Geological Considerations in Finalising Port Louis-Moka Link Road Alignment, Mauritius

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Abstract

Geological investigations have been carried out by the author, with a view to selecting the most viable, and shorter route for Port Louis-Moka link road alignment in Mauritius. There were several alternative proposals put forward by the Project authorities, however, the author proposed an entirely new alignment, taking into consideration the geological and physiographic set-up, environment friendly conditions and nearly 50% shorter distance. This paper gives a detailed account of the regional geology, geology and geomorphology of the project area and tectonics. Various problems, which are likely to be encountered in executing the project, have been highlighted and remedial measures have been suggested. On the basis of field and laboratory test data, the author has attempted to classify the rock mass and predict the likely rock loads inside the proposed tunnel along the road alignment for designing suitable support system.

Introduction

Port Louis-Moka link road project, Mauritius, aims at relieving congestion on Highway M1 by diverting some traffic from Plaine Wilhems, Moka and further east to Port Louis or vice-versa through an alternative link route via Moka range of mountains. This would provide a direct link and also reduce the distance and travel time. At present the traffic from east has to take a longer route to Port Louis from Moka via M1, which is about 14 km.

Initially, there were several alternative proposals. On the basis of geological studies carried out by the author along various alternative road alignments, the best choice was considered through Moka saddle, Les Guibies valley, Goat-Rock - Spear Grass hill range and Pouce valley (Fig.1). This route would provide a direct and short link between Port Louis and Moka, bypassing the urban settlements. Even in this choice, the author suggested two alternatives. The first one without any tunnel, i.e., through the surface road only and the second one through a half km long tunnel in the Goat Rock area connecting the Les Guibies and Pouce valleys. However, in view of steep gradients and sharp curves, as well as longer route in negotiating the Spear Grass peak through a surface road, the second alternative, i.e., negotiating it through a tunnel was preferred.

Later on, at the instance of Govt. of Mauritius, feasibility studies were also carried out for two more projects *viz.* (a) New road alignment from Grewal Junction on M1 to the proposed Port Louis-Moka link road bypassing the township of Pailles and Camp Chapelon, and (b) Volcy Pougnet to Quarry D round about, a section of the proposed Port Louis Ring Road.

Since these projects are to be properly integrated and harmonised, to get full benefit for the rapid traffic movement, it became imperative to modify and change the proposed road and tunnel alignment. In

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the proposal, the length of the road from the start point to the end point is only 6.8 km., which means reduction in road length by about 50%. However, in the new proposal there are two tunnels. The first tunnel would be nearly 280m long in the Moka saddle and the second about 700m long in the Quion Bluff area.

Geomorphology of the Project Area

The project area is represented by hilly terrain rising from El 100m in the north (Port Louis end) and El 360m in the south (Moka end) to 760m high Le Pouce Peak, and bounded by fairly plain country towards north and south. There are three main ridges:

i) The Junction Peak-Guiby Peak running almost E-W.

ii) The Quoin Bluff-Goat Rock-Snail Rock peaks running NW-SE.

iii) The Priests Peak-Le Pouce Peak running almost N-S.

In between the junction peak and Quoin Bluff-Snail Rock peaks lies the Leas Guibies Valley, which is drained by St. Louis stream in the west and another stream in the east. In between the Quoin Bluff-Snail Rock-Le Pouce lies the densely forested Pouce Valley, which is drained by Pouce stream.

Palaeo-Glaciation

There are three distinct phases of glaciation in Mauritius:

i) Mindel Glaciation, which happens to be the oldest glacial episode, occurred between 0.7 and 0.5 million years ago.

ii) Riss Glaciation occurred between 0.3 and 0.25 million years ago.

iii) Wurm Glaciation took place around 0.1 million years ago.

The different phases of glaciation were accompanied by worldwide sea level changes. There is strong probability that the intermittent and intervening volcanic activity has buried the parts of older reefs and beaches under later lava flows.

Regional Geology

Mauritius has been described as "a bowl with chipped rims (the old volcanoes) filled with piles of young formations, the excess of which flowed away outside the rim. The Central Plateau constitutes the inside (Fig. 1) of the bowl and the plains are the margins formed by the late Pleistocene lava flows. The positive relief is provided by the rim of the bowl, which protrudes above the sea of younger volcanoes. The heterogeneity in the percentage of volcanic flows has resulted in the heterogeneity of rock mass. In general, the Old lava is more impervious than younger lava.

Barring some coral reefs, raised beaches and terraces, Mauritius entirely owes its origin to two distinct phases of volcanic activity, the Old period (10-5 million years) and Recent period (3.5 million years to 25,000 years). The principal rock types are basaltic lavas, agglomerates, dykes and volcanic ash deposits, generally under cover of semi-pervious brown soil (low land humid soil) or coarse gritty soil. There are two main volcanic formations constituting the island. (1) The Older Volcanic Series of Late Tertiary Period. During this period, a huge volcanic dome was formed over a period of 5 million years. The dome collapsed with the formation of a large crater in the centre, followed by a long period of quiescence. Volcanic activity was resumed with the pouring out of the early formations of the Younger Volcanic Series in Late Pliocene (3 million years) period, followed again by a period of quiescence. The late volcanic activity was resumed in Late Pleistocene (0.5 million years) with emission of late formation of the Younger Series. This lava flooded and blanketed the depression of the old topography.

The sequence of lava flows and the principal rock types are given in the table below.

Older Volcanic Series

The old lavas mainly comprise basaltic lava flows and pyroclastic intra-flow sequences that can be classified as agglomerates. The individual lava flows are massive and homogenous ranging from 2 to 20m in thickness. The intervening pyroclastic horizons are quite often of similar thickness, though generally subordinate to the flow lavas. The pyroclastic rocks are extremely altered, chiefly chloritic material and zeolites, but a few xenocrysts of olivine and augite can be recognised. There is, however, no sign of ultra basic inclusion and injection. Although, alteration is commonly associated with weathering and weakening of rock mass, but, it does not apply to the Mauritius agglomerates, which are generally competent. Maximum thickness of old lavas may be about 400m. The intrusive lavas comprise mainly fine-grained, dark grey, olivine basalt with subordinate varieties of other related rock types. Dykes of olivine basalt are common and trachyte domes are also present. The old lavas, probably originated from a single major source, hence they have overall consistency and are massive in nature. In spite of extensive degree of erosion, they are more competent, dense and resistant to weathering.

Younger Volcanic Series

The Younger Volcanic Series can further be sub-divided into early, intermediate and late lavas. The early lavas are composed of fine-grained, alkali olivine basalt, massive to somewhat vesicular, 3-10m thick flows in a stratified sequence with basalt agglomerates.

The intermediate and late lavas cover nearly 70% of the land area in comparison to earlier volcanism of limited volume (Fig. 2). They comprise whole series of flows from about 1-8m in thickness of highly vesicular basalt, often with coarse grained, doloritic texture. The younger lavas, because of their extrusive nature are much more variable and have a tendency to weather more quickly. It may also be mentioned that the rock types in Mauritius are geologically young, belonging to Late Tertiary (Pliocene) and Quaternary (Pleistocene) periods. The youngest lava flows probably occurred within the last 100,000 years.

Raised Reefs, Beaches and Old Dunes	
Late Lavas – Earlier Flows Late Lavas – Main Flows Late Lavas – Recent Flows	Younger Volcanic Series (Pleistocene)
Intermediate Lavas	
Basic Dykes Trachyte Domes Volcanic Vents	Intrusive into Older Volcanic Series
Early Lavas	Younger Volcanic Series (Pliocene)
Old Lavas	Older Volcanic Series (Late Tertiary)

Dykes and Intrusives

Dykes of hard, black olivine basalt are seen as intrusives in the old lavas, as observed in the Le Pouce peak.

Geology of the Project Area

The foot hill zone and plains in the low lying areas around Port Louis are comprised of brown lateritic silty clays with occasional gravel, pebble or boulders of lava and dark brown expansive clays containing high percentage of montmorillonite. These clays are highly compressible and correspond to soft cohesive material. However, because of its expansive properties, it should be considered as “very soft” for preliminary design purposes.

The hill slopes are generally comprised of colluvial soils, which are a mixture of residual clays derived from Old, as well as, Young Volcanic Series, together with various lava fragments ranging in size from sand to boulders. The laboratory tests conducted on these soils reveal that it corresponds to stiff and very stiff cohesive material or loose granular material.

Lithology

The higher reaches of the mountain and escarpments are comprised of basaltic lavas of Older Volcanic Series. At places it has varying degree of weathering and thin cover of residual soil. Vesicular Intermediate Lavas of Younger Volcanic Series are exposed at some places on the lower reaches of the slope and plains. The blue basaltic lava can be classified as extremely strong and competent.

Around Port Louis area, the basalt lavas and associated flows are essentially comprised of a single massif of identical rock types extending from ocean depth to the mountain peaks irrespective of elevation and flow position. The lava flows and agglomerates are, in general, competent rocks with significant geochemical stability. Pyroclastic tuffaceous horizons are also present along with the alternate sequence of basalt lava and agglomerates (Pyroclastic flows).

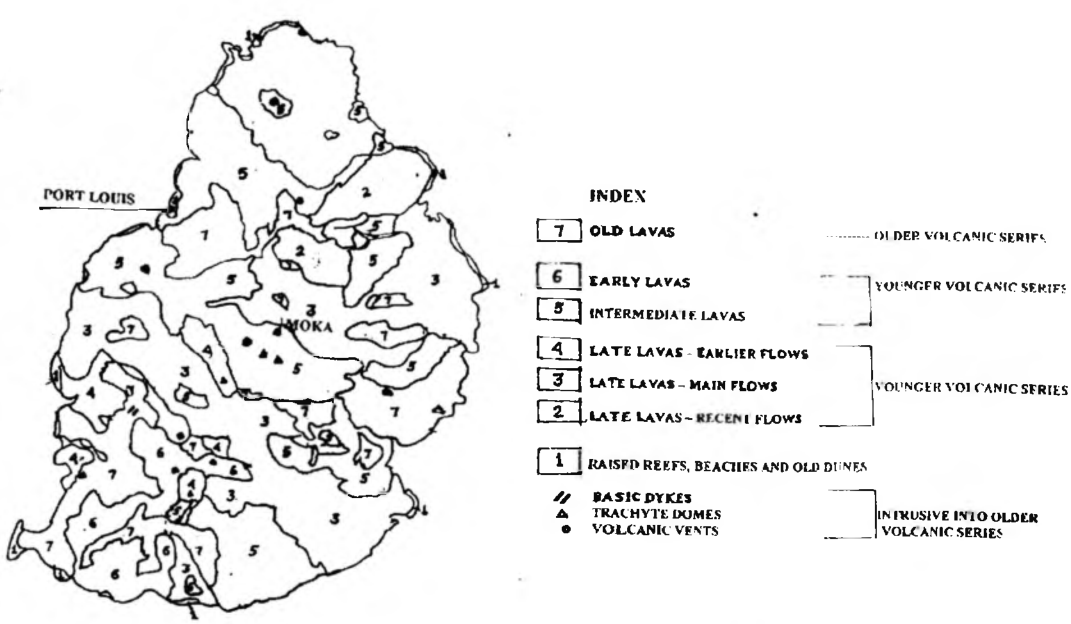

Fig.3 GEOLOGICAL MAP OF MAURITIUS
(source: CWA Hydrology Year Book 1987-91)

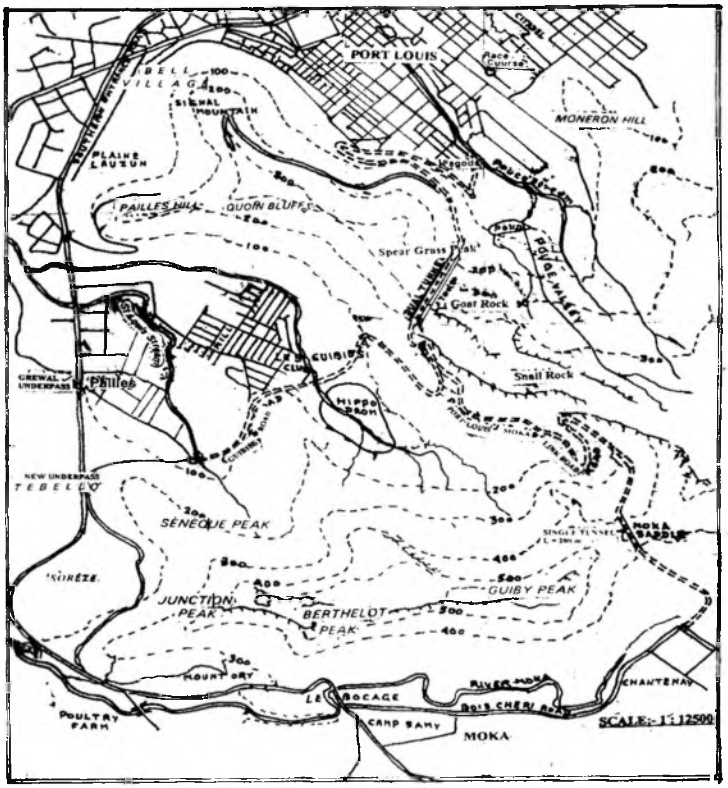

Fig. 2 PLAN SHOWING NEWLY PROPOSED PORT LOUIS-MOKA LINK ROAD & GHIBIES ROAD, MAURITIUS

Basalt is uniformly fine grained, with conchoidal or platy fracture. Development of aragonite, beautifully crystallized zeolites is most conspicuous. The basalt flows sometimes show flow banding that has given rise to incipient shear joints that can become well developed on weathering as observed in Snail Rock cliff. Other flows generally exhibit poorly developed cooling joints, which are typically arcuate in nature and contain dark purple mineralisation. These joints may be incipient at depth.

Most of the tuffaceous interbeds are weathered to some degree. The flow contacts appear to be generally irregular and do not form prominent discrete weakness within the flow sequence. On some contacts there is evidence of red discoloration at the top of basalt flow extrusion. Such weathering or alteration is not persistent. Intercalations of 100-200 mm thick tuffaceous material, often yellow-orange, banded and weathered are present at few major flow contacts in the exposures. However, thicker lenses could be expected locally. The seaward dipping flows can be considered radially uniform and continuous over several kms. The apparent dip of the flows varies from 10° to 15° in the north-westerly direction i.e., towards the sea.

Geo-mechanical Properties

The laboratory tests conducted on rock samples indicated that basalts have a significantly higher ultrasonic velocity (5873.13m/second) than the agglomerates (3970.97m/second). The moisture content in the rock samples tested indicated that basalts contain much less water than agglomerates. It appears that there is direct relationship between the moisture content and ultrasonic velocity of the rocks. Similarly rock samples with higher dry density have higher ultrasonic velocity.

The results of uniaxial compression tests indicate that basalts are significantly stronger (average strength 151.06 Mpa) than the agglomerates. The strength of agglomerate is comparatively low and highly variable (27.00 to 35.67 Mpa). This is, also reflected by their lower ultrasonic velocities and higher moisture content.

The field and laboratory studies clearly indicate that the agglomerates are highly altered, showing extensive iron oxide staining. The presence of weathered olivine and calcite in most of the agglomerates may pose durability problem in concrete or as road aggregate.

The basalts are very fine grained, sometimes containing vesicles and sometimes without vesicles possibly indicate different positions in the flows. Olivine may be weathered and calcite veins are generally present. The basalts are essentially composed of plagioclase feldspars, pyroxene, olivine and opaque (iron oxide) minerals. The chemical composition of basalts shows that SiO_2 is the main constituent of basalt < 50%. Basalts contain reactive silica, which can react with alkalis (Na, K, OH) in the presence of high moisture and suitable temperature to cause expansion in concrete, which lead to development of cracks on its surface in due course of time. It is imperative to test suitability of basalt as aggregate in concrete mix, well in advance.

Tectonics

Mauritius is located in the southern part of Mascareignes plateau, an area of "Oceanic type" basalt. It lies on a kind of SW-NE trending, horst midway between the mid-oceanic ridge east of Indian Ocean and Madagascar to the west. It is bounded by Mauritius trench towards east and by a depression separating it from the Reunion area towards west. These depressions appear to end against Rodrigues fracture zone, which cuts them eastwards across the mid oceanic ridge.

According to UNDP report, depth of oceanic floor exceeds 3600m to the west and east of the island and even exceeds 4000m (incidentally, the largest depth found in Mauritius trench, which is still subsiding is $\pm$2 km), towards SW it is $\pm$5 km, and to the east, the shelf width varies from 3 to 11 km. The eastern shelf is widest near Grand Port Mountain range.

Seismicity

Earthquakes of low magnitude have occurred a number of times in Mauritius. The first one on record was on the night of 3-4th August 1786. An earthquake occurring on 6th January 1863, even damaged a masonry house at Pample Mousses. On the 26th July 1925, earth tremors were felt between Port Louis and Beau Basin. More recently, on 13th February 1992, an earthquake of magnitude 3.5 on the Richter Scale occurred in the early hours in the Reunion. The earth tremors were also felt in Mauritius on the same day, and also about the same time in various parts such as Camp de Masque, Plaine Verte, between Port Louis and Beau Basin and Mare Gravier.

Identification of Geological Problems along the Road Alignment

Various problems occurring along the road alignments during their construction can be apprehended by examining the geological condition and study of soil/rock mechanical properties.

Some of the geological factors, which play important role in deciding the choice of road alignment in the hilly areas and need due consideration include; nature of rock and their attitude (dip, strike etc.), presence of competent and incompetent layers in the rock sequence, lineaments of structural weakness, folds, faults, joint spacing and their orientation etc.

In an ideal situation problem zones should be avoided, opting for geologically better alternatives. Dips of the formation should face away from the proposed alignment. If this is unavoidable, proper cut slopes in accordance with the rock mass characteristics should be made on the hillside. In stretches with problematic formations a careful study of soil mechanics and rock mechanics properties like cohesion 'c', Angle of internal friction 'ϕ' swelling properties of clay, moisture content, plasticity index of shales and clayey soils etc. should be determined. Road alignment over fissile or fragile rocks should be avoided by changing the levels on the hill slopes. Sometimes, such measures make matters simpler and more stable. As such a lot of terrain and geological evaluation/ studies are needed for aligning the roads, right from the planning stage. An analysis of the relevant toposheets and aerial photo interpretation can lay the foundation for an optimum alignment, followed by micro-level studies during field investigations.

If it emerges that certain problematic bad patches are unavoidable during conceptual stage of alignment as in case of the proposed Port-Louis-Moka Link Road, where certain stretches (chainages 2100 to 3500 m) need to be carefully investigated by detailed geological mapping.

Slope Stability Problems

The causes of instability of road sections are numerous. Some are natural causes, such as presence of fragile and crumbling rock formations, existence of adversely oriented discontinuities etc., exposed by the road construction activity, presence of thrusts and faults, formations with incompetent layers/strata facing the road section, spring emergence zones, uncontrolled surface run-off over the cliff face, toe cutting by stream and rivers in the foot hill area, earthquakes etc., while others are induced by biotic interference.

Among human factors, apart from the effect of road construction in geologically bad patches, the following are some situations endangering road stability/ maintenance and they should be avoided.

i) Badland use in urban areas, with land-sliding due to overload on slopes above the road section.

ii) Improper drainage in urban areas with roads receiving the effluents and washes besides monsoon run-off.

iii) Extensive deforestation near the road section.

iv) Shifting (*Jhum*) cultivation is another serious triggering factor for landslides and debris falls on roads in some hilly areas.

v) Proximity of urban settlement to road cliff sections is often tampered with for water, soil and building material.

vi) Unplanned quarries along the road are amongst the most damaging human factors.

The proposed 6.8 km long (from start point to the end point) Port Louis- Moka Link Road takes off from Roselyn Cottage (elev. 370m) in the SE and passes through the open field having sugar-cane cultivation up to the foot hill of Moka saddle, before entering into the 2800m long Moka tunnel (elev. 360m). This area comprises mostly of red brown lateritic silty clays with occasional gravel, pebble or boulders of lava and dark brown expansive clays containing high percentage of mont-morillonite.

The clay is highly compressible and has high to very high plasticity (liquid limit exceeding 100% and PI values well over 50%). CBR values vary from 3% (average in-situ value) to an average soaked laboratory value of 1% at 95% compaction. From the extrapolation of 'N' values from the DCP tests and average in-situ value of 'N'=4 under saturation can be assumed which corresponds to a 'soft' cohesive material. However, because of its expansive properties it should be considered as very soft for preliminary design purposes.

After negotiating the Moka saddle through a tunnel, the road is mostly aligned along the lower reaches of hill slopes between elev. 350m and 90m upto Quoin Bluff tunnel, in Les Guibies Valley. This area in general is comprised of colluvial soil, which is a mixture of residual clays derived from Old as well as, Young Volcanic Series, together with various lava fragments ranging from sand to boulders in size. These soils have been defined as lava rock fragments in a matrix of clay. The compaction tests gave maximum dry density of 1.92 to 1.445 gm/cu cm at OMC of 15% to 25%. The *in situ* CBR values range between 5% and 15% with soaked laboratory values between 1% and 4%. From the extrapolation of 'N' values from DCP tests, values ranging between 'N'=10 and 'N'=20 have been estimated which correspond to stiff and very stiff cohesive material or medium dense to dense granular material. However, under saturated conditions these values should be halved, indicating either firm cohesive material or loose granular material.

The higher reaches of the mountain and escarpments are comprised of basaltic lavas of Older Volcanic Series. At places it has varying degree of weathering and thin residual soil cover. Exposures of more vesicular Intermediate Lavas of the Younger Volcanic Series can be observed at some places on the lower reaches of the slopes and plains.

Some of the more coloured and weathered lavas do not exhibit very good compaction properties. One soaked sample in the laboratory gave a CBR value of 10%. However, the *in situ* CBR values from the DCP tests all tended to be well over 10%. From extrapolation of 'N' values from DCP tests, value>15 can be estimated, for more weathered lavas, which indicate either stiff to hard cohesive material or medium dense to dense granular material.

The blue basaltic lava can be classified as extremely strong and competent with strengths < 200 MN/sq m. The cohesive strength, bearing capacity and design CBR values of different types of materials are given in Table-1.

Table-1 Cohesive strength, bearing capacity and design CBR values

Soil/ Rock type	Cohesive strength KN/sq m	Bearing capacity KN/sq m	Design CBR Values %
Red brown silty clays	40-75	100-200	2-5
Dark brown expansive clays	Up to 20	Neg. to 50	Up to 2
Cohesive colluvial soils	20-75	50-200	2-5
Cohesive weathered lava	15-300	400-800	5-15
Lavas	> 300	> 800	> 30

The greatest potential problem would be caused by residual and colluvial soils. These brown expansive clays have poor foundation characteristics for road construction and they would require suitable stabilization measures.

In certain part of the Port Louis -Moka Link road, the alignment passes through rock terrain, where deep cuts in rock cliff have been suggested to achieve the desired grade. Such reaches have slope stability problem like rock falls and rock slides, primarily because of the presence of adversely oriented planes of discontinuities in basalts. The following sets of prominent joints have been observed in the escarpment face comprising massive basalts and agglomerates in the Quoin Bluff area (Table-2).

Table-2 Discontinuity Data in the Quoin Bluff Area.

Sl. No.	Direction of strike	Amount & Direction of dip	Remarks
1.	NW-SE	35° towards SW & 35° towards NE	Spacing 1.5m to 2m, open, stained at surface.
2.	N-S	85° to 90°	Spacing 4-5m, rare, gaping at surface.
3.	N60° - S60°E	70° towards N 30° E	Rare, tight.
4.	E-W	30° towards S	Spacing 0.5 to 1m, tight.
5.	N60°E- S60°W	10° to 20° towards N30°W	Tight, closely spaced, no infilling.

General Corrective Measures

For tackling the slope stability problems in the hill section having fragile rocks and adverse geological features, the following remedial measures will have to be adopted, singly or as a package, depending upon the actual field situation in the problematic stretches.

i. Benching and grading of the cliff section, to reduce susceptibility to sliding/slumping, and reducing the overload on the cliff face. This needs planning from the trace cut stage, starting from top.

ii. Bitumen mulching with plant seeds or husk, guniting for loose soil zones.

ill. Planned aforestation is imperative to ensure better water retentivity and reduce run-off during heavy rains, on the upper, as well as, down hill slopes of the road. Revegetation of cut slopes exposed during road construction activity would also be helpful in stabilizing the slopes.

iv. Contour drains on the slopes towards the hill face of the road for collecting and guiding the surface flow and discharging it beyond the sensitive section/areas is one of the most important measure and needs proper implementation to ensure road stability.

v. Apart from benching, retaining structures, breast walls, gabions as directed by the site conditions, will have to be provided with adequate drainage/ weep holes etc. in critical reaches.

vi. Proper dressing of the cut faces/slopes to remove bulge or overhanging/loose rocks would be necessary. Shotcreting with rock bolts and wire mesh may also be needed in some areas.

vii. In the vicinity of streams and rivers, toe protection will have to be provided below the road section, to avoid toe erosion and ensure road stability.

viii. Blasting should be minimal and calculated, with easer holes as an essential accompaniment. It is desirable and advantageous to do final dressing of the slopes manually or mechanically..

ix. During construction period, day to day geological advise would be needed to tackle the slope stability problems and suggest suitable remedial measures as per individual site conditions.

x. Trial pits at regular intervals along the road alignment would be helpful in defining the boundaries of different rock types and soil types. In-situ full range tests and laboratory tests on the rock and soil samples would be needed to ascertain their mechanical properties for design purposes.

Problems Along Tunnel Approach Roads And Corrective Measures

The proposed 280m long Moka saddle tunnel is aligned in N 28° W- S 28° E direction, which is almost normal to the strike of bedding, a very favorable situation (Fig. 1). However, highly weathered and decomposed basalts and agglomerates dipping at 10° to 20° in the NW direction are exposed in the trace cuts of the forest road. The following sets of prominent joints have been observed in the Moka saddle area.

The tunnel approach road from Moka side (SE side) will be nearly 100m long and will have a maximum depth of 30m, in the open cut section. The tunnel approach road from Les Guibies side will be nearly 60 m long and 30m (maximum) deep. The joint set no. 1 striking N20°W - S20°E and dipping at 35° to 70° in the SW direction, as well as, 70° in NE direction will have a direct bearing on the stability of cut slopes on account of being sub parallel to the direction of tunnel (Table-3). Proper cut slopes with berms at suitable height intervals will have to be provided. Two boreholes (BH 5 & BH 6), one at each portal location, were recommended to know the nature of strata and depth of weathering. Details of these holes are furnished in Table- 4.

Table- 3 Discontinuity Data in the Moka Saddle Area.

Sl. No.	Direction of strike	Amount & Direction of dip	Remarks
1.	N20°W - S20°E	35° to 70° towards S70°W 70° towards N70°E	Most of the joints are open at surface with clay infilling.
2.	N30°E - S30°W	Vertical	Joint surface is rough & dry.
3.	N70°W - S70°E	65° towards N20°E	-
4.	N - S	85° to 90°	-
5.	E - W	30° towards S	Rare.

Table-4 Borehole Data along Tunnels

Sl. No.	Bore Hole No.	Location	Coordinates of Borehole location	Coordinates of Borehole location	Elev. in m.	Depth of Hole in m.	Vertical/ Inclined
			Easting	Nothing			
Tunnel No. 1 (Quoin Bluff)							
1	BH1	Port Louis side	997040.217	1002335.278	118.776	53.00	Vertical
2	BH2	Port Louis side	996977.561	1002227.906	175.001	107.00	Vertical
3	BH3	Les Guibies side	996712.592	1001774.611	177.081	92.00	Vertical
4	BH4	Les Guibies side	996662.101	1001688.483	132.525	45.00	Vertical
Tunnel No. 2 (Moka saddle)							
5	BH5	Les Guibies side	998975.192	999333.746	393.035	49.00	Vertical
6	BH6	Moka side	999099.611	999064.488	398.166	45.00	Vertical

The proposed 700 long Quoin Bluff tunnel is aligned in N 30° E- S 30° W direction, which is 15° skew to the strike of beds (Fig. 1). The tunnel approaches on both the sides will have open cuts of about 70m length and maximum 30m depth each, in the overburden, as well as, in the country rock comprising columnar jointed basalt, agglomerate and tuff dipping at 15° to 22° in the northerly direction. Proper slope cuts with berms at regular height intervals will have to be provided, besides rock bolting, shotcreting with wire mesh may have to be carried out in some specific reaches to check rock falls and planer failures along the adversely oriented planes of discontinuities. Similar treatment would be necessary in the vicinity of tunnel portals for the safety of civil engineering structures, equipment and operating vehicles.

The following criterion has been taken into cognisance, for alignment of approach roads for both the tunnels.

i) The tunnel approaches should be at least 0.5 km away from the nearest intersection, to allow for traffic acceleration and flow stabilisation.

ii) The approach should have near horizontal alignment without excessive curves for providing safe and even traffic flow into the tunnel.

iii) Vertical slope cuts to be on shallow upgrade to promote drainage, as well as, uniform safe speed attainment.

iv) Side hill cuts to be utilized in favour of fills with split-level carriageways as required.

Subsurface Explorations

For deciphering the extent and nature of various rock units at tunnel grade, four boreholes (BH-1 to BH4) were recommended on the Quoin Bluff tunnel alignment and two bore holes (BH-5 & BH-6) on Moka saddle tunnel alignment (Fig. 1). The details of these holes are furnished in Table-4.

The author had recommended for conducting water permeability tests in a 3m test section, in each 6m tier, using double packers, in ascending as well as descending order in all the six bore holes. It was also suggested that at least five rock core samples from each water test section of all the bore holes should be collected from each lithological unit for conducting laboratory tests, to find out their Uniaxial Compressive Strength, Natural Dry Density, PLI, Rate of Water Absorption and Porosity, Young's Modulus and Poissons Ratio etc. The details of test zones in each borehole are given in Table-5.

Table-5 Water permeability tests data in boreholes

Hole No.	Location	Tunnel	Total Depth in m	Water test Section in m		
				I	II	III
BH1	Port Louis side	Quoin Bluff	53	26-32	35-41	47-53
BH2	-do-	-do-	107	79-85	90-96	101-107
BH3	Les Guibies side	-do-	92	65-71	74-80	86-92
BH4	-do-	-do-	45	20-26	30-36	39-45
BH5	-do-	Moka Saddle tunnel	43	24-30	34-40	43-49
BH6	Moka side	-do-	45	20-26	30-36	39-45

Interpretation of Field and Laboratory Test Data

On the basis of their physical properties, the rocks in Quoin Bluff tunnel area can be broadly categorized in to four groups (Table-6). These would form the tunneling media. The fifth category i.e., highly weathered and disintegrated basalt and agglomerate having RQD <30 has not been taken in to account, because it is not expected at the tunnel grade.

With a view to recategorising and attempting the Rock Mass Classification of tunneling media, the bed rock exposures of basalt and agglomerates, along the approach road to Signal Mountain, in the vicinity of proposed Quoin Bluff tunnel were examined. The detailed study of Rock Mass Quality- 'Q' after Barton *et al*., (RMR- System) and the Rock Quality Designation (RQD after Deere, have been computed and support system has been derived.

The rock mass description and rating for Q - values in each of the above mentioned four categories of geo-technical units are given in Table - 7.

Table-6 Category wise data on Rock Types

Rock Category	Nature of Rock	RQD	% of Rock outcrop of individual unit	Overall % of Rock outcrops
I	Thickly bedded & Massive basalt	70-100	65	Basalt (category I + III) is 60%
II	Thickly bedded & Massive agglomerate	75-100	40	Agglomerate (category II + IV) is 40%
III	Thinly bedded & jointed basalt	30-75	35	
IV	Thinly bedded & jointed agglomerate	40-75	60	

Table-7 Parameters for determining 'Q'

Parameter	Category I (Thickly bedded & massive basalt)	Category II (Thickly bedded & massive agglomerate)	Category III (Thinly bedded & jointed basalt)	Category IV (Thinly bedded & jointed agglomerate)
RQD	95	95	60	40
Jn	3	3	6	6
Jr	3	2	3	2
Ja	1	1	2	2
Jw	1	1	1	1
SRF	2.5	2.5	2.5	2.5
'Q' Value	38	25.33	6	2.7

The Rock Mass Classification category I, having 'Q' value of 38 is a good tunneling media, category II having `Q` value of 25 is also a good tunneling media, while category III having `Q` value of 6 is a fair tunneling media and category IV having `Q` value of 2.7 is a poor tunneling media.

An attempt has also been made to assess the tunneling quality index 'Q' for the cores obtained from BH1 and BH2. They have given the 'Q' values in the range of 2-28 for basalts 3-12 for agglomerates up to the depth of 40m in both the holes.

In connection with the investigation for Signal Mountain tunnel of Ring Road Project, few bore holes were drilled earlier by DDS Irrigation Ltd. The borehole nos. 1.3, 1.4 and 1.5 are located in the close proximity of existing holes BH 1 and BH 2, hence, an attempt has been made to analyse and utilise that data for Rock Mass Classification. Borehole no. 1.3 located towards Port Louis end had been drilled from elev. 123.00m down to the depth of 82m. This hole had intercepted 11 beds of basalt varying in thickness from 1.3 to 18.4m (total thickness 50.10m) and 10 beds of agglomerate varying in thickness from 1.1 to 8.24m (total thickness 31.30m). Thus the percentage of basalt is 61, agglomerate is 38 and overburden is 1%. The RQD of basalt generally varies from 50-100 and that of agglomerate varies from 40-90. However, the RQD of highly weathered basalt is 30.

In case of Quoin Bluff tunnel, having an excavated height of nearly 9m the De= 9/1 =9.0

The relationship between `Q` values as obtained from BH 1 and the De of the proposed Quoin Bluff tunnel is illustrated in Fig. 6a.

The recommended permanent roof support measures (Barton *et al.*) for various ranges of rock quality for tunnel lining of excavated diameter > 7m are given in Table-8.

Table-8 Recommended permanent roof support measures for different categories.

Rock Mass Quality 'Q'	**Recommended Permanent Roof Support Measures**
Q > 100	Spot bolting with untensioned, full length grouted bolts.
40 < Q < 100	Spot bolting, with untensioned, full-length grouted bolts, when RQD/Jn>20 or pattern bolting, with untensioned, full-length grouted bolts. Bolt spacing in the order of 6ft to 10ft c.c. when RQD/Jn<20.
10 < Q < 40	Spot bolting with untensioned, full length grouted bolts RQD/Jn>10 and JR/Jn> 1.5 Pattern bolting, with untensioned, full-length grouted bolts. Bolt spacing in the order of 5-6ft c.c. when RQD/Jn>10 and Jr/Jn <1.5 when RQD/Jn <10 and Jr/Jn>1.5. In addition to the pattern bolting above, include a 2 inch thick application of shotcrete when RQD/Jn<10 and Jr/Jn<1.5.
4 < Q < 10	Pattern bolting, with tensioned grouted bolts. Bolt spacing in the order of 3-5ft c.c. plus chain link mesh when RQD/Jn>5, or pattern bolting as above, plus wire mesh and one or two inch thick applications of shotcrete when RQD/Jn <5.
1 < Q < 4	Pattern bolting, with tensioned, grouted bolts. Bolt spacing 3ft c.c. plus wire mesh and one 2 inch thick application of shotcrete. In addition to pattern bolting and wire mesh above, use two 2 inch thick applications of shotcrete when the tunnel excavation diameter or width exceeds 7m.
0.4 < Q < 1	Pattern bolting with tensioned, grouted bolts. Bolt spacing 3 ft c.c. plus wire mesh and one 3 inch thick application of shotcrete when tunnel dimension or width is less than 7m. In addition to the pattern bolting and wire mesh noted above, use two 3 inch thick applications of shotcrete when the tunnel excavation diameter or width exceeds 7m.

The output from RMR classification method tends to be rather conservative, which can lead to over safe design of support system. This can be overcome by monitoring rock behaviour, during tunnel construction and adjusting rock classification predictions to local conditions.

An attempt has been made to compute the RMR by utilizing the laboratory test data of rock core samples obtained from Bore holes (BH 1.3 & 1.4) drilled earlier in the Spear Grass Peak-Signal Mountain area in connection with the investigation of Ring Road Project tunnel. The Geo-mechanical parameters of various rock types in Spear Grass Peak area are given in Table -9.

From the above table it is evident that the PLI (Point Load Strength Index) of basalt ranges from 6.820 to 9.988 Mpa, for olivine basalt + agglomerate from 9.615 to 12.870 Mpa and for agglomerate it is 2.758 Mpa. The uniaxial compressive strength of basalt ranges from 137.58 Mpa to 152.35 Mpa and for agglomerate it is 30.08 Mpa. Similarly in another borehole BH 1.4, the PLI of basalt ranges from 8.343 to 13.789 Mpa, for olivine basalt + agglomerate it ranges from 5.088 to 6.857 Mpa and for agglomerate from 2.236 to 2.544 Mpa. The uniaxial compressive strength of basalt is 161.93 Mpa, for olivine basalt + agglomerate it is 46.02 Mpa and for agglomerate it is 35.67 Mpa.

Using these values for rock core samples from BH 1, the Rock Mass Rating has been computed. RMR for basalt is 62, for olivine basalt + agglomerate it is 52 and for agglomerate it is 37.

It would be seen that basalt (slightly weathered to fresh) falls under Rock Category II, i.e., Good; olivine basalt + agglomerate (slightly weathered to fresh) falls under Rock Category III, i.e., Fair and agglomerate (moderately weathered) falls under Rock Category IV, i.e., Poor. The guidelines for excavation and support of rock tunnels in accordance with the RMR system are given in Table-8.

The allowable bearing pressure for Rock Category II (RMR: 80-61) ranges from 280-440 t/sq.m, for Rock Category III (RMR: 60-41) it ranges from 145-280 t/sq.m and for Rock Category IV (RMR: 40-21) it ranges from 55-145 t/sq.m.

Identification of tunnel portal locations

Locating the tunnel portals in a favourable geological and physiographic setting is of prime importance in any tunneling project. Although in the present case the country rock, i.e., basalt with intervening layers of agglomerates are supposed to be good tunneling media in dry and fresh state, but the presence of, adversely oriented planes of discontinuities and hexagonal jointing in

Table-9 Geo-mechanical parameters from BH 1.3

Rock types	PLI (Mpa)	UCS (Mpa)	D.D. (Kg/cm^2)	UPV (Km/sec)	Bulk Density (Kg/cm^2)	Ultrasonic Velocity (m/sec)	Bulk unit weight (Kn/sq.m)	Moisture content % after test	'Q'	Remarks
Agglomerate	2.758	30.08	2222	4.01	2355	-	23.70	6.13	1-3	Moderately weathered rock
Basalt	6.821 to 9.988	137.58 to 152.35	2870 to 2988	5.99	2995	5689.96	29.27	0.62	12-39	Fresh rock
Olivine Basalt	-	27.00	2561	-	2667	4574.41	-	4.12	12-13	Fresh rock
Olivine Basalt + Agglomerate	-	-	-	-	-	-	-	-	12-13	Fresh rock

basalt, coupled with deep weathering, poses the slope stability problems near the tunnel portals. Another criteria is having at least 2D (dia.) sound rock cover in the tunnel portal area. Some times the nature of the rock or the topography compels the designers to push the tunnel portals farther into the hill, resulting in increasing the length of open cut section.

Due to the paucity of adequate sub-surface and laboratory test data at the proposed Quoin Bluff tunnel (Spear Grass Peak) and Moka Saddle tunnel alignments, fixing the precise location of tunnel portals posed a real challenge. A solitary borehole (BH 1) drilled down to the depth of 42m at the Port Louis end of Quoin Bluff tunnel (Spear Grass Peak) indicated that the RQD, as well as, Q values show a marked rise from the depth of 18m (elev. $\pm$ 100m). The invert level of the tunnel portal is at elev. $\pm$ 70m and the overt/crown level would be around $\pm$ 79m. Above the crown level, 2D sound rock cover, i.e., up to $\pm$ 97m is available (with minor shear zones). Hence, the tunnel portal can safely be located at this point. The joint set dipping at 60° in the NE direction, if persistent at depth, may necessitate rock bolting and shotcreting, to check planar failure.

The SW portal of Quoin Bluff tunnel (Spear Grass Peak) located in Les Guibies area (invert level $\pm$ 90m) can be fixed only when more sub-surface data becomes available. However, the observations made from surface outcrops indicate that the orientation of some discontinuities is not favourable in this area. They are adversely oriented with reference to the tunnel axis and have variable dips of 5°-75° towards free face. If they persist at depth, then extensive slope protection measures like provision of berms at regular intervals, rock bolting with wire mesh and shotcreting may be needed.

Regarding the location of Moka saddle tunnel portals, it is impractical to predict or decipher the rock condition at the tunnel grade from surface projections. The country rock, i.e., basalt and agglomerate are highly weathered and disintegrated at the surface. Moreover, the ground surface in the proposed portal area is largely covered with overburden.

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