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Landslide Sensitivity Assessment of Existing Twin Tunnels: A Case Study of National Highway-76 between Udaipur - Pindwara, Rajasthan, India

Bhardwaj Govind Singh[1], Mehta Mayank[1], Md Yeasin Ahmed[2] and Robert Evans[2]

[1]Department of Mining Engineering, CTAE, MPUAT, Udaipur, Rajasthan, India
[2]School of Engineering, Department of Civil and Construction Engineering, Centre for Sustainable Infrastructure, Swinburne University of Technology, Australia

Correspondence should be addressed to G.S. Bhardwaj, bhardwaj_gs@rediffmail.com

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Abstract Highways motorway tunnel failure is a major problem in rocky mountainous regions. Modes of failures are in various ways includes failures of cut hills close proximity to the tunnel crown, along the longer axis, internal part of the tunnel and collapse of the civil construction structure. To ensure their continued safe operation as well as appropriate repair and improvement works, a wide range of investigations has been carried out to confirm the conditions of tunnels and establish the causes and extent of deterioration and damage. The geometry of the slope surface, material profile & their spatial distribution, material properties viz. geo-mechanical, structural, phreatic surface, and local climatic conditions are the primary causes. The earthquake force, distributed load and vehicle induced forces acting upon the tunnel area aggravates the failure. Tunnel stability status analysis and data interpretation from the tunnel area helps in predictive assessment of probable modes of failure. Looking to the frequency of failures in the cut hills of adjoining part of the tunnels and traffic blockade, a study has been carried out on twin tunnels of national highway number 76 between Udaipur-Pindwara, Rajasthan India. The twin tunnel road passage is part of the folded Aravalli mountain chain.
Keywords *Aravalli Mountain; Factor of Safety; Failure Surfaces; Four-Lane Road*

1. Introduction

Tunnels are essential part of highways development & strengthening in hilly area, which leads to economic growth, connects people, provides speedy and safe travel. It reduces the gradient of the road, and to preserve the visual line of the hills and provide crossing points for wildlife (en.wikipedia.org/wiki/Engelberg_Tunnel). National Highway number 76 from Udaipur to Pindwara (Longitude 72^0 43’ (E) & latitude 24^0 35’ (N) and 73^0 3’ (E) latitude 24^0 47’ (N) longitude) envisages 4-lanning of the existing single roads (Figure 1). The 4-lanning improvement work extends to all components of the road namely, pavements, bridges, drains, structures within right-of-way, improvement of the road geometry and construction of twin tunnels. The road passes through hilly areas, reserve dense mixed forest, steep slopes and nearly flat stony scrubland. The ground elevation varies from 212 metres above mean sea level (MSL) at Amirgarh to 907 metres above MSL at Jaswantgarh. Annual average rainfall at these locations ranges from 1020 mm to 596 mm (at Udaipur) average maximum temperature varies from 37.8^0C to 41.2^0C with the average minimum being between 3.4^0C and 9.3^0C. The 35 km road passage between Jaswantgarh to Bekaria is prone to landslides and rock fall. Due to landslides and rock-fall several times the twin tunnel have been blocked/closed temporarily for clearing of the fallen soil, debris and boulders. It became inconveniences in vehicular movement through the tunnels and causes fatal accidents repeatedly. The twin motor way tunnels 1 and 2 have been studied in details to assess the sensitivity of failure.

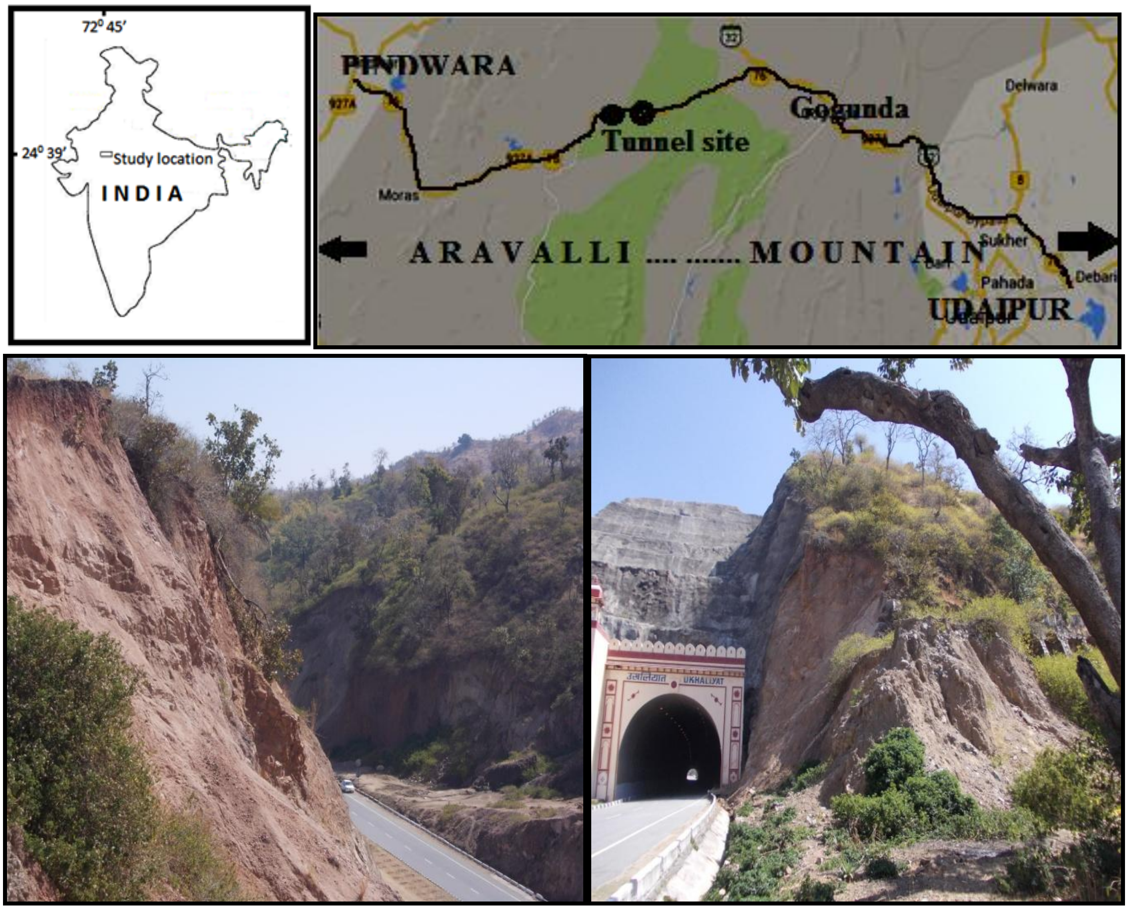

Figure 1: *Showing Location of Tunnel and Photographs Envising the Seriousness of the Problem*

Effective risk management requires in the case of twin tunnels area landslide & assessment of inherently uncertain events and circumstances, typically addressing how likely the uncertainty is to occur, and what the effect would be if it happened. The credibility and value of the risk process is enhanced if data are collected with care and using proper tools to assess (David A. Hillson et al., 2004). The estimation of the long-term probability occurrence of landslides based on the derived distribution technique, where the statistical behavior of the rainfall process and material property and slope parameters considered for establishing relation with Factor of Safety (Estefania Munoz et al., 2012). Robin G. McInnes et al., 2002 published their findings on ground instability problems and stressed upon the importance of implementation of management strategies and integrating the research in to strategic planning. Numerous slopes are affected by small movements related to the progressive failure of rock slopes induced by weathering and water pressure in the structural planars. Prevention and mitigation of landslide hazards requires establishing (O.J. Lateltin, 2002). Importance of such studies has been realized by the facts that the number and extent of roads will expand dramatically this century. Globally, at least 25 million kilometres of new roads are anticipated by 2050; a 60% increase in the total length of roads over that in 2010. Nine-tenths of all road construction is expected to occur in developing nations (Stephen G. et al., 2014). Roads can promote social and economic development and at the same time, they also open a Pandora's Box of environmental problems (William F. Laurance et al., 2014).

2. Materials and Method

2.1. About the Twin Tunnels

Within a span of five kilometers, the tunnels are excavated in the hills which comprises structurally complex geological formations comprises soil, phyllite and quartzites of highly weathered, Jointed and Folded nature (Figure 2). The particulars of twin tunnels are given in Table 1.

Table 1: *Particulars of the Tunnels*

Name of the Twin Tunnel/ Milestone Location Udaipur-Pindwara Road Passage NH27 India	Length (m)	Dia. (m)	Rock Mass in Which it is Constructed	Technical Details
Tunnel-1 (Ukhliyat) Km60.690-Km61.060	370	9.83	Fair to poor	Thin Soil layer as uppermost hill rock mass material, phyllite below the soil and quartzite as intercalations within phyllite and soil. Intense weathered
Tunnel-2 (Khokharianal) Km65.510-Km65.710	200	9.83	Fair to poor	Thick Soil profile as uppermost material, phyllite below the soil and quartzite as intercalations within phyllite and soil. Intense weathered
It is constructed in phase: E-W corridor package 1, Unidirectional travel tunnel, Year of construction: April 2005; Services by SNC Lavalin, Canada International Inc. & Sheladia Associates India Pvt Ltd, Ahmedabad, India.				

2.2. Description of Twin Tunnels Area

The upper hill load height is 85 meters maximum. The engineering design is proper but at some places its modifications are desired. The hill cuts on either side of the tunnel entry-exit are not treated in proper way, road cut hills on either side are sliding on the road. The phreatic surface is above the floor of the tunnels & piezometric surface is erratic, at some of the points it is 1 to 2 meters higher than the natural ground levels. The reason could be joints planes i.e. joint spacing is 0.10 to 2.8 meters, closely spaced and persistence is 12 to 15 meters maximum. Watery conditions of tunnels in tunnel-1 are more serious as compared to tunnel-2. This factor is added to the failure (Figure 2).

Figure 2: Photographs Showing Sensitive Tunnel Side Failures

The location of tunnels is shown in digital elevation model, part of the Aravalli Mountain traversing by the four lane road, generated with GIS software (Figure 3).

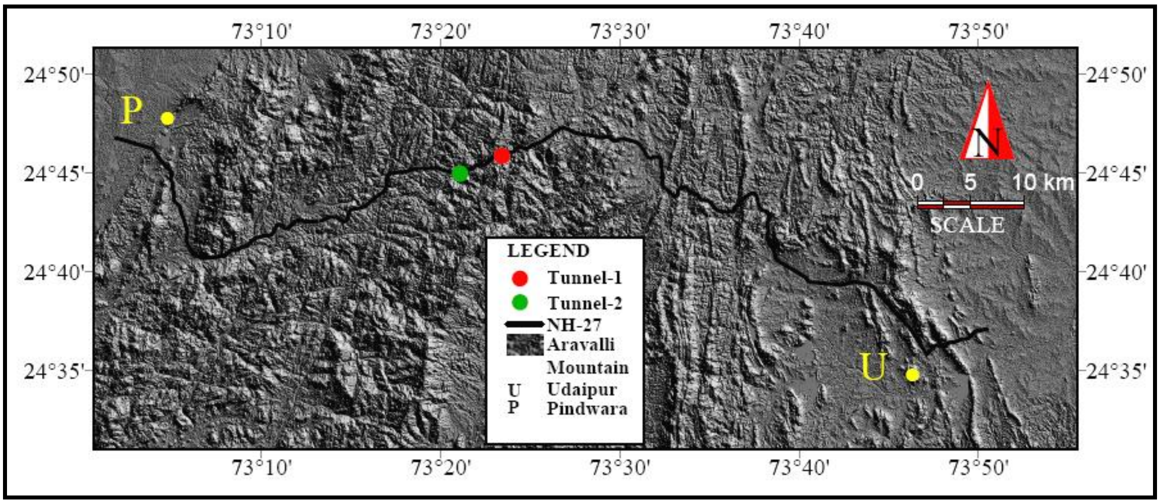

Figure 3: DEM of Aravalli Mountain Showing Tunnels

2.3. Material Properties of the Tunnel Area

Mainly three types of material constituting the tunnel area hill i.e. soil, phyllites and quartzite. The cohesion, phi and unit weight properties of the material ranges from 90-240, 27-36 and 18-21 respectively. The values obtained by the laboratory testing, further matched with the software data file available with the Manual of Galena Slope stability software version 4.0 (Table 2).

Table 2: *Material and Water Properties (3 Materials: Mohr-Coulomb Isotropic)*

Material Type/ Properties	Cohesion	Phi	Unit Weight	Ru
Soil	0.00	36.0	18	1.10
Phyllite	240.00	36.0	21	1.10
Quartzite	90.00	27.0	20	1.10
Unit weight of water: 9.810				

2.4. External Forces

In this case the external forces acting are identified on the basis of site investigations, toll plaza data collected and literature review. The distributed load, vehicular movement noise induced transmitted force and earthquake forces are the active external forces and used for the analysis as input parameter. These particulars of the forces are tabulated in Table 3.

Table 3: *External Forces Acting on Tunnels*

Tunnel Number	Vehicular Forces Type			
	Noise level range (24 hourly)	Frequency of maximum noise level exposure (24 hourly)	Vibrations Range in pseudo-static coefficient (24 hourly)	Frequency of maximum vibration level exposure (24 hourly)
Tunnel-1	64 to 90dB	500	0.02-0.08	500
Tunnel-2	64 to 88dB	500	0.03-0.09	500

4. Landslide and Rock Fall Models of the Tunnel Hills

Roadside hill cut slopes are unsafe; these cuts were developed due to cutting of hills in the Aravalli Mountainous region. The preliminary geological, geotechnical and stability analysis carried out using Galena software shows that most of the slopes are having factor of safety less than one. The stress concentration pattern obtained by finite elemental analysis shows that in the toe area of the cut is indicative of its criticalness from failure aspect (Bhardwaj G.S. et al., 2011, 2012). Rockfall is a major problem in high hill slopes and rocky mountainous regions and construction of highways at these rockfall prone areas often require stable slopes. The causes of Rockfall are presence of discontinuities, high angle cut slopes, heavy rainfall, and unplanned slope geometry etc. Slope geometry is one of the most triggering parameters for rockfall, when there are variations in slope angle along the profile of slope (M. Ahmad et al., 2013). Reliable estimates of slope stability are essential for safe design and planning of road cut hill slopes which accommodate a number of tourist destinations around the world. The failure of cut slopes along these hills puts human life in grave danger and it is also disastrous for the economy (Kainthola et al., 2012). Assessment of the stability concerns of the adjoining part and twin tunnels has been carried out. For software analysis the spatial distribution of the rock mass as a geological material, slope surface geometry, and phreatic surface are given by the X-Y coordinates of the tunnel face analyzed (Table 4).

The computer generated tunnel crown face depicting all details are given in the Figure 4. The tunnel failure sensitivity has been modeled by considering magnitude of the forces applied & their direction in which, acting on the tunnels. The details of acting forces are given in the Table 5 and particulars of generated failure surfaces criticalness in Table 6.

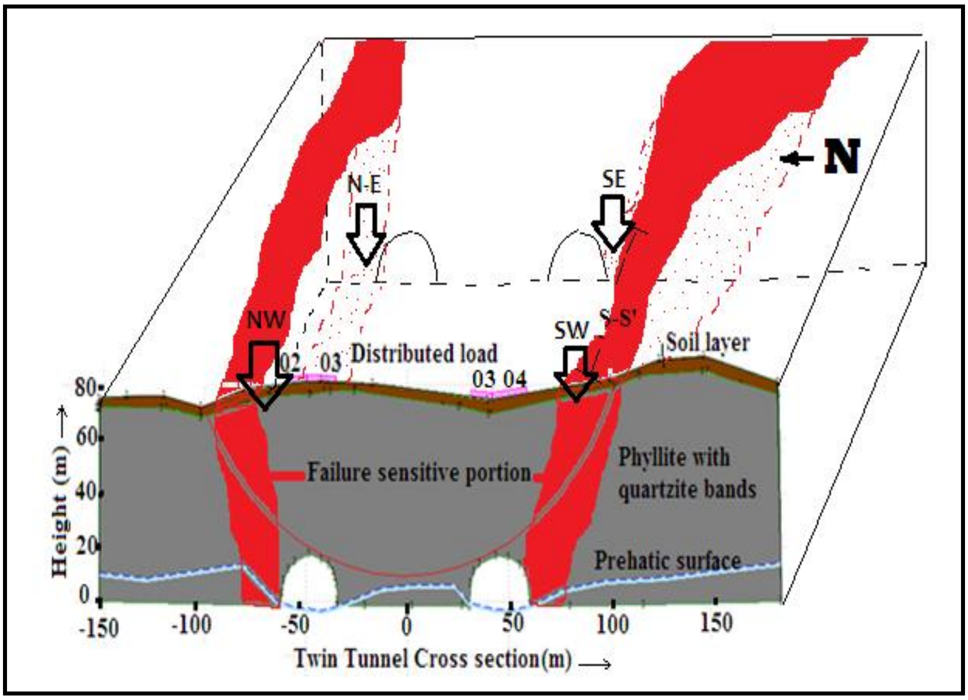

Figure 4: *Showing Twin Tunnel Ukhliyat, NH76 Gogunda-Pindwara, Western India*

Table 4: *Material (10 Profiles), Slope Surface (01) and Phreatic Surface Profiles (01)*

Profile	Material position/ Type	Material Distribution Coordinates (X,Y)
Profile:1 (3 Points)	Material beneath: 1-Soil	(-9.41, 94.21); (106.24,93.68) (106.24, 93.68)
Profile:2 (18 points)	Material within: 2 – Phyllite	(89.97, 0.12) (0.12,0.10) (2.77, 8.22) (5.95, 16.87) (8.42, 24.29) (11.25, 34.70) (5.13, 46.01) (17.96, 52.01) (21.13, 60.66) (24.31, 69.67) (29.43, 79.73) (32.96, 82.56) (44.09, 84.67) (56.10, 85.91) (65.45, 86.26) (75.52, 87.68) (89.47, 89.97) (89.97, 0.12)
Profile:3 (11 points)	Material within: 3 – Quartzite	(21.42, 53.20) (23.08, 59.51) (23.91, 62.34) (24.91 66.49) (26.23, 71.64) (27.90, 76.80) (29.39, 79.95) (30.39, 80.29) (25.40,60.68) (23.08, 54.86) (21.42, 53.20)
Profile: 4 (9 points)	Material within: 3 – Quartzite	(11.94, 25.61) (13.44, 34.09) (15.43, 39.74) (16.26, 45.22) (17.93, 45.89) (16.76, 37.91) (15.27, 33.42) (14.44, 29.10) (11.94, 25.61).
Profile: 5 (10 points)	Material within: 3 – Quartzite	(31.72, 64.83) (32.72, 70.65) (33.55, 74.30) (34.71,79.95) (36.21, 83.11) (40.86, 83.94) (39.53, 78.62) (34.88, 69.48) (33.05, 66.33) (31.72, 64.83)
Profile: 6 (23 points)	Material within: 3 – Quartzite	(21.25, 31.10) (24.07 , 36.42) (26.23, 41.57) (28.56, 47.72) (30.06, 55.86) (32.55, 60.84) (34.71, 65.50) (37.04, 67.32) (38.37, 66.99) (38.53, 64.67) (37.53, 61.84) (35.87, 58.35) (34.21, 53.53) (32.38, 50.71) (30.06, 47.05) (29.56, 43.06) (28.23, 40.07) (26.73, 36.91) (25.07, 34.59) (23.91, 32.59); (23.08, 31.43) (22.75, 30.93) (21.25, 31.10)
Profile: 7 (24 points)	Material within: 3 – Quartzite	(1.81, 0.19) (4.80, 6.01) (6.63, 11.16) (10.28, 18.14) (14.60, 25.28) (16.93, 32.10) (18.42, 37.58) (21.91, 45.72) (23.41, 50.37) (25.40, 51.21) (26.07, 50.54) (26.07, 48.71) (24.41, 45.72) (23.08, 39.91) (20.75, 37.08) (20.25, 33.42) (18.92, 31.10) (17.76, 28.44) (16.76, 26.11) (15.77, 24.45) (12.44,19.13) (7.79, 10.99) (5.13, 4.34) (1.81,0.19)
Profile: 8 (11 points)	Material within: 1 – Soil	(18.42, 47.38) (19.42, 51.70) (20.42, 55.69) (21.75, 59.85) (22.75, 63.17) (24.41, 67.82) (25.40,68.49) (23.74, 61.51) (21.58, 53.53) (20.42, 49.21) (18.42, 47.38)

Profile: 9 (11 points)	Material within: 1 – Soil	(18.42, 39.74) (19.92, 44.39) (22.41, 52.04) (24.91,59.18) (27.73,68.99) (30.06, 79.95) (32.05, 81.78) (28.39,65.66) (25.07, 56.52) (20.75, 43.89) (18.42, 39.74)
Profile: 10 (17 points)	Material within: 1 – Soil	(26.73, 48.55) (28.23, 54.20) (29.39, 60.35) (31.39, 63.34) (34.54, 67.66) (36.54, 72.14) (38.86,77.29) (40.69, 83.61) (43.52, 84.61) (39.86,75.47) (36.70, 70.15) (35.54, 67.32) (34.21, 64.83) (32.55,60.35) (30.39, 57.19) (29.23,52.53) (26.73, 48.55)
Slope surface Profile (16 points)	Comprised of Soil, phyllite and quartzite	(0.12, 0.10) (2.77, 8.22) (5.95, 16.87) (8.42, 24.29) (11.25, 34.70) (15.13, 46.01) (17.96, 52.01) (21.13, 60.66) (24.31, 69.67) (29.43, 79.73) (32.96, 82.56) (44.09, 84.67) (56.10, 85.91) (65.45, 86.26) (75.52 , 87.68) (89.47, 89.97)
Phreatic surface profile (15 points)	Water level surface	(3.75, -0.08) (8.58, 2.25) (16.40, 5.58) (25.05, 6.91) (33.86, 7.08) (49.17, 8.24) (57.98, 7.58) (65.47, 7.08) (71.29, 9.41) (75.95, 9.57) (82.10, 9.74) (85.60, 9.24) (88.09, 8.08) (89.76, 7.91) (90.09, 7.91)

Table 5: *Showing Details of Various Forces Acting on Tunnel-1*

Induced Forces on the Soil & Rock Mass	**Distributed Load (2-Loads)**				**Pseudo-static Earthquake Coefficient**	**External Force (Vehicle Movement Induced)**		
	X-Left	Pressure	X-Right	Pressure	0.150	Value	X-Pos'n	Angle
1	29.56	2.0	32.05	3.0	0.150	2.0	10.12	335.0
2	40.53	3.0	43.02	4.0	0.150	5.0	33.71	270.0

Table 6: *Showing Parameters of Failure Surface for Critical Search Defined by: XL, XR, R*

<table>
<tr><th>Particulars</th><th colspan="2">XC</th><th colspan="2">YC</th></tr>
<tr><td>Circle Centre(C)</td><td colspan="2">-135.82</td><td colspan="2">142.80</td></tr>
<tr><td>Circle radius (R)</td><td colspan="4">189.00</td></tr>
<tr><td rowspan="2">Intersections value assigned</td><td>XL</td><td>YL</td><td>XR</td><td>YR</td></tr>
<tr><td>6.45</td><td>18.37</td><td>44.02</td><td>84.66</td></tr>
<tr><td>Generated Failure surface (X,Y Coordinates)</td><td colspan="4">(6.45, 18.37) (9.08, 21.44) (11.63, 24.56) (14.13, 27.74) (16.55, 30.97) (18.90, 34.25) (21.19, 37.58) (23.40, 40.96) (25.54, 44.38) (27.61, 47.85) (29.60, 51.36) (31.51, 54.92) (33.35, 58.51) (35.11, 62.15) (36.80, 65.81) (38.40, 69.52) (39.93,73.26) (41.37, 77.03) (42.74, 80.83) (44.02, 84.66)</td></tr>
<tr><td rowspan="2">Variable restraints</td><td colspan="4">Parameter descriptor and value assigned</td></tr>
<tr><td>XL</td><td colspan="2">XR</td><td>R</td></tr>
<tr><td>Range of variation</td><td>7.00</td><td colspan="2">11.00</td><td>9.00</td></tr>
<tr><td>Trial positions within ranges</td><td>9</td><td colspan="2">9</td><td>9</td></tr>
</table>

In order to overcome difficulties of tunnel failure, field observation of the deformation behavior seems to be most promising. The stability of tunnels is assessed by comparing the derived strains with critical failure strains of the soil or rock (Sakurai S. et al., 1983). According to Sotirios V., 2007, a fundamental element of the observational method in geotechnical engineering practice is the utilization of a carefully laid out performance monitoring system which provides rapid insight of critical behavioral trends of the work. He has considered general geology and preliminary rock formation data of twin tunnel project of 450 meter long, named as Heshang highway tunnel located in South China (Sotirios V., 2007). Similarly way the numerical analyses of the tunnels have been done and their results are shown in computer generated images (Figure 5).

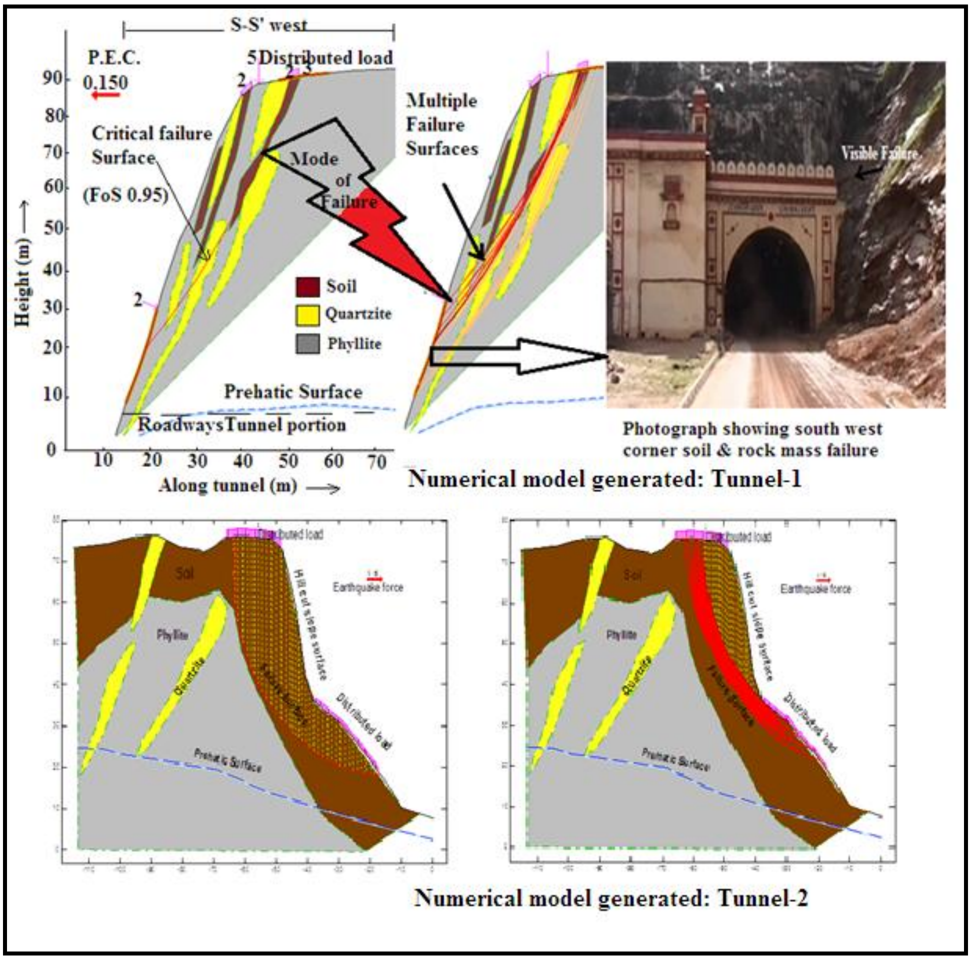

Figure 5: *Showing Numerical Analysis Modeled Failure Sensitive Tunnel Faces*

6. Conclusions and Recommendations, Measures Suggested

Rock-mass of tunnel hills categorized as fair to poor due to variation in material along X, Y and Z axis. External forces acting upon the hill rock material to weaken and resulting failures. The phreatic water surface is above the tunnel floor, which is fluctuating seasonal and related to rainfall precipitation. This causes watery conditions in tunnels. Computer generated model showing the failure sensitive portion by critical search of failure surfaces and factor of safety less than one. The present study identifies several failure planes at the twin tunnel side and entry -exist portion is more sensitive. A regular monitoring is needed for maintaining the safety of the tunnel structure and transport through the passage. Preventive maintenances' works may be undertaken well in advance.

Further works related to the site specific preventive measures like growing species, apply geo-textile, side design modification, lowering phreatic surface, prevention of rain water percolation in the sensitive rock mass, modus operandi about entry-exit side clearance, may be planned and undertaken in nature-friendly way.

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