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Geotechncial Investigations and Slope Stability Analysis of a Landslide

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***Abstract*— Konkan Railway is passing through the most difficult terrain of foot of Sahyadri hills and along the coast of Arabian sea. Pomendi cutting is situated near Ratnagiri, constructed during 1994-1995 and opened for traffic since 1997. It is a soil cutting; the soil is of mixed soft laterite and lithomargic clay. A series of soil slips and landslides were reported at this cutting. Many measures were taken up to stabilize the cutting during the past which went in vain and the landslide during 2011-2012 interrupted the traffic thrice. Geotechnical investigations were carried out by CSMRS and remedial measures were suggested for the landslide problems experienced at Pomendi cutting. The investigation reveals that the existing sections were unsafe and possible slide failures in the coming monsoon and a modified section was suggested. The paper presents the details of the geotechnical investigations and stability analysis carried out and the suggestions made for restoring the problematic area of Pomendi Cutting.**

Keywords*— *Kongan Railways, Pomendi Cutting, Landslide, Geotechnical Investigations, Slope Stability Analysis, Drainage

I. Introduction

Konkan railway Project can be considered as one of the most prestigeous projects in the construction industry of India. The project was launched in 1989 and the track became operational in the year 1998. The 760 km line passes through complex terrains and connects the south to the north of India. In many of the stretches, the available space was restricted and the side slopes were very steep. This formidable terrain and the short construction period necessitated the use of several technological innovations. The construction and widening of the track called for large quantities of cutting in rocks of lateritic and basaltic origin.

The exposed lateritic terrains were subjected to heavy rainfall and in the presence of water, the laterite loses all of its cohesiveness, strength and become very vulnerable to cause heavy slides and slips. This problem necessitated the provision of several landslide mitigation techniques like construction of proper retaining walls and rock fall prevention measures. The ballast which is laid below the tracks primarily serves the purpose of load dispersion apart from giving added resilience. Conventionally, a ballast layer of depth 250 mm is adopted below the sleepers with a depth of 500mm on the sides, sloping outwards. This requires a greater utilization of space on the sides, with sufficient width for embankment. Further over a period of time, due to the repeated use of track, the ballast has a tendency to roll out of tracks.

Konkan Railway is passing through the most difficult terrain of foot of Sahyadri hills and along the coast of Arabian sea. The Geology and topography of the area is ever challenging for the Engineers. Lot of tunnels, cuttings and tall and long bridges had to be made to complete the task of linking the west to the south. The tunnels as well as the cuttings were to be made in hard rock, soft rock and in soft soils. During service, the cuttings in this area give troubles especially during monsoon time. The area receives high intensity rainfall averaging to an annual rainfall of about 3500 mm. The traffic is always interrupted during the month of June to August every year due to landslide problems.

Pomendi cutting is situated at km 208/738 (South face Pomendi – II tunnel) to km 209/400 (null point near the viaduct), having a length of 620m in Ratnagiri – Nivsar section of Ratnagiri region, constructed during 1994-95. The section was opened for traffic since 20.01.1997. It is a soil cutting; the soil is of mixed soft laterite and lithomargic clay. The cutting is having a depth of 40 m at east side and 32 m at west side. The hill where the cutting was made is sloping from east to west. An RCC trough wall was constructed for a length of 200 m from km.208/880-209/080 during the construction phase and the straight track alignment was laid on it. 600 mm dia Piles with pile cap and mass concrete retaining wall for small length were also done on East side cutting. A series of soil slips and landslides were reported at this cutting during the year 2000, 2006, 2007, 2010 and 2011. Construction of retaining wall, flattening of slopes, construction of lined catch water drain etc. were carried out to stabilize the cutting during the past. Even after this, during 2011 – 2012, landslides have reported thrice interrupting traffic.

Geotechnical investigations were carried out by CSMRS during April – May 2012 and remedial measures were suggested for the landslide problems experienced at Pomendi cutting on Konkan Railway. After a thorough analysis of the results of the investigations, the parameters were adopted for carrying the slope stability analysis. From the analysis, it was clear that most of the existing sections were unsafe and in the coming monsoon season, when the soil mass gets saturated there was a high possibility of a slide failures. Therefore, the sections were modified and the further analyses were carried out and the final section to be adopted was recommended. The paper presents the details of the geotechnical investigations and stability analysis carried out and the suggestions made for restoring the problematic area of Pomendi Cutting.

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II. Topography and Geological Conditions

The soils and rocks at Ratnagiri district belong to five main groups such as Archaean deposits, Basalt trap, Ratnagiri plant beds, Konkan laterite and Ratnagiri alluvial deposit. Archaean deposits are the oldest metamorphic rocks in the Ratnagiri district. The origin of these rocks was affected by lineaments (faults) that transverse parallel to the west coast.

Archaean rocks are mostly covered by the volcanic (Basalt) traps and the Konkan laterites [6]. At some locations, these rocks are exposed at the surface and exist as islands surrounded by the volcanic traps. Along the Ratnagiri coast, these metamorphic rocks occur as thin bands of gneiss and mica schists. Quartz and shales can also be observed further south of this region. Shales occur as pockets within the lower sandstone beds. Basalt trap were formed from volcanic eruption and are black to greenish-grey in colour. The flow from the volcanic outburst probably originated deep inland, far away from the Konkan coast because the rock has a seaward dip with visible flow lines. The trap is about 1000m thick near the coast and substantially thicker inland. Basalt traps are covered by thick laterite beds which may otherwise exist as exposed patches beyond the Ratnagiri district. Ratnagiri Plant beds are deposits of white clay with brownish-black carbonaceous seams. It is not uncommon for the plant beds to contain several vesicles filled with quartz. These deposits are only a few hundred millimetres thick and lie mostly over regions where the basalt trap is exposed e.g. near rivers, valleys and ravines. Konkan laterites contain kaolinite and gibbsite clay minerals, both bound with iron oxides. The latter gives reddish brown to black colour to these deposits. Konkan laterites extend horizontally to a little over 30km east of Ratnagiri. If exposed at the surface, laterites occur with bare grass patches and only a few stunted trees. It is not clear if the Konkan laterites had originated by decomposition of the underlying parent rock or because of sediments transported from the Deccan trap, since the above two deposits have similar geological features.

Ratnagiri alluvial consist of silts and sands deposited at the lower reaches of the river. Properties of the alluvial depend almost entirely on the properties of the parent rock and the mode of transportation. Close to the delta, these deposits are stiff when mixed with broken shell pieces. Otherwise, alluvial above the high water mark are covered by Aeolian soils.

III. Brief History of Pomendi Cutting

Pomendi cutting is situated at km 208/738 (South face Pomendi – II tunnel) to km 209/400 (null point near the viaduct), having a length of 620 m in Ratnagiri – Nivsar section of Ratnagiri region, constructed during 1994 – 1995. It is a soil cutting[4]. The soil is of mixed soft laterite and lithomargic clay. The cutting is having a depth of 40 m at east side and 32 m at west side. The hill where the cutting was made is sloping from east to west. A brief history of landslide occurred at Pomendi cutting between RN-NIV section of Konkan Railway is summarized in Table I. The Pomendi cutting before and after flattening of the failed cutting slopes during April 2011 are presented in Fig. 1 and Fig. 2.

TABLE I. History of Landslides occurred in Pomendi Cutting

Location (km)	Incident and clearance	Damage	Remedial Measures adopted
209/2-3 (West)	11/06/00 16/06/00	5000 m^3 of soil fallen on track.	Collapsed soil from berms removed, 3 new berms are provided with proper slope and catch water drains are provided
209/2-3 (East)	05/07/06 05/07/06	7000 m^3 of soil fallen on berms and 150 Cum in side drain.	Collapsed soil from berms removed, cutting lowered and proper berms provided
209/0-1 (West)	31/08/07 02/09/07	2000 m^3 of soil and trough wall of 50m length collapsed.	Mass concrete retaining wall of 251m length at west side, flattening of cutting slope, provision of catch water drain, micro piling and strengthening of 78 m length of trough wall at east side were carried out.
209/1-2 (East)	24/07/10 30/07/10	2200 m^3 of soil and 95m length of retaining wall collapsed.	Mass concrete (M:15) retaining wall for a length of 285m constructed on east side. Berms are made with proper slope for soil cutting.
208/9- 209/0 (East)	16/06/11 19/06/11	5000 m^3 of soil fallen on track and 600 m^3 of concrete wall.	Loose and heaved soil from the berms removed, new berms provided and catch water drains improved.
209/1-2 (East)	17/07/11 21/07/11	Landslide of 10000 m^3 of soil followed by collapse of 60 m long retaining wall on 18/07/11.	Damaged concrete wall is broken and removed. 22 number of poclains were deployed to remove the landslide soil.
209/1-2 (East)	30/08/11 30/08/11	Landslide of 2000 m^3 of soil followed by collapse of 26 m long retaining wall on 30/08/11	Damaged concrete wall is broken and removed. 13 number of poclains were deployed to remove the landslide soil.
209/0-2 (East)	03/09/11 04/09/11	Slush of 2000 m^3 came on track from east side cutting due to heavy rain	Removed the slush deploying 7 BRN formation and 15 number of poclains.

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Fig. 1. Pomendi cutting before flattening of cutting slope

Fig. 2. Pomendi cutting after flattening of cutting slope during April 2011

Fig. 3. Steep slopes in problem area

Fig. 4. Gabion constructed in problem area as solution

Many geotechnical safety works were carried out at the problematic areas (Fig. 3) such as easing of slopes by providing berms and flattening of deep cuttings slopes and protecting slopes by plantation to prevent soil erosion, providing steel boulder netting as isolated boulder fall prevention measures in cuttings, loose scaling, Shot creting and rock bolting of tunnels, providing RCC retaining wall and Gabion wall (Fig. 4), providing micro piling and soil nailing, providing side drains and catch water drain lining etc.

IV. SITE CONDITIONS AND OBSERVATIONS

Three landslides were reported during June to August 2011 due to a heavy rainfall of intensity 683 mm in 10 days period and interrupted the traffic thrice. On 16th June 2011 itself, the rainfall recorded was 206 mm. The hill from East side started sliding towards track due to which heaving of different berms took place and cracks developed in about 60 m length of the East side retaining wall. The retaining wall started tilting towards track at 14:30 hrs of 16/06/11. Tilt was kept under observation and within next 16 to 17 hrs, tilt was increased up to 1.0 m and finally the retaining wall (km 208/990 and 209/005) collapsed at 07:30 hrs on 17/06/2011 for a length of 15 m. After 4 hours, about 45 m more length of retaining wall also collapsed and soil fell on track. It was informed that about 5000 m^3 of soil and 600 m^3 of mass concrete of retaining wall (about 60 m long) fell on track.

Temporary protection measures were adopted and many excavators were deployed at the problem area and the loosened soil mass was removed. The soil mass were very slushy and had very little shear strength. There was subsidence in hill slope having a size of about 120 m wide and 6 m deep at a distance of 98 m from center line of track on East side. The natural ground settled by 6 m to a maximum of 10 m during these 2011 landslides. During the visit, cracks and rain water gullies were noticed in slope adjoining the failed areas. Operational catch water drains were seen in the areas which were not disturbed. Weep holes were provided on retaining wall and water was draining out from the lower most layers of weep holes. Fig. 5 presents the location plan of Pomendi cutting. The site conditions of the landslides during June – August 2011 is depicted in Fig. 6.

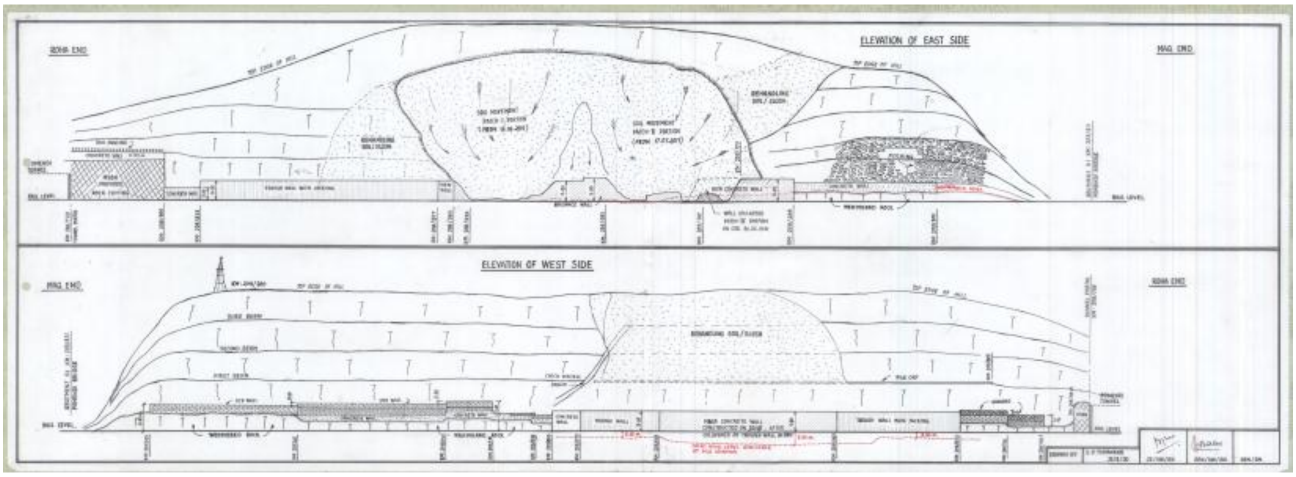

Fig. 5. Plan of Pomendi cutting East and West

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Landslide on 16/06/2011

Failed Retaining Wall on East Side

Landslide on 17/07/2011

Landslide on 30/08/2011

Cracks and Raincuts

Slope Failure and Subsidence

Restoration Work

Widening of berms after 30/08/2011

Fig. 6. Landslide during June – August 2011

V. Geotechnical Investigations

Forensic investigations of the landslide areas were carried out by many agencies or organizations and one among them were RDSO team. The RDSO team visited the project site and submitted a report on landslide and failure of Retaining wall in Pomendi cutting. RDSO tested a total 11 nos. of disturbed and undisturbed soil samples collected from the site and reported that the bore logs indicate strata comprising of Lateritic soil (top layer) underlain by lateritic stone (weathered rock) and Greyish basalt[5]. As per classification tests carried out by RDSO, the strata largely falls under categories of MH (Silt with high compressibility), SM (Silty sand) and GM (Silty Gravel). The Triaxial shear tests carried out on two soil samples of GM and one soil sample each of SM and MH groups of soil classification. The values of angle of shearing resistance (ϕ) of these tested soil samples were 31.3º, 32.1º, 33.1º and 26.6 º respectively. The liquid limit, plasticity index and shrinkage limit of the tested soil strata is in the range of 50-80 indicating high compressibility, 20 to 34 indicating high plasticity and 16 to 23 indicating low degree of expansivity respectively. The Free swell index varies from which indicates low to moderate swelling characteristic of the tested soil.

VI. Geotechnical Investigations by CSMRS

The work of the geotechnical investigations on the soil samples collected from the problem area of Pomendi Cutting, Ratnagiri, Maharashtra was taken up during October 2011. The work includes the geotechnical investigations on the soil samples collected from the problem area of the Pomendi cutting, to analyze the slopes and to study and suggest remedial measures for the landslide problems experienced at Pomendi cutting.

A total of 5 undisturbed soil samples and 5 disturbed soil samples were collected from 5 different trial pits excavated in the problem areas of the Pomendi cutting. Fig. 7 shows the locations of the investigation areas of the problem areas at the Pomendi cutting. All the collected soil samples were subjected to the Mechanical Analysis and the Atterberg limits tests and the results are presented in Table II.

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The grain sizes of the tested soil samples indicate that the clay sizes vary from 8.1 % to 45.2 %, silt sizes vary from 11.6 % to 37.6 %, fine sand sizes vary from 3.7 % to 13.4 %, medium sand sizes vary from 3.4 % to 14.3 %, coarse sand sizes vary from 0.8 % to 10.3 % and the gravel sizes vary from 18.7 % to 51.8 % respectively. The graphical representations of grain size distribution of the tested soil samples are presented in Fig. 8.

Fig. 7. Locations of investigation area at Pomendi Cutting

TABLE II. RESULTS OF MECHANICAL ANALYSIS AND ATTERBERG LIMITS

Soil No.	RD	Mechanical Analysis						Atterberg Limits			BIS Soil Classification
		0.002 mm & less	0.002 to 0.075 mm	0.075 to 0.425 mm	0.425 to 2.0 mm	2.0 to 4.75 mm	4.75 mm & above	LL	PL	PI	
		Clay	Silt	Fine Sand	Medium Sand	Coarse Sand	Gravel				
1	209/005	23.6	29.2	13.4	14.3	0.8	18.7	67.7	39.7	28.0	MH
2	209/005	24.1	27.3	11.3	12.4	1.6	23.3	69.0	42.1	26.9	MH
3	209/147	13.7	11.6	3.7	8.9	10.3	51.8	60.2	32.1	28.1	GM
4	209/147	18.3	12.6	6.6	7.9	4.7	49.9	79.3	39.6	39.7	GM
5	209/175	23.9	36.3	5.6	8.6	2.8	22.8	80.6	40.7	39.9	MH
6	209/175	45.2	13.9	4.1	3.4	1.4	32.0	85.0	40.9	44.1	MH
7	209/000	13.0	37.6	10.4	11.5	4.2	23.3	53.9	37.4	16.5	MH
8	209/000	25.1	29.6	10.0	8.4	2.9	24.0	54.6	36.7	17.9	MH
9	209/025	8.1	28.6	9.7	12.4	3.2	38.0	56.7	37.5	19.2	GM
10	209/025	12.2	29.3	10.7	13.5	1.5	32.8	58.8	38.7	20.1	GM

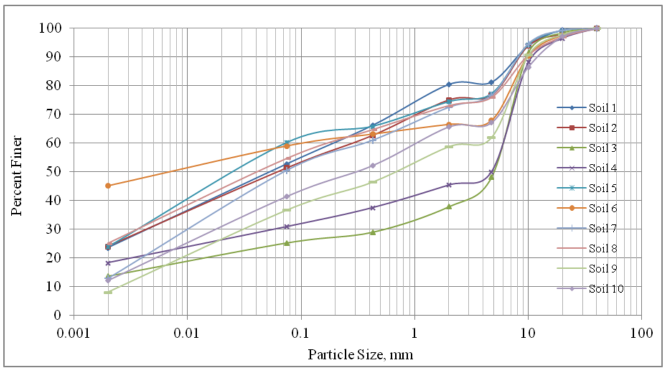

Fig. 8. Grain Size Distribution Curves

All the ten tested soil samples possess medium to high plasticity characteristics. Based on the results of grain size distribution and Atterberg limits tests, out of 10 tested soil samples, six soil samples fall under MH (Silts of High Compressibility) group and the remaining four soil samples fall under GM (Silty Gravel) group of Bureau of Indian Standard soil classification system.

Five selected soil samples were subjected to Differential Free Swell Index tests. The differential free swell index values of the tested soil samples vary from 21.4 % to 66.6 % and are presented in Table III.

TABLE III. RESULTS OF DIFFERENTIAL FREE SWELL INDEX

RD	Differential Free Swell Index (%)
209/005	33.3
209/147	50.0
209/175	66.6
209/000	25.0
209/025	21.4

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The values of Insitu Dry Density and Natural Moisture Content of the tested soil samples vary from 1.28 g/cc to 1.75 g/cc and 13.2 % to 31.9 % respectively. The differential free swell index values of the tested soil samples vary from 21.4 % to 66.6 %.

The Maximum Dry Density and the Optimum Moisture Content values of the tested soil samples vary from 1.34 g/cc to 1.55 g/cc and 32.0 % to 40.5 % respectively. The total shear strength parameters total cohesion (c) and total angle of shearing resistance (ϕ) of the tested soil samples vary from 0.19 kg/cm2 to 0.32 kg/cm2 and 14.8° to 23.1° respectively. The effective shear strength parameters effective cohesion (c′) and effective angle of shearing resistance (ϕ′) of the tested soil samples vary from 0.06 kg/cm2 to 0.23 kg/cm2 and 21.6° to 32.2° respectively. The results of the tested undisturbed and disturbed soil samples are presented in Tables IV and V. The graphical representation of the dry density and the moisture content obtained from the standard proctor compaction curves of the tested soil samples are presented in Fig. 9.

TABLE IV. RESULTS OF UNDISTURBED SOIL SAMPLES

RD	Insitu Density and Natural Moisture Content		Triaxial Shear Test – CU with PP			
			Total shear parameters		Effective shear parameters	
	Insitu Dry Density g/cc	Natural Moisture Content %	c kg/cm^2	ϕ	c′ kg/cm^2	ϕ′
209/005	1.34	26.4	0.21	20.7°	0.12	29.3°
209/147	1.75	13.2	0.22	23.1°	0.18	31.8°
209/175	1.39	31.9	0.19	20.7°	0.06	27.4°
209/000	1.28	22.3	0.32	18.1°	0.23	27.1°
209/025	1.47	21.7	0.32	19.5°	0.21	32.2°

TABLE V. RESULTS OF DISTURBED SOIL SAMPLES

RD	Standard Proctor Compaction Test		Triaxial Shear Test			
			Total shear parameters		Effective shear parameters	
	Maximum Dry Density g/cc	Optimum Moisture Content %	c kg/cm^2	ϕ	c′ kg/cm^2	ϕ′
209/005	1.42	32.0	0.24	20.6°	0.12	31.3°
209/147	1.55	33.5	0.24	18.8°	0.14	29.4°
209/175	1.43	40.5	0.31	15.4°	0.22	26.4°
209/000	1.37	33.5	0.31	14.8°	0.22	21.6°
209/025	1.34	34.5	0.26	17.1°	0.11	30.9°

Based on the findings of the investigations in the problem areas of the Pomendi cutting, the following conclusions have been arrived at.

- The tested soil samples possess silt sizes followed by clay sizes. The presence of the gravel sizes in all the collected soil samples was very predominant and possess medium to high plasticity characteristics.
- The insitu density values indicate that the tested materials in general exhibit low to medium compactness.
- The differential free swell index values indicate that the 50% of the tested materials possess swelling characteristics.
- The Maximum Dry Density and Optimum Moisture Content values of the tested soil samples indicate that the tested materials are capable of achieving good compactness.
- The results of Triaxial Shear tests conducted on the samples indicate that the tested samples are likely to exhibit good shear strength characteristics.

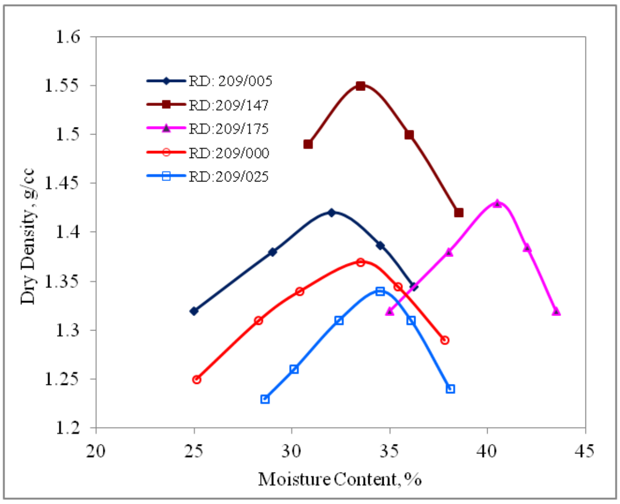

Fig. 9. Proctor Compaction Curves

VII. SLOPE STABILITY ANALYSIS

The purpose of slope stability analysis is to provide a quantitative measure of the stability of a slope or part of a slope. Traditionally, it is expressed as the factor of safety against failure of that slope, where the factor of safety is defined as the ratio of the restoring forces to the disturbing forces, such that a factor of safety greater than unity denotes stability but a factor of safety less than one denotes failure.

There are numerous methods currently available for performing the slope stability analysis. The majority of these methods may be categorized as limit equilibrium method. The limit equilibrium method is widely used due to its simplicity. There are numerous limit equilibrium methods available for evaluation of slope stability, such as Ordinary Method, Bishop Simplified Method, Janbu Simplified Method, Janbu Corrected Method, Spencer's Method, Corp's of Engineers Method, Morgenstern and Price's Method, Lowe-Karafiath Method and Generalized Limit Equilibrium Method (GLE).

The most widely used limit equilibrium method of analysis for slope stability is the Bishop's Simplified Method. In this method, the failure is assumed to occur by rotation of a block of soil on a cylindrical slip surface centered on O as depicted in Fig. 10. By examining overall moment equilibrium about O an expression for the factor of safety is obtained. In this method it is assumed that the interslice shear

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forces may be neglected. The total normal force is assumed to act at the centre of the base of each slice, and is determined by resolving the forces on each slice vertically.

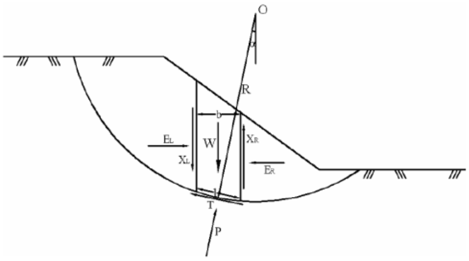

Fig. 10. Slice forces - Bishop's Simplified Method

The normal force is then given by the expression:

$$P = \frac{\left[W - \frac{1}{F}(c'l - ul \tan \phi') \sin \alpha \right]}{m_{\alpha}}$$

$$\text{where } m_{\alpha} = \cos\alpha \left[1 + \frac{\tan\phi' \tan\alpha}{F} \right]$$

The factor of safety (FOS) is evaluated iteratively from the following expression:

$$FOS = \frac{\sum (c'l + (P - ul)\tan\phi')}{\sum W \sin\alpha}$$

The method of analysis involves a total of 2n-1 assumptions. Thus the problem is over specified, and in general overall horizontal equilibrium is not satisfied. However, the factor of safety is not particularly sensitive to the value of interslice shear force provided overall moment equilibrium is satisfied.

Bishop simplified method yields results which are fairly accurate and adequate enough for practical purposes. Hence this method is widely used by investigators around the world for analyzing the stability of slopes.

Software Used

The software used for the present work is SLIDE. It is a 2D slope stability program for evaluating the safety factor or probability of failure, of circular or non-circular failure surfaces in soil or rock slopes. Even complex models can be created and analyzed quickly and easily including the external loading, groundwater and supports. The stability of slip surfaces is analyzed using vertical slice limit equilibrium methods (eg. Bishop, Janbu, Spencer etc). Individual slip surfaces can be analyzed, or search methods can be applied to locate the critical slip surface for a given slope.

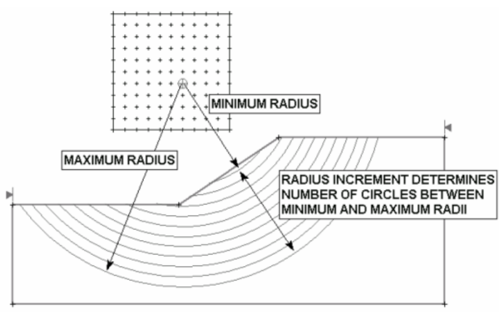

Fig. 11. Slope Stability – Radius increment

The stability analysis of the slope is carried out by choosing the failure surfaces with the grid of centers, interval of radius and number of iterations. For each slip center in a grid, suitable Minimum and Maximum radii are determined, based on the distances from the slip center to the slope surface. The radius increment is used to determine a number of equally spaced circles, between the Minimum and Maximum radii, for a given slip center which is illustrated in Fig. 11.

The analysis has been carried out using the software SLIDE 5.0. The software is capable of carrying out slope stability analyses using six different methods such as: Bishop Simplified Method, Ordinary Method, Lowe and Karafiath, Corps of Engineers, Janbu Simplified, Janbu Corrected, Morgenstern and Price's and Spencer's method. But the present report presents the results obtained using Bishop Simplified Method only. Bishop simplified method simulates the moment based limit equilibrium method of analysis for slope stability. This method yields results which are fairly accurate enough for practical purposes, and has been widely used by investigators around the world for analyzing the stability of slopes. Hence this method has been chosen for the present analysis.

Geotechnical Properties

A total of 5 undisturbed samples and 5 disturbed samples have been investigated [2] [3] to characterize the soil mass prone to landslide. After a thorough analysis of the results of the investigation, the parameters given in Table VI have been adopted for carrying the slope stability analysis. Also in the absence of any details of the underlying material, it is assumed that the soil parameters are the same throughout the sections analyzed.

TABLE VI. GEOTECHNICAL PROPERTIES OF SOIL MASS

Bulk Density kN/m^3	Cohesion (c) kPa	Angle of Internal Friction (ϕ)
17.8	20	28º

Analysis of Slopes

A total of seven sections of the east side of the existing Pomendi cutting have been analyzed. The sections are designated as per their reach along the existing railway line. A total of 10000 slip circles have been analyzed using the Bishop Simplified Method. The global minimum factor of safety obtained for the all the cases are presented in Table 4. Fig. 12 and 13 presents the cross section at km. 209/000 (Pomendi Cutting / East Side).

From the above table, it is clear that most of the existing sections (Case 1 – 7) are unsafe and in the coming monsoon season, when the soil mass gets saturated there is a high possibility of a slide failure. The analysis of the final section to be adopted (Case – 8) has a factor of safety of 1.49 and is safe, even though the desired factor of safety is 1.5.

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TABLE VII. GLOBAL MINIMUM FACTOR OF SAFETY

Section	Factor of Safety
Cross Section At km. 208/920 (Pomendi Cutting/East Side)	1.31
Cross Section At km. 208/960 (Pomendi Cutting/East Side)	1.07
Cross Section At km. 209/000 (Pomendi Cutting/East Side)	1.05
Cross Section At km. 209/040 (Pomendi Cutting/East Side)	1.09
Cross Section At km. 209/070 (Pomendi Cutting/East Side)	0.78
Cross Section At km. 209/130 (Pomendi Cutting/East Side)	0.53
Cross Section At km. 209/160 (Pomendi Cutting/East Side)	0.96
Final Cross Section to be adopted (Pomendi Cutting/East Side)	1.49

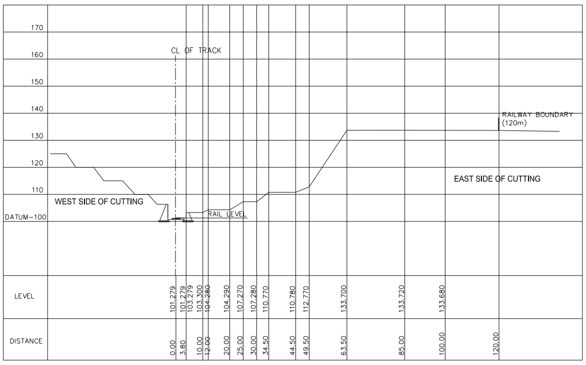

Fig. 12. Cross Section at km. 209/160 (Pomendi Cutting / East Side)

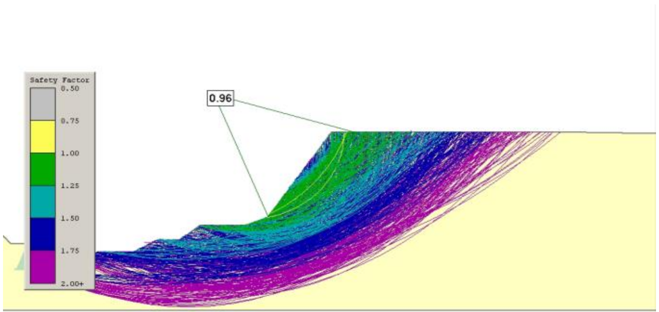

Fig. 13. Slip Surfaces for Cross Section at km. 209/160 with FOS between 0.5 and 2.0

VIII. CONCLUSIONS

The final section adopted is shown in Fig. 7. The stability analyses clearly shows that most of the existing sections are unsafe and when the soil mass gets saturated there may be a high possibility of a slide failure in the coming monsoon season. Therefore it was suggested that the slopes of the Pomendi cutting may be constructed with proper compaction and with proper turfing to arrest surfacial erosion. In order to avoid consequences of failures due to saturation of the soil mass, proper drainages need to be provided at the slopes such as cross drains, catch water drains etc. Provision of Geomembranes and Geosynthetics materials in the cross drains and catch water drains shall provide a leak proof system.

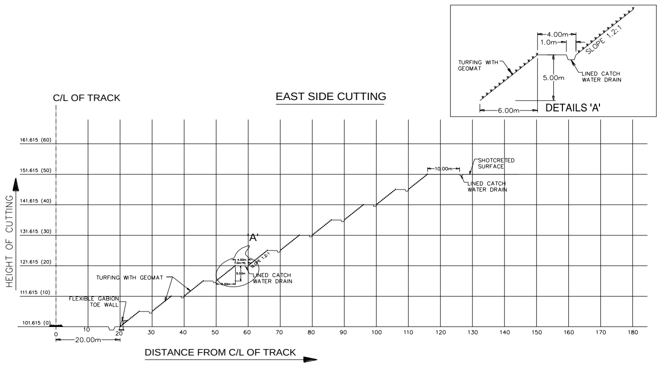

Fig. 14. Final Cross Section adopted (Pomendi Cutting / East Side)

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