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Study of Stabilization of Unstable Area and Development of Mitigation Measures for Landslide at Peradeniya, due to Widening of Town Roads

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Abstract: This paper investigates the current and future road traffic requirements around Peradeniya town, provides a summary of the detailed study of stability analysis of the adjoining slope area at Peradeniya town and finally a slope area re-shaping design solution is worked-out based on slope stability analysis for the unstable area in the town. The classified traffic movement data and road geometrical data were used to illustrate the present traffic conditions and future traffic requirements for a design period of 20 years. The required carriageway width for each road and the lateral distance towards the slope that requires to be excavated from the centre of the existing road (i.e. land requirement for Colombo-Kandy road widening) was decided based on the outcome of the study. The slope area was analysed with the ground water levels, field and laboratory test data for its stability using Morgenstern-Price finite slope stability method under three different scenarios: firstly, considering actual observations, secondly for an adverse condition, and thirdly for a situation after rearranging the shape of the slope to an angle of 35^0 with controlled ground water table. The results of the study indicate that the road towards Colombo has to be widened up to 25m from the centre of the existing road towards slope area at Peradeniya. The stability of most parts of the area is in critical state and there is a higher percentage of probability for occurrence of landslide hazards during rainy seasons and the results of reshaping the slope area gives a remarkable level of stability.

Keywords: Road Capacity, Service Flow, Level of Service (LOS), Slope Stability.

1. Introduction

Sri Lanka is frequently affected by hydro-meteorological related disasters such as cyclones, floods, landslides, storm surges, droughts, coastal erosion and epidemics. Landslides which are often triggered by intense rain are an increasing problem due to development activities and urbanization. In Sri Lanka, there are major areas in seven districts (Nuwaraeliya, Badulla, Ratnapura, Kegalle, Kandy, Matale and Kalutara) which are prone to landslides. Peradeniya town is one of the main areas facing this landslide or mass movement problem during past few decades.

On 11th November 2006 around 21:00 hours, a mass of soil and rock blocks failed at the upper slope of Peradeniya town due to the heavy rainfall from 09th to 11th November 2006. Due to this failure one shop was completely damaged and few other shops situated at the toe of the slope were partially damaged as a result of the debris that moved down to the Colombo-Kandy road (A01). Subsequently with heavy rains, the same land slide was again re-activated on 14th October 2009, after being quiet for quite some time, since 2006 incident.

As a result of these landslide occurrences, the road stretch from Peradeniya junction to Gannoruwa road junction towards Colombo along A01 road had to be closed for a couple of weeks for vehicular traffic and pedestrian movement, until the immediate threat was eliminated. Unstable rock blocks had been removed from the upper slope by blasting and for further safety, a temporary earth blockade was constructed at the toe of the slope by National Building Research Organization (NBRO) at this location.

In addition, there are some sections along A01 where the road width is narrower compared to the average width of the road, since it is one of the oldest tarred roads in the country.

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One such section is at the Peradeniya town, where one side of the road lies along the embankment of river Mahaweli, and the other side lies along a section constantly subject to active land-slide during rainy season as mentioned before. Subsequently, the road approaching from Gampola (A05) joins A01 at Peradeniya junction, resulting in heavy vehicular movement during daytime bottlenecking the traffic towards Kandy town.

With November 2006 landslide, the disaster management center of the Ministry of Disaster and Human rights along with NBRO conducted a detail investigation to evaluate the level of hazard and to identify the required mitigation measures to reduce the risk from slope instabilities to the Peradeniya town. Moreover, there has been a proposal made by the Road Development Authority (RDA) to widen the A01 road at Peradeniya up-to 25m from the center of the existing road, and the NBRO suggested that the slope area has to be removed towards the slope horizontally and a vertical cut has to be made at the end of this 25m. This will again lead to further destabilise the landslide area and thus, it is essential to apply stability measures to above proposed slope from the point of view of pedestrians, vehicles, the commercial community living in the affected area, property existing at the toe of this landslide, and finally affect the economy of the country.

Therefore, the aim of this study is to identify and recommend long term stability solutions to the unstable landslide area located by the road side of A01 at Peradeniya, considering the future road traffic requirements and proposed road widening.

The major objectives of this project are,

- To determine the adequacy of existing road dimensions for future traffic requirements and also to determine horizontal depth of excavation of soil towards the slope area to accommodate the land for the road carriageway width.

- To find the causative factors behind the landslide at Peradeniya town and to assess the Engineering Geological and Hydro-geological situation as well as the respective behaviour, of the particular landslide area.

- To stabilize the unstable area by taking remedial measures, and as per future traffic and road requirements to come-up with recommendations to communities and regulatory bodies for avoidance of this type of failures in future.

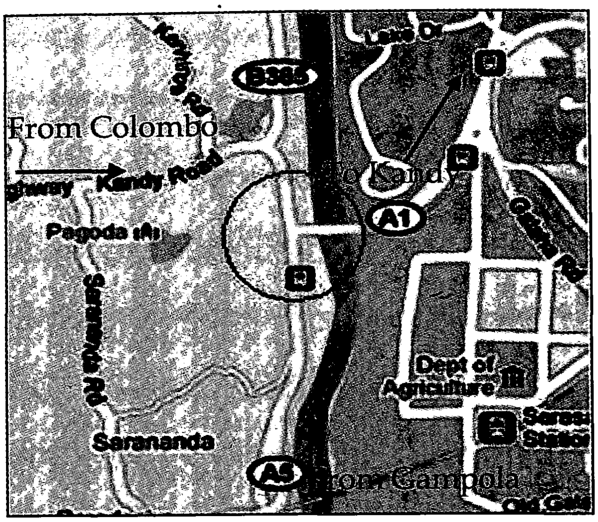

Figure 1 - Location of the Study Area

2. Literature Review

2.1 Highway and Traffic Studies

The highway and traffic engineering studies mostly involve in counting the number of vehicles, which is crossing a selected section of the road per unit time at any suitable selected time duration. These vehicle counts are more or less referred to as traffic volume studies; where there are different types and have to select according to the purpose of highway and traffic study involved. These volumes can be used as a measure of traffic flow, which is to measure, how many vehicles of what type and from which direction have passed a definite section of the road per hour and per day. Comprehensive classification data are difficult to obtain, but manual count methods can be adopted to achieve some reliable data. Classified volume studies are one of the important vehicle counts which is useful for the structural and geometric design of the carriageway and computing road capacity.

2.2 Highway Capacity and Concept of Level of Service

2.2.1 *Highway Capacity*

In general the highway capacity is defined as the maximum number of vehicles per unit of time (i.e. highest hourly volume (HHV)) that can be handled by a particular roadway component under prevailing roadway, traffic, and control conditions [1], [4]. The capacity is defined for prevailing roadway, traffic, and control conditions, which should be reasonably uniform for any section of the road analysed. Any change in prevailing conditions will result in a change in the capacity of the road.

2.2.2 Concept of Level of Service

The concept of level of service (LOS) is defined as a qualitative measure describing operational conditions within a traffic stream, and their perception by motorists and/or passengers [1]. There are six LOS's defined and are given in designations, from A to F, with LOS A representing the best operating conditions and LOS F is the worst.

The LOS is associated with different operating conditions that may occur on a road when it accommodates various traffic volumes. Thus, the six LOS's therefore indicates the condition of traffic in a given traffic volume. The Volume to Capacity (V/C) ratio and the resulting operating speed can determine what LOS is available on a particular road stretch. This is also important in traffic control to enable traffic authorities to institute measures to improve the LOS of a particular road.

2.3 Service Flow Rate

The maximum volume that can be carried at any selected LOS is referred to as the "service volume" for that level. Furthermore, it is the maximum hourly vehicle rate which reasonably could be expected to transverse a point or uniform section of a roadway during a given time period under prevailing roadway, traffic, and control conditions while maintaining a designated LOS. Thus, each road has five service flow rates, one for each LOS A to E. The service flow rate for LOS F is unstable and therefore it is not defined for each road.

2.4 Slope Stability Studies

2.4.1 Causes of Slope Failure

There are many causative factors that can be identified regarding the landslides, such as human activities, natural and geological causes and geodynamic causes. Though, typically a number of causes contribute to a landslide, often there is only one which triggers the movement of slope failure [5], [10]. Following are some of the factors that cause and triggers most slope failures in hilly country in Sri Lanka.

➢ *Human Causes*
- Improper modifications on slopes and slope toe
- Construction activities (cutting, loading of slope at its crest, filling embankments, bunts on soft soils)
- Interference with, or changes to, natural drainage (drawdown of underlying reservoirs or aquifers)
- Mining, quarrying activities and artificial vibration with blasting
- Removal of vegetation and deforestation

➢ *Natural And Geological Causes*
- Weak or sensitive weathered material and weak soil strata
- Sheared, jointed, or fissured material
- Adversely oriented discontinuities (bedding, schistosity, unconformity, fault, contact, and so forth)
- Elevation of pore water pressure by saturation of slope material from either intense or prolonged rainfall and seepage
- Subterranean erosion (solution, piping)
- Undercutting of cliffs and banks by waves or river erosion

➢ *Geodynamic Causes*
- Earthquake vibrations
- Deposition loading slope or its crest
- Freeze-and-thaw weathering
- Shrink-and-swell weathering

2.4.2 Mitigation Methods Adopted For Slope Failures

Landslide mitigation refers to lessen the effect of landslides by constructing and implementing various man made projects artificial or natural at the slopes which are vulnerable to slope failure. Hazards are mitigated mainly through precautionary measures and adopting various direct methods ([5], [10]) of preventing slope failure. Some of the precautionary measures and direct methods are listed below.

Precautionary measures
- Restricting or even removing populations from areas with a history of landslides
- Restricting certain types of land use where slope stability is needed
- Installing early warning systems based on the monitoring of ground conditions such as strain in rocks and soil, slope displacement, and groundwater levels (using seismic wave technology)
- Avoiding constructions on steep slopes and areas prone to landslides
- Directing surface water away from the landslide
- Minimizing surface irrigation

Direct methods

- *Geometric Methods* - in which the geometry of the slope is changed (i.e. by means of reducing the slope angle, Slope height or both together simultaneously).

- *Hydro-geological methods* - in which an attempt is made to lower the groundwater level or to reduce the water content of the material.

- *Chemical and mechanical methods* - in which attempts are made to increase the shear strength of the unstable mass (e.g. grouting rock joints and fissures) or to introduce active external forces (e.g. anchors, rock or ground nailing) or passive structures (e.g. structural walls, piles or reinforced ground) to contrast the destabilizing forces or adding surcharges at slope toe.

2.4.3 *Computer Aid Design of Slope Stability Analysis*

Morgenstern-Price method [3], [9], is one of the most popular limit equilibrium method, since it satisfies both the moment and force equilibrium conditions; side force inclinations can be the same or can vary from slice to slice and assumes that inclinations of side forces follow a prescribed pattern; side force inclinations are calculated in the process of solution so that all conditions of equilibrium are satisfied; involves least numerical difficulties and relates non-circular shape of slip surfaces.

The Morgenstern-Price method in SLOPE/W uses the equation $X = E \lambda f(x)$ to inter-relate the inter-slice shear (X) and normal (E) forces. The function $f(x)$ is not a constant, but can assign different relations within the SLOPE/W [3]. These characters facilitate to arrive at a safer solution that the ordinary slice method is not, where it assumed that for each slice the resultant of the inter slice forces are zero [3].

3. Overview of the Landslide Area

The main causative factors that have been identified by NBRO, in relation to the Peradeniya landslide were; (i) human activities, (ii) hydro-geological setting of the area, and (iii) rapid climatic variations. Among the causative factors that have been identified by NBRO, in relation to the Peradeniya landslide, the rapid climatic variations are what mainly cause the landslide.

3.1 Human Activities

The activities such as construction of buildings and heavy structures where they exert a measurable amount of thrust on instable slope area (at the moment of the landslide there was a transmission tower) and excavation of toe of the slope to facilitate road pedestrians caused very high influence upon the instability of the slope area by-reducing the natural strength of the volumes of earth material. This way of progressive people interaction to the slope area increases the susceptibility of the stability.

3.2 Geological Setting of the Area

Peradeniya is located near the boundaries of Highland complex and Wanni complex and located within the Wanni complex. Apart from that, the area is located in the Eastern limb of one of the arena structures (Double plunging synform - Vithanage - 1972) known as the Gadaladeniya arena. To the East of the Gadaladeniya arena, Udawela antiform and to the West Aranayaka arena are located. Furthermore, the landslide area is located close to a shear zone [7], [8].

This area is rich with remnants of previous occurrences of landslides. Number of small to medium scale old landslide scars and deposits are recognized in the slope area by NBRO. The average inclination of the slope is about 45° in scars of previous landslides and in debris deposits the slope is varying from 20° to 30°[7]. Geologically, fresh-moderately weathered Biotite Gneiss bedrock can be observed at the base of the slope close to the road. In the middle parts of the slope, especially at the scar of recent landslides, moderately-highly weathered bedrock is visible. Structurally, this slope is a scarp slope and rock strata are dipping westerly. The rock beds are trending along the ridge with most prominent two sets of joint systems. Those are,

- 090°/90° 5/m - trend parallel to the slope direction. Rock blocks can be easily separated along these joints.
- 030°/55°NE 4/m - trend along the ridge and the surfaces formed by these joints act as a plane for sliding of rock mass.

The direction of these joint sets are varying place to place , at the toe of the failed mass it was $000^0/40^0$ E and strike of the bed rock, Garnet Biotitic Gneiss was $002^0/ 58^0$ W [7], [9].

According to the stereo-net structural analysis, two joint systems associated with the area were N16°E /38°SE and N89°W /78° SW. The instability is facilitated by these joint systems and weak foliation planes. The latter joint plane of above is the plane which appears mostly like vertical in the area. This plane helps in separating rocks into blocks. The joint plane of former is the plane which could mostly act as a failure plane [7]. Combination of these two joint systems and foliation creates rhomboidal rock blocks in various sizes. Obviously, size of rock blocks depend with the intensity of joints.

3.3 Hydrological Setting of the Area

There is no proper drainage system established in the slope area except the two earth drains, at the right side and the left side of the slide boundary, where left one is about 20m away from the slide area. All water from upper slope lands are coming to the affected area freely. Most of rainwater infiltrates to the ground during rainy seasons due to this poor drainage system exists in the slope area. The springs and seepage is common at the toe of the slope during rainy seasons. This is an indication of subsurface groundwater flows on top of bed rock and along the joint systems exists in the area. Thus, these orthogonally oriented joints are distributed throughout the area forming varying sizes of openings [7], which are filled with clayey material to facilitate and to act as deep infiltration paths to rain water. At the upper part of the ridge, these joints are tight while at the lower part they are more open.

3.4 Rapid Climatic Variation

The area experience heavy rainy as well as dry climate conditions. The rainfall data gives an important indication that this instability was triggered by prolonged high rainfall as each major landslide took place relates to the high rainfall periods. Monthly rainfall analysis for the period of 1967-2009 shows remarkably high monthly rainfall values in October 1977 (638 mm), October 1994 (583 mm) and November 2006 (550.5 mm) where major landslide occurred [7]. Moreover, past data indicates the daily rainfall was more effective than two or three consecutive rainfalls in cause of slope failure and it was seen that, when infiltration and cumulative accumulation of water within the joints and fissures is considered, the time taken to infiltrate to the deeper depth, three days cumulative rainfall may be more involved.

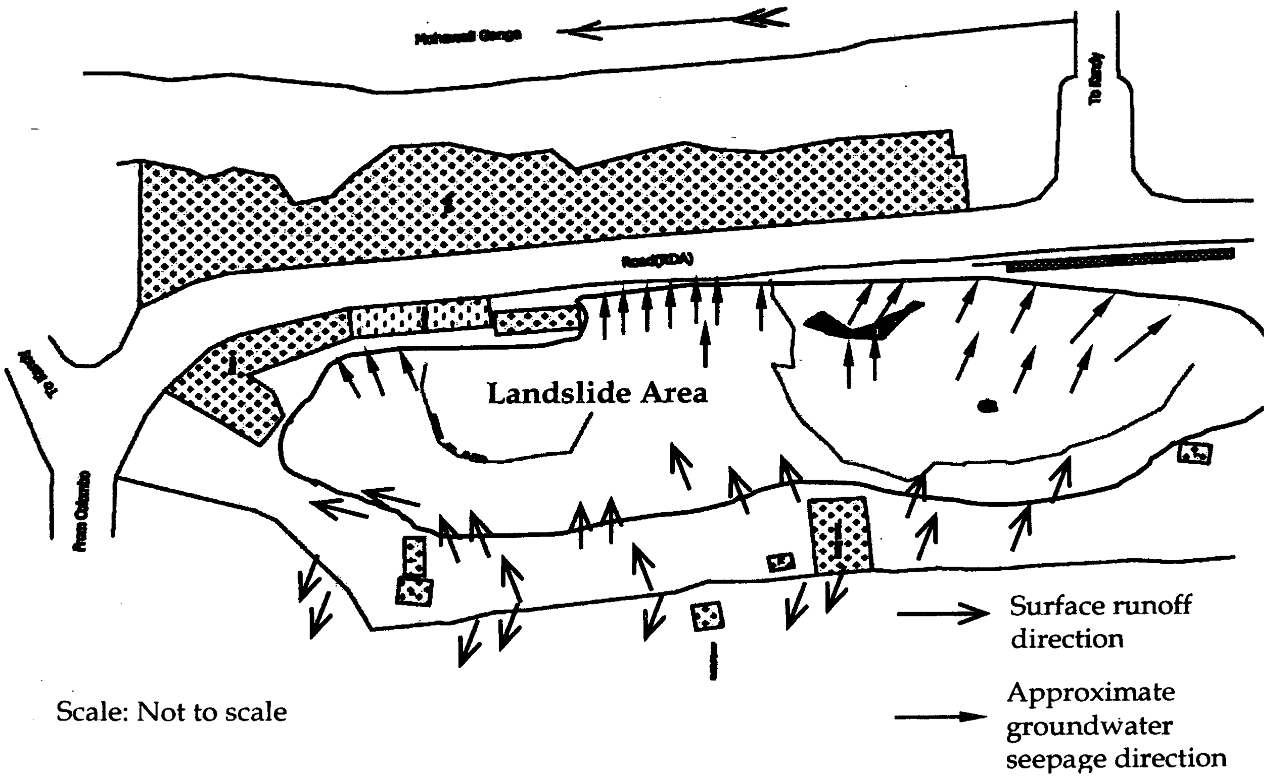

Figure 2 - Approximate hydrological setting of the landslide mass at Peradeniya.

4. Methodology

The following sequential guidelines have been carried out under the methodology.

➢ *Traffic engineering study*

- Study the traffic conditions with the geometric layout of roads during daytime around Peradeniya junction.
- Study the possible peak hours around Peradeniya town using previous average daily traffic counts done by the RDA prior to carrying out traffic volume studies at Peradeniya junction.
- Conduct relevant traffic volume studies (classified turning movement traffic survey) to identify peak turning flows, and the turning movements by different vehicle categories at the junction.
- Analyse traffic volume studies to perform road capacity checks to ensure the adequacy of present road layout against future traffic capacity requirements.
- Present traffic was projected for 20 years and the adequacy of the road was checked for a reasonable LOS.
- Design the new road and traffic layout at the junction to meet the future traffic requirements at end of design period.

➢ *Geotechnical engineering study*

- Study of topographical, geological, hydrological conditions with the help of earlier reports related to the landslide area and investigates other similar landslides along with the mitigatory measures that have been adopted.
- Study and analysis of landslide area for its subsurface hydrological and engineering geological conditions.
- Verify and evaluate the consistency of engineering properties of soil and rock by using the primary hydrological and engineering geological data obtained from laboratory tests.
- Accomplish the slope stability analysis against a Factor of Safety (FOS) of 1.5, with help of computer aided software (AutoCAD and GeoStudio2010) to stabilize the unstable area by feeding the outcome of the traffic engineering study in slope stability analysis.

4.1 Classified Turning Movement Survey

All three roads merging at Peradeniya are presently two-way, two-lane and the junction consists of conflicting movements such as diverging, merging and crossing movements. A classified vehicle turning movement survey was conducted at the junction to identify the peak hours, and to obtain the necessary data in order to check whether the present road layout is sufficient for each leg (i.e. Colombo leg, Kandy leg, and Gampola leg). However, prior to conducting in a turning movement traffic survey at the junction, the possible peak hour ranges for each road leg was identified from the Average Daily Traffic (ADT) data of RDA. These data sequentially helped to identify the necessity of widening and improving of existing roads at the junction.

In classified vehicle counts the vehicles are categorized into separate groups as; passenger cars, motor cycles, buses, trucks, and lorries (small, medium and heavy), three-wheelers, etc. and are counted, each category separately. These classified volume studies are useful for structural and geometric design of the carriageway and computing road capacity. The classified counts were recorded at 15min intervals, starting at 06:00 hrs to 18:00 hrs during a week day, August 2009.

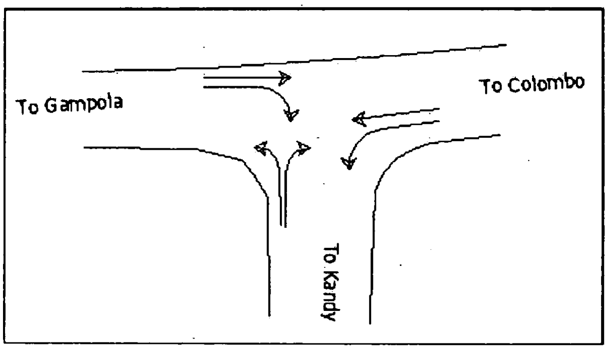

Figure 3 - Turning Movement at Peradeniya junction

4.2 Traffic Volume Forecast and LOS Criteria

4.2.1 *Traffic Volume Forecast*

It is required to determine the future traffic demand at Peradeniya junction and the forecast traffic volumes for the design period of 20 years, was determined in this study by using the present traffic volume data and relevant annual traffic growth rate obtained from RDA. This facilitates to have an overall understanding of how the traffic requirement is going to be at the end of design period. This in turn helps to decide the highway capacity regarding a suitable level of service for the predicting time period. To determine the design traffic volume after 20 years in the future, present peak hour vehicle volume was projected assuming a 4% annual growth rate [6] based on RDA traffic projections on local highways using the equation;

$$\{ \quad P_n = P_0 \times (1 + r/100)^n \quad .... (1) \quad \}$$

P_n = Forecasted peak hour vehicle flow for n years in vph
P_0 = Present peak vehicle hour flow in vph
r = Annual traffic growth rate in percentage
n = Number of years

4.2.2 LOS Criteria

LOS criteria is defined in terms of service capacity for multilane and two lane highways in US highway capacity manual (US HCM), 1985. The LOS of present roads can be evaluated by performing capacity check analysis using the tables and clauses in US HCM, on the basis of above classified traffic counts. The process of determining the present and forecasted LOS for each road leg begins with identifying respective peak hour traffic volume encountered at the junction.

If found that the present road layout is insufficient for present and/or forecasted traffic demand by means of respective LOS for each leg, new geometric design with additional lanes has to be designed to arrive at a meaningful LOS at the end of design period.

4.3 Capacity Analysis

The principal objective of capacity analysis is to estimate the maximum amount of traffic that can be accommodated by a given road section while maintaining prescribed operational qualities. Capacity analysis therefore provides a set of procedures to estimate the traffic-carrying ability of a road over a range of defined operational conditions and improvement of existing road conditions, for planning and design of future road requirement while accomplishing the concept of LOS. The time period used in the capacity analysis is 15-min [1], which is considered to be the shortest interval during which stable flow exists.

4.4 Determination of Shear Strength Parameters of Slip Surface by Back Analysis Method

In order to arrive at a safe stability analysis, it is required to check the reliability of soil strength parameters C' & Φ', obtained from laboratory experiments. The method referred as "Shear Strength determination by back analysis of slope failures [2]" was adopted. The following sequential steps were adopted in back analysis method.

1. Software ArcGIS was used along with the contour maps of the area to develop the existed ground profile at the sliding area as it was before November 2006 and AutoCAD 2010 was used to develop the cross sections of the area that is needed for stability analysis.
2. Fed the shear strength parameters obtained from NBRO (i.e. C'= 10kN/m^2 and Ø'= 29^0) to the SLOPE/W of GeoStudio geotechnical software to analyse the developed section adopting the "Morgenstern and Price method" with pore-water pressures defined as piezo-metric lines with pore pressure ratios and entry and exit methods were used to demarcate the possible slip surface that occur during November 2006 incident.
3. Locate the slip surface to match with the November 2006 slip failure and check the minimum FOS against 1.0 [2].

4.5 Stability Analysis Procedure for Reshaping Slope Area

For the convenience of analysis process the landslide area was divided into 16 land strips of 10m wide, starting from section A and going up to section R, as indicate in the Figure A-1 in Appendix A.

The analytical method adopted to demarcate the possible slip surface was the Morgenstern & Price with pore-water pressures defined as piezometric lines with pore pressure ratios and entry and exit method facilitate in the Slope/W. Groundwater level was modelled for two scenarios. One is as it is observed at the boreholes (dry conditions) and the second was for an adverse condition that can happen in a very high rainfall, like November 2006.

The stability analysis was conducted to determine the minimum FOS under three scenarios as indicated below.

1. Firstly, the existing surface profile (i.e. after November 2006 incident) and the ground water table as observed from the field borehole data (i.e. lay below the bedrock surface) was considered.
2. Secondly, the above mentioned surface profile and the adverse ground water condition that can arise during a very high rainfall like November 2006 where the

water table level is noticeably above bedrock surface were considered.

3. Thirdly, the proposed reshape of slope with a controlled water table in the slope area (i.e. the ground water table will control just on top of the bedrock surface), by means of providing cross drains and stepped drains to remove runoff resulting in less infiltration in the slope area, was considered.

5. Data Analysis, Design and Results

5.1 Identification of Peak Hours and Traffic Volumes

Peak hour indicates the maximum traffic flux, and it is the critical period of traffic operation for a particular road section that is considered. Hence to perform road capacity checks and to conduct other traffic analysis, peak hour traffic flow was considered. It can be easily observed from the classified turning movement survey data that there are 3 peak traffic periods, and the most critical out of the 3 peaks occurs in the morning. It was found that morning peak hour occurs between 7.45am to 8.45am, and is the same for all road legs even though in general peak hour for different legs can differ by few minutes at a junction. Table 1 indicates the 3 peak hours during the day time and the corresponding time interval with the peak hour traffic volumes in number of vehicles.

5.2 Capacity Analysis and Design

The road capacity for the present peak traffic flow and for the projected peak traffic flow was checked against the maximum service flow rate, for each and every road at Peradeniya junction, against each LOS by processing the relevant data as per US HCM, 1985.

5.2.1 *Design of Two-Lane Highways*

A two-lane, two-way highway is a roadway having one lane for use by traffic in each direction. Overtakes of slower vehicles requires the use of the opposing lane where sight distance and gaps in the opposing traffic stream safety permitted. As volume and/ or geometric restrictions increases, the ability to pass decreases. The basic relationships and formulas in designing Two-Lane highways are stipulated in chapter 8 of US HCM - 1985, and followings are some of the important definitions and formula used to carry out the capacity analysis extracted from chapter 8 of USHCM (1985).

$$\left\{\begin{array}{lr}\text{Peak Hour Factor (PHF)} = V/(4 \times V_{15}) & \dots (2)\\ \text{Service Flow Rate (SF)} = V/\text{PHF} & \dots (3)\end{array}\right\}$$

Where,

V_{15} = flow rate for the peak 15-min, total for both directions of flow, in vph;

V = full- hour volume total for both directions of flow, in vph;

The general relationship describing traffic operations in two-lane rural highways, on general terrain segments is as follows,

$$\left\{\begin{array}{lr}SF_i = 2800 \times (v/c)_i \times f_d \times f_w \times f_{HV} & \dots(4)\\ f_{HV} = 1/[1+P_T(E_T-1)+P_B(E_B-1)] & \dots(5)\end{array}\right\}$$

Where,

SF_i = Service flow rate; total service flow rate in both directions for prevailing roadway and traffic conditions LOS_i, in vph

$(v/c)_i$= ratio of flow rate to ideal capacity for LOS_i

f_d = adjustment factor for directional distribution of traffic

f_w = adjustment factor for narrow lanes and restricted shoulder width

f_{HV} = adjustment factor for the presence of heavy vehicles in the traffic stream

P_T = proportion of trucks in the traffic stream, expressed as a decimal;

P_B = proportion of buses in the traffic stream, expressed as a decimal

E_T = coefficient of passenger car equivalent for trucks

E_B = coefficient of passenger car equivalent for buses

Table 1- Identified peak hours in each direction at Peradeniya junction

Peaks	Kandy Leg		Colombo Leg		Gampola Leg	
	Peak Hours	Vehicles	Peak Hours	Vehicles	Peak Hours	Vehicles
Morning	7.45-8.45	1990	07.45-8.45	1275	7.45-8.45	1377
Midday	10.45-11.45	1592	11.00-12.00	1127	11.00-12.00	1194
Evening	16.30-17.30	1716	16.30-17.30	1233	16.45-17.45	1298

5.2.2 *Design of Multilane-Lane Highways*

A multi-lane highway is a road having a carriage width of more than two lanes each direction for traffic manoeuvre.

The basic relationships and formula given in USHCM (1985) under chapter 7 for designing a Multi-Lane highway are below.

$$\left\{\begin{array}{lll} SF_i & = MSF_i \times N \times f_w \times f_{HV} \times f_E \times f_P & \dots (6) \\ MSF_i & = C_j \times (v/c)_i & \dots (7) \\ f_{HV} & = 1/\ [\ 1+ P_T(E_T - 1) + P_B(E_B-1)] & \dots (8) \end{array}\right\}$$

Where:

SF_i = Service flow rate; the maximum flow rate that can be accommodated by the multilane highway segment, in one direction, under prevailing roadway and traffic conditions, while meeting the performance criteria of LOS *i*, in vph;

MSF_i= Maximum service flow rate; the maximum flow which can be accommodated by the multilane highway segment, per lane, under ideal conditions, while meeting the performance criteria of LOS *i*, in pcphpl;

C_j = Capacity per lane for a multilane highway with design speed *j*; 2,000 pcphpl for *j*>100 kmph, 1900 pcphpl for *j*= 80kmph;

N = Number of lanes in one direction;

$(v/c)_i$= maximum volume-to-capacity ratio allowable while maintaining the performance characteristics of LOS *i*;

f_E = adjustment factor for the development environment and type of multilane highway;

f_P =adjustment factor for driver population.

5.2.3 *Design of Colombo Road Segment from Peradeniya Junction*

➢ *Determine the present LOS of Colombo leg from Peradeniya junction for prevailing road and traffic conditions.*

Data Available (as per August 2009):

Terrain condition - Rolling terrain

Lane width	- 3.7m
Average Shoulder width	- 1.2m
Directional split	- 60/40
No passing zones	- 40%
Assume design speed	- 70 km/h
PHF	- 0.94

P_T = 0.08, P_B = 0.14

Both direction peak hour flow - 1275vph

Road condition - Two-lane, Two-way road

Both directional HHV $_{present}$ = 1275/0.94

-- do -- = 1356 ≈ 1360vph

The service flow rates for each LOS,

LOS	C_j	$(v/c)_i$	f_d	f_w	f_{HV}	SF_i
A	2800	0.07	0.94	0.92	0.6579	112
B	2800	0.19	0.94	0.92	0.6039	278
C	2800	0.35	0.94	0.92	0.6039	512
D	2800	0.52	0.94	0.92	0.6305	794
E	2800	0.92	0.94	0.97	0.6305	1481

Both directional HHV $_{present}$ = 1360 vph < 1481 vph. Thus, at present the road is operating at LOS E with (v/c) = 0.92.

This indicates that, there is definite possibility of present capacity exceeding the maximum service flow in near future.

➢ *Design a suburban multilane highway for the Colombo leg from Peradeniya junction to accommodate future traffic demand.*

At the end of design period, 20 years

Terrain condition	- Rolling terrain
Lane width	- 3.7m
Shoulder clearance width	- 2.0m
Center median width	- 1.0m

Design speed - 80km/h, with average of 50km/h

Operating Condition - LOS C with (v/c) = 0.60

Two-sided obstructions include one road side and one median obstruction.

Annual traffic growth rate is 4% [6]

PHF for the design year as 0.90

P_T = 0.10, P_B = 0.10, P_R = 0.00

E_T = 4.0, E_B = 3.0 and E_R = 3.0

The directional HHV $_{present}$ = 785vph

Considering the directional design hour volume (DDHV) rather than the both directional HHV [1]. By forecasting the present traffic flow,

$DDHV_{future}$ = 1720 vph

SF_{future} = $DDHV_{future}/PHF$

= 1720/0.90 = 1911vph ≈ 1910 vph

The number of lanes required after 20 years,

$N = SF\ /\ [C_j \times (v/c)_i \times f_w \times f_{HV} \times f_E \times f_P]$

Where,

$f_{HV} = 1/\ [\ 1+ P_T(E_T - 1) + P_B(E_B -1) + P_R(E_R -1)]$

f_{HV} = 0.67

Thus required number of lanes,

N = 1910/[1900×0.60×0.98×0.67×0.90×1.00]

= 2.84

That is number of lanes per direction is three.

That is number of lanes per direction is three.

- *Determine the future LOS and the SF rate in Colombo road leg from Peradeniya junction for the projected traffic requirements.*

The service flow rates for each LOS,

LOS	C_j	$(v/c)_i$	N	f_w	f_{HV}	f_E	f_P	SF_i
A	1900	-	3	0.98	0.67	0.9	1.0	-
B	1900	0.45	3	0.98	0.67	0.9	1.0	1516
C	1900	0.60	3	0.98	0.67	0.9	1.0	2021
D	1900	0.76	3	0.98	0.67	0.9	1.0	2560
E	1900	1.00	3	0.98	0.67	0.9	1.0	3368

SF_{future} = 1910 vph < 2021 vph.

Thus, the Colombo road leg requires six-lanes, two-way road to operate at LOS C, with (v/c) = 0.57 at the end of design period and new proposed traffic layout is present in Figure A-2 in Appendix A.

5.2.4 *Design of Kandy Road and Gampola road Segment from Peradeniya Junction*

It is possible to demonstrate the LOS at present and future traffic requirements, for the Kandy road leg and Gampola road leg by performing similar calculations as above for the prevailing and required road geometric and traffic conditions.

Under the present traffic and geometric conditions that the Kandy road leg functions at LOS D with (v/c) = 0.72 and once the traffic projects the road leg functions at LOS F for the prevailing road conditions. Thus, the Kandy road leg required a six-lanes, two-way road at the end of design period to operate at LOS D, with (v/c) = 0.70 to cater the traffic requirements after 20 years time and the new proposed traffic layout is present in Figure A-3 in Appendix A.

Simultaneously, the Gampola leg also operates at LOS E with (v/c) = 0.66 for the present traffic requirements. The Gampola road leg requires Four-lanes, two-way road to operate at LOS C, with (v/c) = 0.62 at the end of design period and new proposed traffic layout is present in Figure A-4 in Appendix A.

5.3 Design Procedure for Reshaping Slope Area and Its Stability Analysis

The horizontal distance that required excavating slope area is 22.2m for the proposed road from the existing road centre. In contrast to the proposal made by RDA, the proposed horizontal distance to the vertical cut that has to be made in sloping area is 25 m from the existing road centre. Therefore, the slope stability analysis carried out based on the proposed distance made by the RDA, which is a vertical cut has to be made at the end of 25 m from the existing road centre.

The results of stability analysis govern by back analysis method indicate that the shear strength parameters (C' = 10 kN/m^2 and Φ' = 29^o) determined by laboratory experiments were fairly acceptable. Simultaneously the analysis indicates, the November 2006 failure slip surface yields a unit FOS with ground water level just about 2.0m above the existing bedrock surface which relate with the adverse weather condition.

5.3.1 *Determine the FOS of surface profile after November 2006 landslide for dry weather condition.*

The stability analysis carried out based on data obtained from boreholes, DCP tests, and test pits. For the stability analysis the ground water table of the effective slope area was modelled according to the borehole data by NBRO; and the ground water levels were interpolated and extrapolated within the effective periphery. Results of this stability analysis interpret a FOS for a dry weather condition.

5.3.2 *Determine the FOS of surface profile after November 2006 landslide for adverse weather conditions*

Adverse weather condition represent the heavy prolonged precipitation periods for the slope area. Seeping of sub surface water from rock and soil strata interface can be well experienced during and after heavy precipitation and indicates that the ground water table is above the bedrock and the air voids in soil mass are mostly filled with infiltrate water particles causing to reduce the shear strength of the soil by developing pore water pressure within soil mass. The ground water table considered in determining the FOS of the slope area for the adverse weather condition was 2.0m above from the existing bedrock, which was evident from back analysis carried out for the slope area.

5.3.3 *Determine the FOS of proposed reshaped slope under controlled water table in the slope area*

It was apparent that the slope area has to improve to a greater stability for the adverse weather conditions. Thus, the stability of the area can be improved by reducing the driving forces that causes the land slide. This can be accomplished by reducing the overburden soil mass that is unstable along with the tension cracks. The reduction of overburden soil mass was achieved by addressing a reshaping profile in step wise manner having a certain slope angle from the horizontal to the sliding mass. Finally the reshaped slope was checked for its stability, against a FOS of 1.5 to overcome the adverse situation.

The proposed reshape of slope consists of three steps with intermediate horizontal landings of 5m wide and this proposed shape follows a certain pattern as indicate in Figure A-5 in Appendix A. That is every landing area is followed by a slope having a lower slope angle than original ground profile forming a three-step slope. Therefore by any chance, if the slope is to fail, then failure takes place in these steps individually or as a combination of two or three steps. Since these steps are now individual and separate from one another the failure of one step would make no contribution to the failure of next step, whereas original profile would collapse at once. Thus, the design of reshaping slope area involved six stability checks as;

i. Stability check for only step I alone
ii. Stability check for only step II alone
iii. Stability check for only step III alone
iv. Stability check for only steps I and II alone
v. Stability check for only steps II and III alone
vi. Stability check for all steps as one slope

Table A-1 and Figure A-1 in Appendix A. illustrate the results of stability analysis, and accordingly it is clear that there is greater possibility to initiate landslides in the slope area during rainy seasons.

6. Conclusions and Recommendations

6.1 Traffic study

- At present with a single lane either direction on Colombo and Gampola legs are operate at LOS E with (v/c) = 0.92 and (v/c) = 0.66 respectively in peak hours while, with 2 lanes either direction on Kandy leg operates at LOS D with (v/c) = 0.72 during peak flows.

- This indicates that with present road widths for all legs, the present road capacity in near future will exceed. This will create to a problem of queuing of traffic most of the day time at this junction if no remedial measures are taken. Therefore, it is advantageous to improve the existing road by means of widening the carriageway, to cater to future traffic flow demand.

- By increasing the number of lanes in single direction to 2 in Gampola road leg and 3 in Colombo road leg will result in improve in operating condition to LOS C with (v/c_i) = 0.62 and (v/c_i) = 0.57 respectively in road legs in the design year.

- Despite the fact that the Kandy leg operates LOS D at present, once the traffic is projected for the future, and if the number of single directional lanes are increased to 3, the results indicate that the Kandy leg will be operates at LOS D with (v/c_i) = 0.70 during peak hours in the design year.

- Thus, to reduce the traffic conjunction in Kandy leg during peak hours, implementing an alternative road system is ideal. There is a possibility of diverting the traffic flow through Gannoruwa road from Gannoruwa junction and Gatembe junction.

- At present, the colonial bridge across Mahaweli River at Peradeniya facilitates only single lane on either direction for the traffic movement result in bottlenecking the traffic at the junction during day time.

- Therefore to cater and avoid bottlenecking of future traffic flow at the junction during day time, the existing bridge has to improve by means of widening its carriageway width to six-lane, two-way or a new bridge has to construct over the river having six-lane, two-way carriageway.

- Provision of a roundabout or a signalized intersection in the design year will minimize the cause of interruption to the traffic movements at this intersection since it will be multilane highways (A01 and A05) joins at this junction.

- As per road design analysis, the depth required to excavate towards the slope area is 25m from the existing road center. This is to reserve land area for future road expansion in Colombo leg.

6.2 Stability study

- The previous disturbances (in 2006 and 2009) which have occurred in this area are especially due to the prolonged heavy rains together with the instability of the geological structure. The geological, Structural maps and the past data of the area reveal that a shear zone passes close to this area and field results indicate that the rock layers underneath soil over burden had been weathered to varying degrees.

- There are two sets of joint systems established in these weathered rock layers and these joint systems allow storm water to infiltrate as much as possible through them and the infiltration increases with the help of top surface lining, of small bushes and grass.

- It has been observed during the field survey that there is a separate weathered soil strip lining (enriched with silica and mica) in between the weathered rock blocks formed as a result of the joint system. During the rainy seasons the water seeps easily through these silica and mica linings while weakening the shear strengths of the adjacent rock blocks and weathered soil. This leads to form landslides in this area.

- There is no proper drainage system in the slope and at crest area, which cause the surface water to seep into the affected area freely while saturating most of the sliding part. Therefore a proper drainage system has to be established in order to minimize the infiltration in the sliding area.

- Horizontal drilling and installation of lateral drains will reduce the possible pore water pressure development and reduce the groundwater level, especially during the rainy period. Even in normal rainy days, seepage water can be observed at the interface of fresh bedrock and loosen, weathered rock strata. That has to be minimized by introducing good horizontal drainage system of weep holes.

- It is obvious from the results of re-shaped slope, that a remarkable level of stability where ground slope is less, and also the overburden becomes thin after the proposed cut. This is same as the result of the natural stabilization process known as 'denudation processes', where the slope area transforms to natural stability with time by erosion and landslides during the rainy sessions.

- Therefore, without any other expensive measures, by cutting and smoothening the slope, stability of the area can be improved. Therefore, the most suitable remedial measure for the area at present condition was re-shaping the slope to improve the stability of the area.

- In the case of improving the stability, much attention is required to maintain the slope and to minimize the infiltration to avoid initiating any small scale failures. To minimize rain water infiltrating, most of the rain water has to collect as runoff from the area and should direct out of the area. Thus, provision of gullies and proper storm water management is important.

- Excavation of slopes for road reservation may involve the blasting of bed rock, and usual blasting techniques cannot be recommended. Hence, special techniques like, chemical blasting can be applied. If the requirement is essential then other re-enforcement measures may be required to ensure the safety of slope when it is excavated.

- Lower slope below the road has to be well maintained to prevent possible river erosion and small scale failures. The existing buildings seem to be not constructed according to good engineered designs. Therefore, all haphazard construction (buildings) at the river side, just close to the road need to be removed and/or constructed with the guidance of Geotechnical engineers.

- The re-shaped slopes should be well managed by planting deep rooted grass and without disturbing the slope (adopting Bioengineering techniques of slope stabilization). Horizontal drilling and installation of lateral drains are required as the measure applied to reduce the possible pore water pressure development and reduce the groundwater level, especially during the rainy period.

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Appendix A

Table A-1 - Results of Stability Analysis of the Peradeniya landslide area

Section	Factor of Safety (FOS)			Remarks
	Dry weather condition	An adverse condition	Rearrangement profile of slope	
A	1.230	1.050	1.570	This profile does not show instability in a worst condition too.
B	1.284	1.043	1.513	The area is already subsided by a previous landslide. In an adverse situation, highly possible to fail.
C	1.093	0.964	1.508	Unstable in an adverse situation.
D	1.093	0.998	1.503	Unstable in an adverse situation
E	1.605	0.996	1.525	Unstable in an adverse situation
F	1.605	0.984	1.507	Unstable in an adverse situation
G	1.026	0.860	1.507	Unstable in an adverse situation
H	0.883	0.778	1.507	It is possible to initiate instabilities in this area during rainy seasons. Urgent attention is required as it is the most vulnerable area in the sliding mass.
I	0.948	0.878	1.508	
J	1.081	0.987	1.502	
K	1.066	0.997	1.509	
L	1.502	0.971	1.508	
M	0.975	0.873	1.536	
N	0.912	0.846	1.503	
O	0.927	0.818	1.500	
P	1.002	0.924	1.508	
Q	1.200	1.013	1.554	
R	Not considered due to slope is in to a different direction and stability is good in that direction. Possible failures may not into considered direction.			

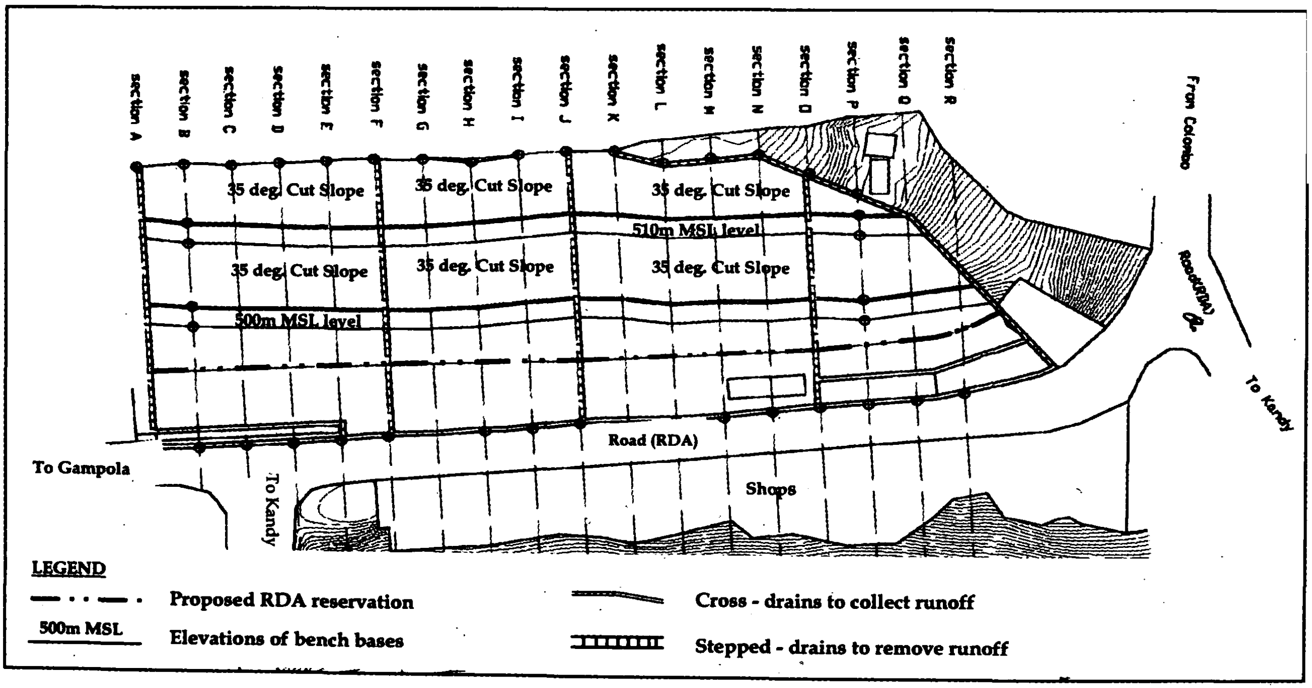

Figure A-1 - Proposed re-arrangement of slope at Peradeniya town

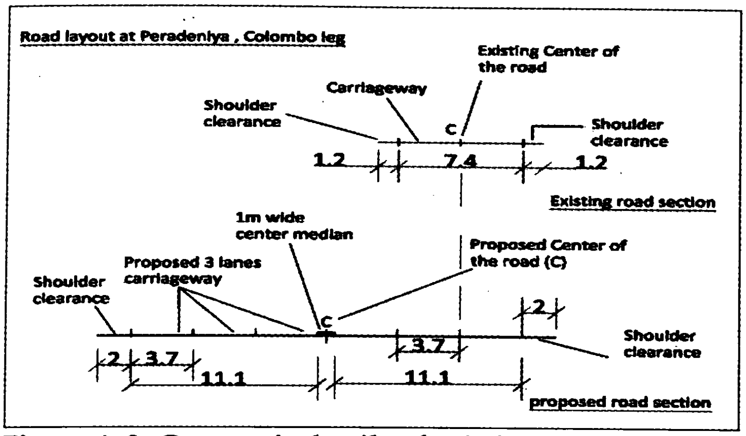

Figure A-2- Geometric details of existing and proposed road sections for Colombo leg

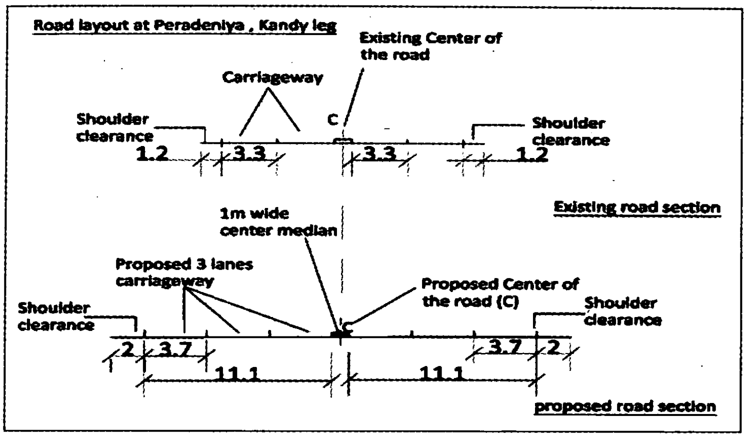

Figure A-3- Geometric details of existing and proposed road sections for Kandy leg

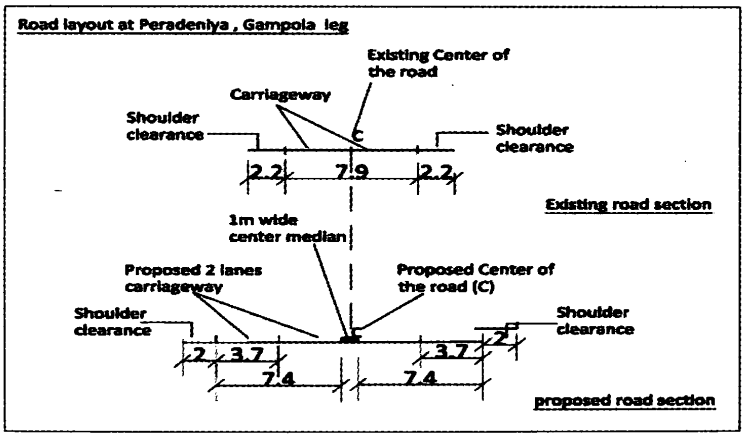

Figure A-4- Geometric details of existing and proposed road sections for Gampola leg

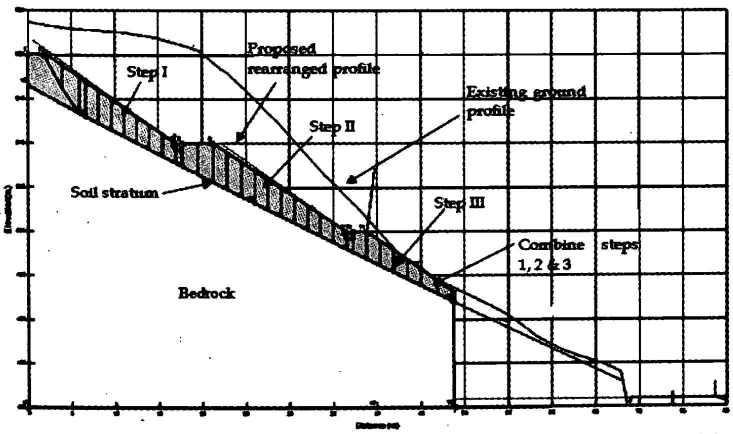

Figure A-5 - Reshaping steps of slope area considered in stability analysis.