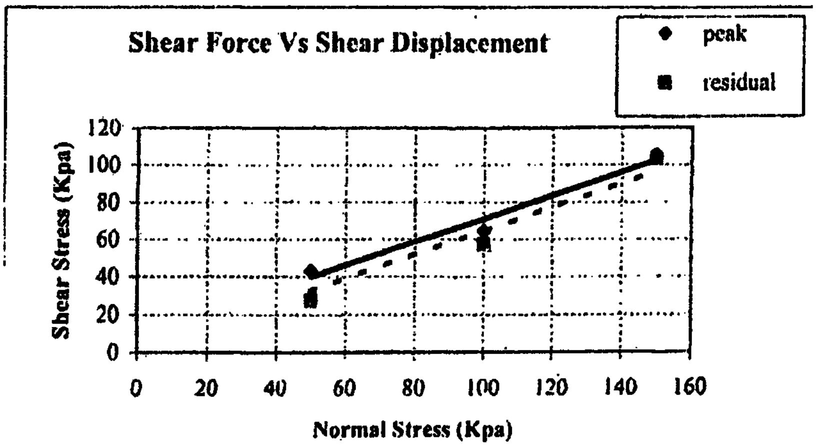


Fig. 6 A Schematic Soil Profile at the Scarp of the Slide

3.2 *Direct shear tests*

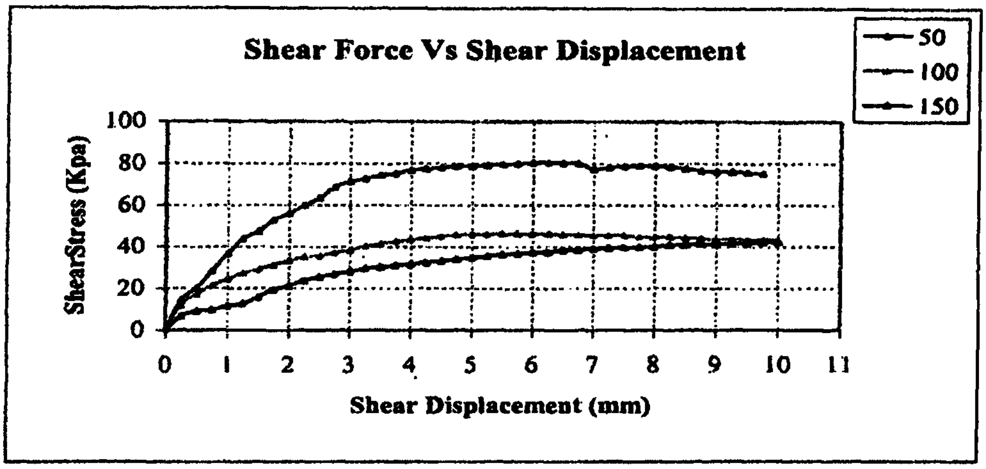
Figures 7,8, and 9 show direct shear test results and the angle of friction values of the slip surface soil material. The angle of friction ϕ values of the slip surface materials is found to range between 23.3° and 32°. The cohesion component found to vary between 0 and 11 KPa.

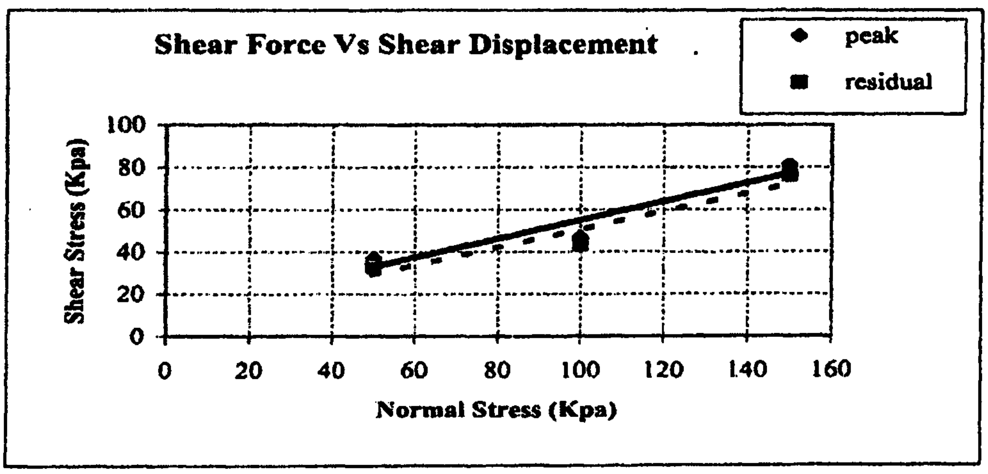




	Peak Shear Properties	Residual Shear Properties
Equation	y = 0.625x + 8.3 R^2 = 0.9686	y = 0.628x R^2 = 0.9861
Cohesion	8.3	0
Friction	32	32

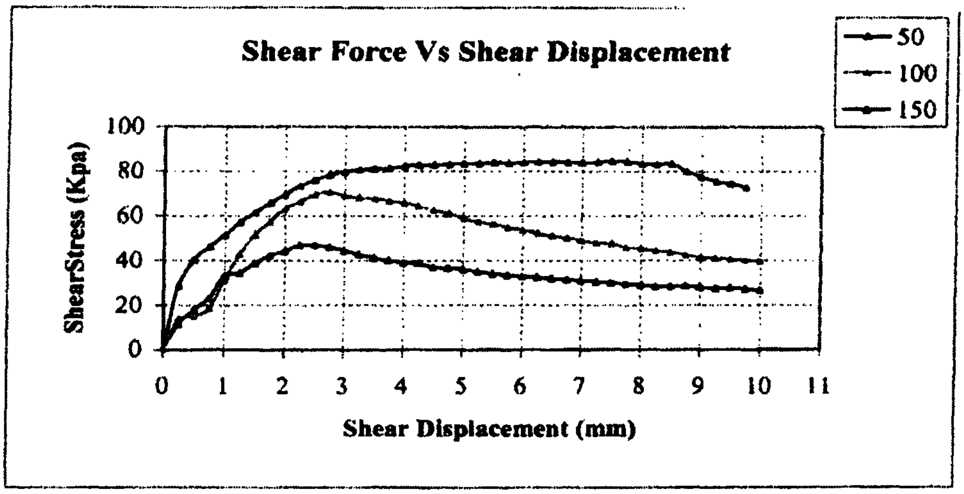
Fig. 7 Direct Shear Test Results of the Whitish to Greenish Slip Surface material (TP1 in Fig.2)

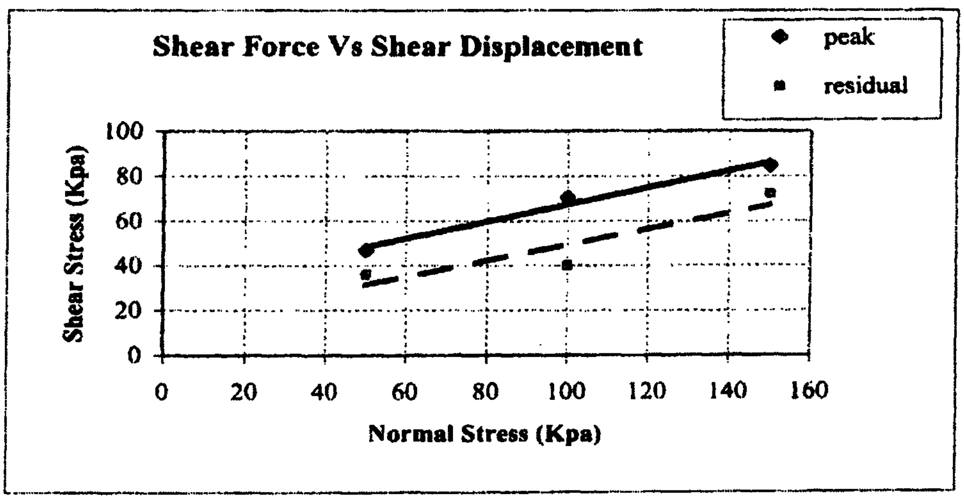




	Peak Shear Properties	Residual Shear Properties
Equation	y = 0.44x + 11 R^2 = 0.9098	y = 0.43x +6.6667 R2 = 0.9129
Cohesion	11	6
Friction	23.7	23.3

Fig. 8 Direct Shear Test Results of the Whitish to Pinkish Slip Surface Material (TP2 in Fig.2)





	Peak Shear Properties	Residual Shear Properties
Equation	$y = 0.378x + 29.4$ $R^2 = 0.979$	$y = 0.36x + 13.333$ $R^2 = 0.8922$
Cohesion	29	13
Friction	20.7	19.7

Fig. 9 Direct Shear Test Results of the Pinkish Slip Surface Material (TP3 in Fig.3)

3.3 Grain size distribution of soils

Figure 10 shows the grain size distribution of the three soil layers from the surface A, B, and C in that order. The soil layer is classified as clayey sands and sand clay mixture (SC) according to the Unified Soil Classification scheme [6]. The completely weathered pegmatite rock serves as the slip surface material and there are two upper and lower layers. The upper layer is pinkish to whitish and is classified as inorganic silts (MH) and the lower layer is whitish to greenish and is classified as inorganic silt (MH). The upper slip surface material shows plastic limit (41%), liquid limit (95%) while the lower slip surface material shows plastic limit (30%) and liquid limit (51%).

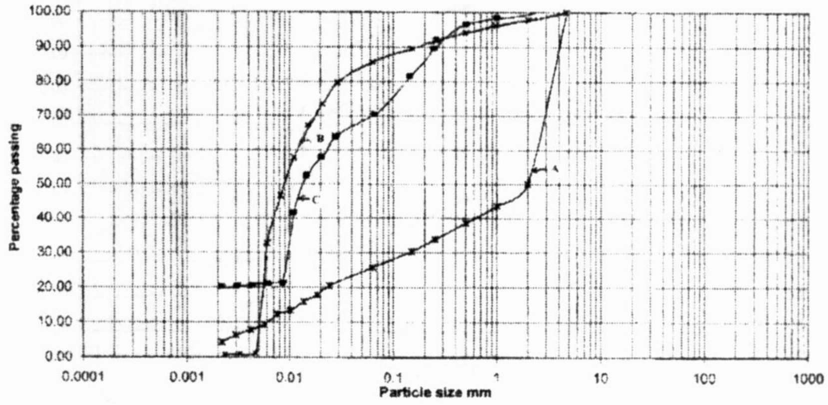


Fig. 10 Grain Size Distribution Curves of Three Soil Layers (A,B,C) from Top to Bottom of the Soil Profile

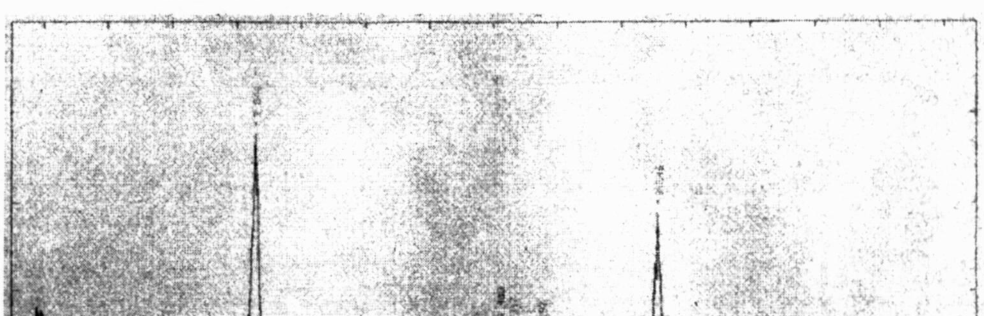


Fig. 11 The X-ray Diffraction Pattern of the Slip Surface Material (MH) shown in Fig.4

Fig. 12 Toe of the landslide (left) buttressed against Talatuoya stream flowing along a marble band. Some of the toe materials appear to have been absorbed into sink holes developed within this band

When land subsidence was observed close to the crest and head scarp area, an upheaval is observed in the middle and lower parts of the creeping mass. The newly developed tension crack pattern indicates that the movement had taken place in stages along three slip surfaces giving rise to three benches on the slope. It also appears that karstic marble existing close to toe area possesses solution cavities, which probably absorbed the flowing debris of the slide and prevented damaging of the Talatuoya stream as shown in the Fig.12.

3.4 XRD Interpretation

Figure 11 shows X-ray diffraction (XRD) diagrams and the fine fraction of the soil layers is found to be rich in kaolin clay mineral particles as indicated by the 'd –value' of 7.044. The slip surface material also contains unweathered primary minerals in the form of microcline feldspar as indicated by 'd-value' (4.137) together with gibbsite by d-value (4.317), goethite by 'd-value' (4.40) and quartz with 'd-value' (3.456) (according to ASTM card index in Muller [7].

The observations in the three test pits TP1, TP2, and TP3 reveal that there exists a perched water table at a depth varying from 2.5m to 3m below the surface of the slope. Seepages are found to flow underneath the top clayey sand layer. The slip surface of inorganic silty (completely weathered pegmatite) material becomes saturated during the heavy rains due to infiltration of rainwater through the top clayey sand layer.

3.5 Relict structures and slope failure

It is observed that there are three main discontinuities in the underlying bed rock (Fig .2). They include the foliation plane, first joint set(J-1) and the second joint set (J-2). The strike and dip of the J-1 plane is 06°NE and 68° NW respectively. The J-1 discontinuity is very prominent and runs through the completely weathered soil mass as a weak relict structure, which is parallel to the head scarp of the sliding mass. The J-2 discontinuity is parallel to the lateral boundary of the slide and its strike and dip were found to be 10°NE and 80° SE respectively.

4. DISCUSSION

The detailed engineering geological map, Fig 2 shows that the Pooliyadda creeping slope failure occurred in the soils of a weathering profile. The weathering profile has developed on the bed rock mass over a long period of time (Fig. 4). As this is a dip slope type failure, rock bands are parallel to the slope, the slope cover is the weathering product of the upper lithologic layer, quartzite bed rock. The two lower soil layers- the pinkish to whitish inorganic silt (MH) layer and whitish to greenish inorganic silt (MH) layer are found to be the weathering products of the lower lying conformable pegmatite rock layer in the bed rock mass. The parent quartzite rock appears to contain a greater quantity of coarse grained quartz minerals, with feldspar and iron oxides as accessory amounts. The clayey sand layer (SC) has evolved as a result of decomposition of feldspar and iron oxides together with the residue of quartz grains of sand and gravel sizes. As a coarse grained soil the upper layer (SC) has developed to become a highly permeable layer, which could have influenced the faster infiltration of water during the rainy period.

The lower lying layers represent the slip surface materials as evidenced in the three test pits and the scarp exposure of the slide. This is the completely weathered material of the parent pegmatite, which had consisted dominantly of feldspar and phlogophite mica. Chemical weathering of pegmatite rock had produced kaolin clay, (Fig. 6), and chlorite mica rich upper inorganic silt (MH) and lower inorganic silt (MH) layers. The upper layer (MH) is pinkish to white in colour due to precipitation of ferric oxide that had leached from the top clayey sand layer(SC). Fig.2 shows a marble bed rock existing at the toe of the slope and underlying Talatuoya stream. The marble with solution cavities underlies a pegmatite as confirmed during the field mapping. The sliding material apparently enters into such solution cavities as evidenced by the unaffected width and non dammed nature of the Talatuoya stream against which the slope had buttressed. The evidence of upheaval of the middle and toe area of the slope indicates that slips surface runs in a curved plane, which points upwards, its middle and lower parts.

It is also important to understand the engineering characteristics of the weak soil material in which the slip surface of the slide had developed. Shear strength parameters ((ϕ, c) of the slip surface weak materials are shown in the Fig. 7, Fig. 8, and Fig. 9. Direct shear test was carried out on undisturbed box samples carefully taken from the slip surface area from three test pits and exposures. The upper fine grained soil layer (MH) and the lower layer (MH) have been sheared by the slope failure as evidenced in the test pits and the scarp exposures. Tests were run in saturated condition as the real slope failure also takes place in that condition under the perched water table. The friction angle ϕ and the cohesive component 'c' of the shear strength property of these soils indicate that very weak soils have developed in the weathering profile to form the slip surface. The friction angle ϕ which ranges from 23.3^0 to 32^0, is due to local variations of chlorite mica and unweathered feldspar content (XRD pattern in Fig.11 shows presence of feldspar) and small amounts of quartz sand grains constituted in the slip surface materials. The cohesion = 0 and low amounts indicate that silt size kaolin mineral particles with mica flakes in the slip surface material had reduced this value. The grain size distribution curves shown in the Fig.10 indicate that the slip surface material consisted mainly of particles of silt size but not clay size. This is found to be the cause of very lower cohesive strength component as a shear strength parameter of the slip surface material.

As shown in Fig. 2 a perched water table was found to exist at a depth 2.5 to 3.0 m below the surface. The fast infiltrating water from the surface tends to saturate the slip surface materials. As a result shear failure occurs in the slip surface soil layers, the upper pinkish to white layer and the lower whitish to greenish layer. It is clear that under saturated condition very low shear strengths can be attained by the slip surface silty material. Direct shear test results obtained in saturated condition supported this fact as indicated in the Figs.7, 8 and 9.

Figure 2 shows the structural joint discontinuities of the bed rock mass. The two main joint sets are visible in the 1C horizon/ completely weathered rock as faintly developed stained and secondary mineral filled relict discontinuities. The study shows that the relict discontinuity planes controlled the development of tension cracks as well as the surfaces of the head scarp and the lateral scarp.

5. CONCLUDING REMARKS

It is concluded that a detailed study of the weathering profile underneath a slope would help to recognize potential slip surface materials. If the failure is a dip slope type, the slip surface material could be formed from a single lithologic unit and would be relatively homogeneous if on scarp type failures, the slip surface material would derive from a number of different rock bands and would be relatively heterogeneous. The fore-going observations show that the engineering properties of slip surface materials depend on the type of failure and the composition of the original bed rocks. Further , a careful examination of the completely weathered zone/ 1C horizon in a weathering profile is found to be very significant as slip surface development is highly favored by this material. Soil particles of silt size in this horizon seem to yield lower cohesive component to shear strength. The joints and other discontinuity pattern may be discovered in the weak completely decomposed zone and these may manifest as tension cracks on the surface and the slide configuration. The present finding can be generally used to predict the potential depth of slip surface materials when stability of slopes is assessed.

6. ACKNOWLEDGEMENTS

The research study on the landslide at Pooliyadda was funded by the Postgraduate Institute of Science (PGIS) , University of Peradeniya and the National Science Foundation (NSF) . We wish to extend our gratitude to Mr. H Abeyruwan, Head of the Department of Civil Engineering, University of Peradeniya for providing laboratory facilities to carry out soil tests at the soils engineering laboratory. Prof. H.M.N. Bandara and Mr.M.V.K. Perera of the Department of Chemistry, University of Peradeniya are thanked for their assistance in X-ray diffraction studies. Dr.Rohan Fernando and Miss Chamindi Wijeratne of the Department of Geology kindly advised and assisted in the preparation of maps. Our thanks are also due to Mr. R. Bomaluwage, Grama Niladhari, Pooliyadda for providing support during the site investigations. Mr.Senarath Amunugama and Ms. Jayanthi Wijesekera of the Department of Geology kindly helped in drafting work. Mr. Rasika Athapaththu is thanked for valuable help during field studies.

REFERENCES

1. P.G.Cooray, The Precambrian of Sri Lanka: historical review Precam. Res., 66' pp.3. 1994
2. D.U. Deer, ,F.D. Patton,. , Slope Stability in Residual Soils, Proceedings of the 4th PanAmerican Conference on Soil Mechanics and Foundation Engineering, SMFE,v.1, pp 871971.
3. Beetham., R.D at el , Landslide development in schist by toe buckling Proc. Of the 6th Int. Sym. On Landslides, Christchurch, New Zealand,1991
4. P. Lumb., *Slope failures in Hong Kong*, Q.Eng. Geol., v.8 pp.311975.
5. Hsai-Yang. Fang, *Introduction to Environmental Geotechnology*, CRC Press BOCA-Raton, New York, 1997, pp 402.
6. G.Muller, , *Methods in Sedimentary Petrology*,1967.
7. Unified Soil Classification System , *American Society for Testing and Materials* (ASTM-D-2487), 1969.