Geotechnical assessment regarding feasibility of tunneling in high cutting zone of Rengali left bank canal, Rengali Multipurpose Project, Dhenkanal District, Odisha

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Abstract

Rengali Multipurpose Project envisages construction of a 71m high and 1040m long gravity masonry dam with a 464m long centrally located gated spillway across Brahmani River having 55550 cumec of maximum design discharge. The project has an installed capacity of 250 MW of hydroelectric power generation through the powerhouse located at the left bank dam toe at 3 km north of Rengali village($21^0$15'30": $85^0$02'00",73G/3). A 12.5m high and 530m long barrage at Samal village has been constructed at the downstream of Rengali Dam, from which the 143km long Rengali Left Bank Canal is taking off. Though the headwork portion was constructed long back (in 1994), irrigation could not be provided due to absence of canal. Water from Samal barrage will be routed through this canal to provide irrigation to the drought prone Anugul, Dhenkanal and Keonjhar Districts of Orissa. This canal alignment for a length of 4km between RD 31.500 Km and RD 35.500km has to negotiate undulatory topography involving 18m to 30m excavation. In this stretch , canal has bed width of 18.70m for carrying 145.26 cumec discharge with a velocity of 1.39m/sec. Department of Water Resources , Govt. of Orissa, proposed to drive a 9.50m diameter tunnel for avoiding the huge excavation, disposal of the excavated materials and slope failure problems in these deep cutting reaches. Accordingly, the authors undertook the study to evaluate the feasibility of constructing a tunnel in that reach. The proposed tunnel passes through moderately hard to soft horizontally disposed carbonaceous shale and subordinate amount of argillaceous sandstone and soft greenish shale belonging to Talchir group of rocks.

Study of subsurface exploration data shows inadequate rock cover (<2D) over tunnel crown with respect to tunnel diameter , presence of sub horizontally disposed soft areno-argillaceous interbedded litho assemblages, extremely poor to fair rock mass having low to moderate compressive strength at tunnel crown level and moderate to high support load. As the tunnel alignment has been fixed along topographic depression and the proposed tunnel will pass below water table, possibility of occurrence of flowing ground condition of geologically adverse zones is also possible. Since the major part of the tunnel will be driven through carbonaceous shale, occurrence of swelling or squeezing ground condition in contact with water, particularly in low cover zone is anticipated. Tunnel should be restricted between RD31.500 km and RD 33.800 km where moderately reasonable rock cover (about 2D) is available over tunnel crown and will pass through

comparatively better rock mass (sandstone) and much below the vulnerable contacts of different litho units. For tunneling, heading and benching method with controlled blasting has been suggested. Forepoling method has been recommended between RD 32.95 km and RD 33.15 km. because of its extreme poor rock mass condition. Installation of immediate support in view of very short stand up time and provision of steel fibre shotcrete are preferred. Cut and cover duct is to be constructed in the remaining portion i.e. between RD 33.8 km and RD 35.5 km.

1.0 Introduction:

Rengali Multipurpose Project consists of a 71m high and 1040m long gravity masonry dam with a 464m long centrally located gated spillway across Brahmani River having 55550 cumecs of maximum design discharge. This project has an installed capacity of 250 MW of power generation through the powerhouse located at the left bank dam toe. This is located at 3 km north of Rengali village ($21^0$15'30": $85^0$02'00", 73G/3). A 12.5m high and 530m long barrage at Samal has been constructed at the downstream of Rengali Dam, from which the 143km long Rengali Left Bank Canal is taking off. Though the headwork's portion was constructed long back (in 1994), irrigation could not be provided due to absence of canal. Water from Samal barrage will be routed through this canal to provide irrigation to the drought prone Anugul, Dhenkanal and Keonjhar Districts of Orissa. This canal alignment for a length of 4km between RD 31.500 Km and RD 35.500km ($20^0$56'30", $85^0$21'45"; 73H/5) has to negotiate undulatory topography involving overburden removal varying between 18m and 30m. In this stretch , canal has bed width of 18.70m for carrying 145.26cumecs discharge with a velocity of 1.39m/sec. Department of Water Resources, Govt. of Orissa proposed to drive a 9.50m diameter tunnel for avoiding the huge excavation of poor rock mass, disposal of the excavated materials and slope failure problems. Geological Survey of India was approached for studying the feasibility of this tunnel alignment. The authors carried out a detailed study to evaluate the feasibility of tunneling through poor rock mass.

2. Site Condition:

The site under study is located at the southeastern margin of the Talchir Basin of Coal bearing Gondwana Super group (figure 1). This stretch passes through gentle undulatory terrain. The area is predominantly soil covered with few exposures of weathered, soft, brown, argillaceous sandstone with E-W strike and 3^0-5^0 dip towards north (figure 2). Prominent bedding joint along with N-S trending subbvertical dipping joints have been noted in this rock. This alignment makes an angle of about $5^0$with regional strike of Talchir sandstone. As the area considered for tunneling is covered with soil, for assessing tunneling condition, subsurface exploration was necessary. It appears that the canal will pass through a group of sedimentary rocks comprising a topmost soft green shale, friable at its top 5m to 6m, succeeded at depth by a pink and grey soft to moderately hard argillaceous sandstone and deep grey to black soft carbonaceous shale belonging to Talchir Group, the basal member of the Gondwana Super Group. All these litho units show intertonguing relationship particularly between RD 32.300km and RD 34.400km

(Figure 3).The topmost green shale and the basal carbonaceous shale form fairly continuous units except in the middle part of the alignment while the sandstone occurs as lensoid bodies interbedded with carbonaceous shale and green shale. These rocks are unconformable underlain by partially weathered to fresh Precambrian basement. Khondalite - charnockite suit of rocks forming two basement highs at RD 33.300 km and RD 34.000km (Figure 3). At around RD 33.100km, sheared contact between the overlying sedimentaries and the basement Khondalite-Charnockite suit of rocks was apprehended (Figure 2). All these litho units are capped by a 1.50m to 3.50m thick sandy, lateritic and clayey soil.

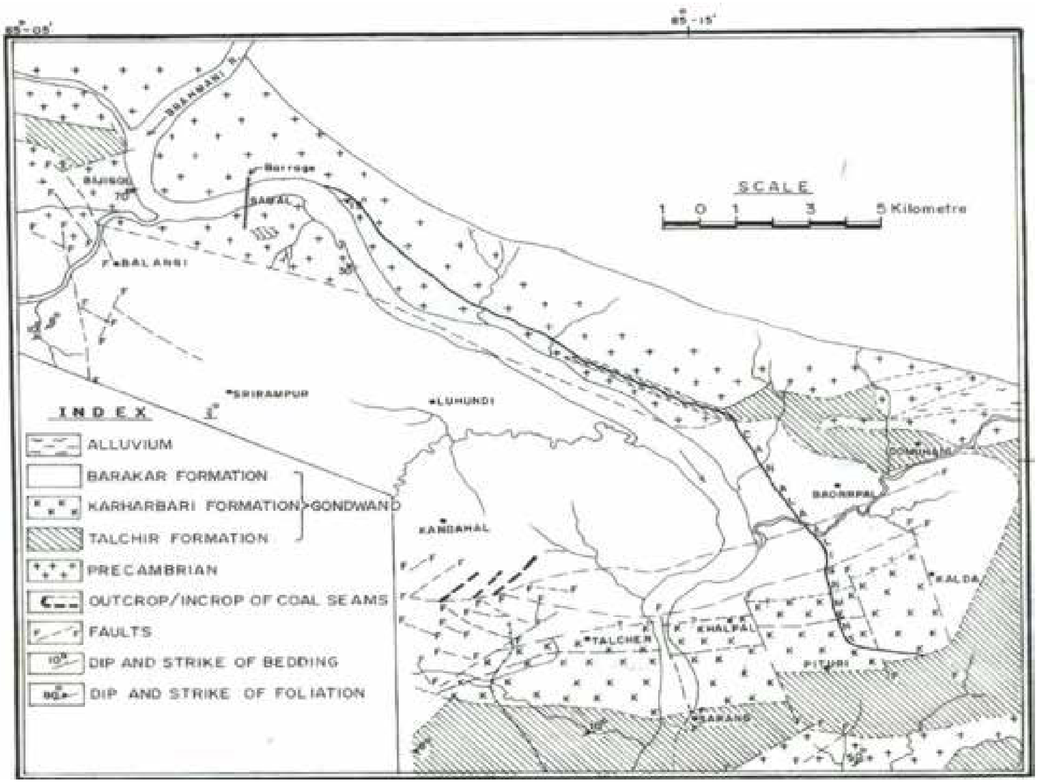

Figure 1 Regional geological map

The groundwater levels recorded in boreholes vary between depths 0.50mand 4.0m from the surface. Five earthquake incidences (magnitude varies between 4.1 and 4.3) have been recorded in between 1958 and 1993 at Talchir, Anugul, Parjang areas. The repeated earthquake occurrences along the boundary fault between Archaean Basement and Gondwanas indicate that the area is seismically active.

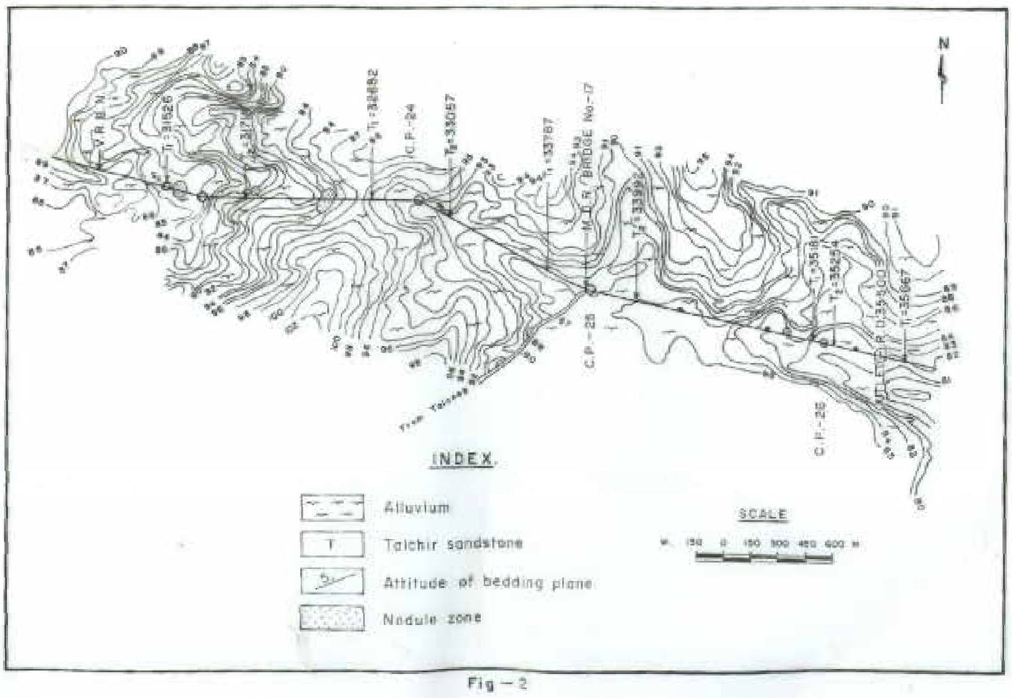

Figure 2 Detailed site geological map

2.0 Sub Surface Exploration:

On the basis of study of cores from twelve boreholes drilled along the problematic stretch between RD 31.50 km and 35.50km indicate presence of argillaceous –arenaceous-carbonaceous sediments of Talchir Group of Lower Gondwanas overlying the Archaean Basement. Topmost unit is represented by soft green shale forming a fairly continuous litho unit between RD 31.50km and RD 32. 33km, RD 34.47km and RD 35.50km. This green shale is very loose and friable in its top 3m to 6m zone and is underlain by moderately hard to soft, grey to black carbonaceous shale. In between RD 31.500km and RD 32.33km, thickness of green shale varies from 7.5m to 12m and between RD 34.470km and RD 35.50km, the same varies from 3m to 4m. Two lenses of green shale were also intersected in hole nos. 4(at RD 33.30km), 5(at RD 33.80km) and 12(at RD 34km). This shale laterally grades into a sequence of grey, pink, soft to moderately hard, medium to fine grained argillaceous sandstone with thin interbeds of carbonaceous shale between RD 32.330km and RD 34.37km either directly overlies carbonaceous shale or Basement khondalite. The latter forming two basement highs at RD 33.30km and RD 34km as intersected in borehole nos. 4 and 12 clearly indicating the highly uneven surface of the basin floor at the southern margin of Gondwana Basin during deposition of Talchir Group of rocks (Figure 3).

3. Rock Mass Classification:

Due to almost absence of exposures , rock mass classification (Barton etal,1997) was carried out from the cores in every 1.5m run length of twelve vertical boreholes drilled between RD 31.500km and RD 35.500km to evaluate the tunneling condition and to suggest the support system. Since the Gondwana sediments occur as interbedded discontinuous units, rock mass quality (Q value) determined in every 1.5m run length by total number of run length. Q values of green shale vary between 0.001 and 1.02, green shale with sandstone inter beds between 0.02 and 4.20, grey sandstone with or without thin carbonaceous shale and green shale inter beds between 0.001 and 35.07, pinkish sandstone between 0.001 and 4.07, black carbonaceous shale and sandstone inter beds between 0.08 and 4.65, brittle carbonaceous shale 0.02 and khondalite –charnockite suit of rocks between 5.50 and 32.32.

Rock mass quality (Q) above and below crown levels of the proposed tunnel vary between 0.001(at RD 33km, RD 33.8km) and 42.71 (at RD 33.3), between 0.08 and 2.75 ,between 0.001 and 32.32.Average Q values above this tunnel crown indicate very poor to fair rock mass quality. The following table (table 1) shows the synoptic rock mass classification and the related computations:

Table 1
Synoptic rock mass classifications and related computations

Hole no	Location	Rock cover	Q above crown	Q below crown	Q at crown	Computed compressive strength at crown (kg/cm^2)	Computed support load at crown (ton/m^2)	Computed ultimate support load at crown (ton/m^2)
1	32.100	1.40D	1.80(P)	3.40(P)	1.76(P)	180.169	6.10	10. 67
2	32.500	1.82D	2.57(P)	12.44(G)	14.24(G)	417.598	2.05	3.58
3	32.800	1.54D	0.81(VP)	0.68(VP)	0.063(EP)	68.554	18.57	32.49
4	33.300	1.23D	2.15(P)	29.98(G)	42.71(VG)	548.075	0.53	0.92
5	33.800	1.08D	0.51 (VP)	0.27(VP)	0.001(EP)	107.06	10.70	_
6	34.300	0.84D	0.70(VP)	0.24(VP)	0.186(VP)	85.426	12.81	22.41
7	34.800	0.62D	0.08(EP)	0.04(EP)	0.018(EP)	39.108	27.80	48.65
8	35.300	0.56 D	0.81 (VP)	2.36(P)	2.36(P)	198.677	7.40	12.93
9	33.000	1.55D	0.15(EP)	0.001(EP)	0.001(EP)	17.230	94.20	_
10	33.600	1.25D	2.00(P)	2.27(P)	4.00(F)	236.881	4.63	8.10
11	32.900	1.60D	2.75(P)	28.22(G)	6.44(F)	298.888	3.98	6.96
12	34.000	0.94D	0.2(P)	5.51(F)	1.12(P)	162.830	7.04	12.32

P=poor, VP=very poor, EP=extremely poor, F=fair, G=good

Compressive strength=$7\gamma Q^{1/3}$
Where γ =density (shale 2.09, Sandstone 2.413, Khondalite 2.196)
Short term support pressure =$2/Jr.(5Q)^{-1/3}f$

Where Jr= joint roughness and f=H-320/800, H=overburden thickness
Ultimate support pressure = Short term support pressure *1.75

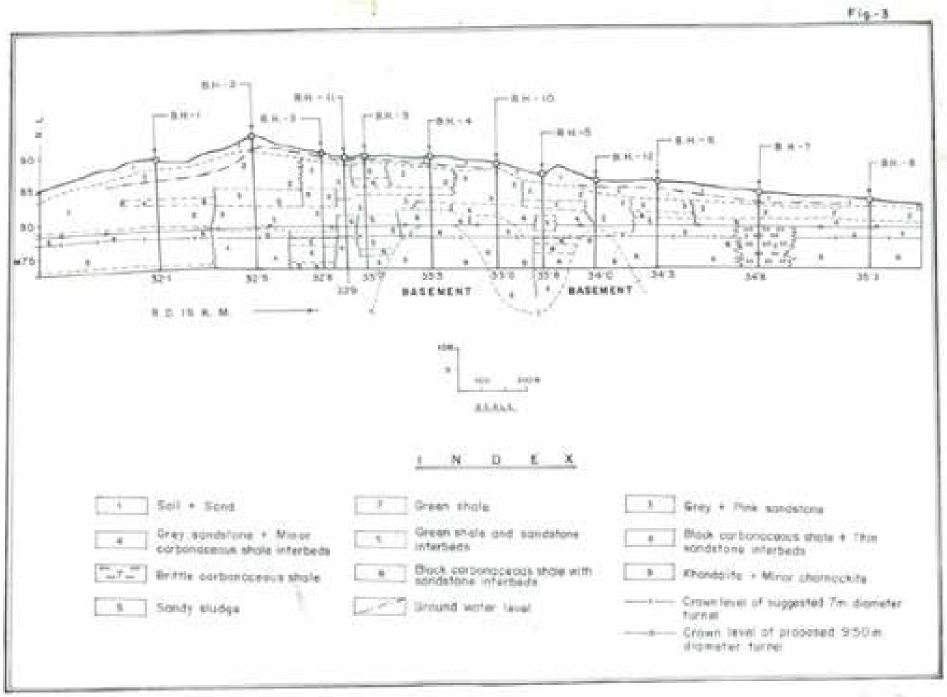

Figure 3 Geological section based on drill hole data

4. Tunneling Condition:

The prerequisites to avoid tunnel collapse are to ensure adequate sound rock cover above tunnel crown, sufficient side cover and forecasting of adverse tunneling stretches. In view of inadequate rock cover, presence of sub horizontally disposed soft arenoargillaceous interbedded litho assemblages having poor rock mass, extremely poor to fair rock mass above crown, low to moderate compressive strength at tunnel crown level and moderate to high support load, chances of frequent tunnel collapse in the form of chimney formation cannot be ruled out.

It is revealed from geological longitudinal section along the tunnel alignment that the ratio between rock cover above crown and tunnel diameter varies between 0.56 and 1.82. The tunnel will pass through soft carbonaceous shale for about of 2360m, moderately hard to soft grey, pink sandstone – carbonaceous shale interbed for 920m and basement khondalite for 720m. But the rock types from the crown level and above are markedly different. A very soft green shale, thin lensoid grey and argillaceous sand stone interbeds occurs just from crown between RD 31.500km and RD 32.340 Km. and between RD 34.470 Km. and RD 35.500 Km while in the middle part of the alignment between RD 32.340 Km and RD 34.470 Km an interbedded sequence of grey and pink argillaceous sand stone and minor green shale forming lensoid bodies occur from the crown level upwards. This tunnel alignment will pass through a 100m wide fault zone at the contact between grey sandstone and underlying basement Khondalite at RD 33.150Km . The green shale and argillaceous sandstone become soft on exposure to atmosphere. Besides soft green shale and argillaceous grey sandstone and green shale predominantly occurring just above the tunnel crown are not considered to be good arch action forming media. Hence, for driving a 9.50m diameter tunnel through such weak arch action forming rocks maximum emphasis was laid on the availability of at least 2D cover over the tunnel crown but for which frequent tunnel collapse may result. As the tunnel alignment has been fixed along topographic depression and the proposed tunnel will pass below water table, possibility of occurrence of flowing ground condition of geologically adverse zones is also possible. Since the major part of the tunnel will be driven through carbonaceous shale, occurrence of swelling or squeezing ground condition in contact with water, particularly in low cover zone is anticipated.

The main problematic stretches identified are between:

A) RD 32.950 km and RD 33.150 km (presence of sandy sludge)- extremely poor rock mass class
B) RD 34.700km and RD 34.950km (presence of highly brittle carbonaceous shale)- extremely poor rock mass class
C) RD 33.200km and 33.450 km, RD 33.950km and RD 34.050 km (presence of sheared contact of Archaean basement and Gondwanas) - poor rock mass class.

Though the assessment of support from the borehole data has got its own limitations due to wide spacing of boreholes, a tentative support system based on rock mass classification is given below in Table 2.

Table 2
Rock mass classification and support type

Stretch	Rock type(s)	Average Q value	Rock mass class	Support type
31.800km to 32.350km	Black carbonaceous shale	3.66	Poor	Sfr+ B; T=5to 9cm, B. length 2m,sp 2m
32.350km to 32.650 km	Argillaceous sandstone +/_ carb. shale inter beds	12.07	Good	B; B.length 2m,sp 2m
32.650km to 32.850km	Do	0.81	V. Poor	Sfr+ B; T= 9to 12cm, B.length 2m,sp 1.6m
32.850km to32.950km	Do	41.75	Very Good	Sb; B.length 2m,sp 3m
32.950km to 33.050km	Sheared contact between sandstone and khondalite	0.001	Exceptionally Poor	CCA
33.050 km to 33.560 km	Khondalite	32	Good	B: B.length 2m, spacing 2.5m
33.560 km to 33.770 km	Black carb. shale	1	Poor	Sfr + B ; T= 5 to 9 cm, B.length2m,spacing 1.5m
33.770 km to 33.880 km	Sand stone + / - carb. shale inter bed	0.29	Very Poor	Sfr + B ; T=12 to 15 cm, B.length 2m,spacing1.4m

Sfr= Steel fibre shotcrete, T = Shotcrete thickness, B= Systematic bolting, sb = Spot bolting, CCA = Cast Concrete Lining

5. Discussions:

The site proposed for tunneling is located at the southeastern margin of the Talchir Basin of coal bearing Gondwana Super group. The area is predominantly soil covered with few outcrops of soft ,brown ,weathered , argillaceous sandstone bed with E-W strike and 3^0-5^0 dip towards north .Study of cores from twelve(12) vertical boreholes drilled along the problematic stretch between RD 31.500 km and 35.500 km indicate presence of mostly sandstone intercalated with green shale and carbonaceous shale of Talchir Group of Lower Gondwanas overlying the Archaean Basement in the form of khondalite. The sedimentary litho units show both vertical and horizontal facies variation and intertonguing relation is prominent. Due to almost absence of outcrops, rock mass classification (Barton et. al, 1997) was carried out from the cores in every 1.5m run length of these boreholes to evaluate the tunneling condition and to suggest the support system. Q values of green shale vary between 0.001 and 1.02, green shale with sandstone inter beds between 0.02 and 4.20, grey sandstone with or without thin carbonaceous shale and green shale inter beds between 0.001 and 35.07, pinkish sandstone between 0.001 and 4.07, black carbonaceous shale and sandstone inter beds between 0.08 and 4.65, brittle carbonaceous shale 0.02 and khondalite –charnockite suit of rocks between 5.50 and 32.32. Average Q values above the proposed tunnel crown indicate very poor to fair rock mass quality.

6. Recommendations:

However taking all the aspects in to considerations, the following recommendations are made:

i. Tunnel should be restricted between RD31.800 km and RD 33.800 km where reasonable rock cover is available over tunnel crown and will pass through comparatively better rock mass and much below the vulnerable contacts of different litho units. Cut and cover duct is to be constructed in the remaining portion.
ii. As a 9.50-m diameter tunnel does not appear to be feasible through such poor rock mass and low cover zone, it has been suggested to examine the viability of driving two 7m-diameter tunnels with a separation of at least 2D from wall to wall.
iii. Alternatively viability of depressing bed level of the tunnel by 2m to 3m may be examined if a 9.5m diameter tunnel is preferred on engineering considerations. This will reduce the possibility of tunnel hazard substantially
iv. Heading and benching method of tunneling using minimum charge is to be followed.

v. In adverse zones like RD 32.950km to 33.150 km, forepoling method of tunneling should be adopted.

vi. It has been determined from the classification appears that steel fibre reinforced shotcrete (Sfr) and systematic rock bolting will be the main support beside closely spaced steel rib support may required in problematic stretches

vii. Installation of immediate support is required after excavation and before mucking operation as the rock mass class indicates very short standup time .

viii. A layer of shotcrete first on the crown and sidewalls of the tunnel immediately after blasting and minor scaling may be applied.

ix. Arrangement for invert strut of steel rib support should be made as there is a possibility of heaving at bottom or side walls of tunnel.

x. As the weak Talchir shale possess short stand up time for avoiding the possibility of tunnel collapse during excavation of a 9.5m diameter tunnel- a double drift method of tunneling/driving a pilot tunnel in the centre followed by widening may be done.

xi. Davy's safety lamp should be used for identifying poisonous gases like methane / carbon monoxide.

xii. Suitable safe seismic coefficient is to be considered in designing the tunnel in view of repeated seismicity in this belt.

Picture 1 & 2 Excavated section showing sandstone- shale layer

Picture 3 Excavated section showing carbonaceous shale

Picture 4 Cut & cover duct under construction in problematic stage

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