Expression of Interest (EOI) for Selection of Firms /Experts to accelerate the progress of Heading excavation at four critical faces in the Head Race tunnels (HRTs) of 500 MW Teesta-VI HE Project, Gangtok, Sikkim

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NHPC LIMITED
(A GOVT. OF INDIA ENTERPRISE)
Regd. Office: NHPC Office Complex, Sector-33, Faridabad-121003 (Haryana)
International Competitive Bidding
(Expression of Interest)
(Open Tender Enquiry)
(E-Tendering-Web Notice)

Tender ID.:2026_NHPC_916799_1 **Date: 10-07-2026**

1. Online Expression of Interests (EOIs) are invited from eligible domestic as well as international firms / companies in Single Stage -One Part Bidding Basis (i.e. Cover-I: Techno-Commercial Application) for and on behalf of NHPC Ltd. (A Govt. of India Enterprise) for "Expression of Interest (EOI) for Selection of Firms /Experts to accelerate the progress of Heading excavation at four critical faces in the Head Race tunnels (HRTs) of Teesta-VI HE Project, Gangtok, Sikkim" on open invitation basis. The term of conditions is as per the EOI document.
   Complete document can be viewed and down loaded from the e-Publishing Portal of Central Public Procurement (CPP) Portal **https://eprocure.gov.in**. The site can also be viewed through e-procurement corner of NHPC website **www.nhpcindia.com**. The application is to be submitted only within the deadline for online submission.

   OBJECTIVE

   The primary objective of this Expression of Interest (EOI) is to empanel an Expert Agency to expedite the heading excavation of four active critical faces (i.e., Face-3A, 3B and Face-4A, 4B) between Adit-2 & Adit-3 in twin Head Race Tunnels (HRTs). The excavation progress of aforesaid critical faces is currently going very slowly and average heading excavation rate is approximately15 m/month. This progress is being adversely affected by poor to very poor geological conditions, including seepage, ingress of water/slush, cavity formation, face collapses, and the presence of methane gas.
   The Expert Agency shall provide specialized technical expertise, innovative excavation technologies, optimized design solutions, and continuous engineering supervision to facilitate safe, stable, and accelerated tunneling at all active faces while ensuring adherence to strict project schedules. Interested firms are encouraged to obtain further comprehensive details by visiting the Teesta-VI HE Project.

A. The brief details of the EOI are as under:

Sl. No.	Item	Description
i)	Mode of EOI	e-Procurement System or designated e-mail Cover-I: Techno-Commercial Application
ii)	EOI ID	2026_NHPC_916799_1
iii)	EOI reference No.	NH/CCW/CC-II/Teesta VI /EOI-91 dated 10-07-2026

iv)	Period of Validity of application	120 Days
v)	EOI inviting Authority	General Manager, CC-II, Contracts Civil Division, Corporate Office, Faridabad, Haryana, 121003 e-Mail:contcivil2-co@nhpc.nic.in
vi)	Venue for opening of Application received through designated e-mail	O/o General Manager(Civil)-HOP NHPC Limited, Teesta-VI HE Project, Balutar, East Sikkim(Sikkim)-737134 e-Mail: "hopteesta6@nhpc.nic.in

B. The critical dates for EOI Applications are as under:

Sl. No.	Particulars	Date & Time
i)	Publishing Date & Time	10.07.2026 (12:00 Hrs)
ii)	Document Download Start Date & Time	10.07.2026 (12:00 Hrs)
iii)	Last date of Receipt of clarification on EOI	Within 14 days.
iv)	Online Application Submission Start Date & Time	10.07.2026 (12:00 Hrs)
v)	Online Application Submission Closing Date & Time	24.08.2026 (15:00 Hrs)
vi)	Opening of EOI Application (Cover-I)	Date & time: 25.08.2026 (15:30 Hrs.)

2. *BACKGROUND AND PROJECT OVERVIEW*

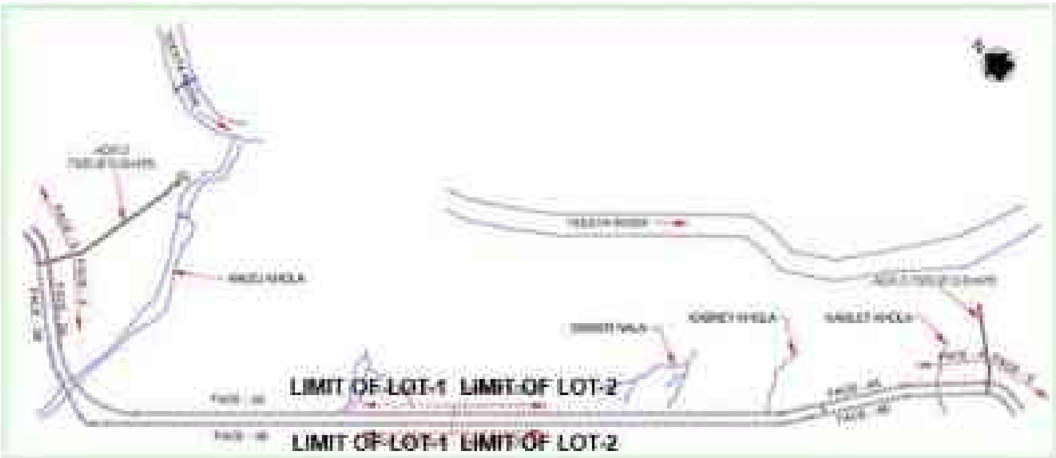
Teesta Hydroelectric Project, Stage-VI is a 500 MW (4 x 125 MW) run-of-the-river hydroelectric project located in South Sikkim. NHPC took over the partially constructed Teesta-VI Project in 2019 from M/s Lanco Teesta Hydro Power Limited for its completion. The project envisages the construction of a 26.5 m high barrage across the River Teesta near Sirwani village (Singtam), two Head Race Tunnels (HRTs) each of 9.8 m diameter and approximately 13.76 km in length, leading to an underground powerhouse near Tarkhola village. The approximate distance of Project Barrage site from different important towns is as below:

From Singtam to Barrage Site	:	4.0 kms(approx)
From Rangpo to Power House Site	:	12.5 kms(approx)
From Singtam to Siliguri	:	95 kms(approx)
From Barrage site to Siliguri	:	99 kms(approx)

From Power House site to Siliguri	:	67 kms(approx)
From Siliguri to Kolkata	:	577 kms (approx)

The excavation of the HRTs is presently progressing from multiple faces, wherein four (04) critical faces - Face-3A, 3B & Face-4A, 4B between Adit-2 & Adit-3 are the primary focus (hereinafter referred to as the "four faces of HRT").

- **Lot-1 Package:** Face-3 (Face-3A in HRT-1 & Face-3B in HRT-2) falls under the scope of Lot-1, executed by M/s JAL.
- **Lot-2 Package:** Face-4 (Face-4A in HRT-1 & Face-4B in HRT-2) falls under the scope of Lot-2, executed by M/s Patel Engineering.



3. *GEOTECHNICAL BRIEF OF HRT*

3.1 Background:

The Teesta VI Hydroelectric Project is presently in an advanced stage of construction, with excavation activities nearing completion across most tunnel faces. As of 21st June 2026, the heading excavation of about 23.8Km out of the total 27.6Km required for both HRTs have been completed but significant challenging section between Adit 2 to Adit 3 remain to be excavated, whereas heading excavation at other various sections of HRTs is nearing completion. In the challenging section, a cumulative balance of approximately 3477m remains between HRT Faces 3A-4A and 3B-4B. During the last few months, progress of heading excavation in said faces has drastically hampered due to severe, adverse geological conditions. The project teams are currently dealing with Class IV and Class V rock masses, cavity formations, groundwater ingress, ground strengthening, poor stand-up time, and the presence of methane gas. However, four critical faces designated as 3A, 3B, 4A, and 4B remain pivotal to the overall project schedule, as timely commissioning is directly dependent on progress in these sections.

Geological projections indicate that poor-to-very-poor rock mass conditions will persist into the upcoming advance zones. ***With a fixed project completion target of June 2028 across all four headings, the remaining period carries a high risk of severe timeline overruns particularly at Faces 4A and 4B, where current progress rates are insufficient.***

3.2 Critical HRT Alignment Section

The alignment locations span the twin Head Race Tunnels, specifically targeting the critical remaining links between Faces 3A and 4A on HRT-1, and Faces 3B and 4B on HRT-2. This challenging reach is situated between Ch. 5.2 km to Ch. 7.0 km of each tunnel's total length. Excavation for these sections is being executed simultaneously from four headings: downstream (southerly) advances from Faces 3A and 3B are being executed under Lot 1 by M/s Jaiprakash Associates Ltd. (JAL) via Adit-2, while upstream (northerly) advances from Faces 4A and 4B are being driven under Lot 2 by M/s Patel Engineering Ltd. (PEL) via Adit-3. The design gradient in this section of the HRTs is almost 1 in 260 between Adit 2 to Adit-3. To facilitate subsequent benching and lining operations, three cross-passages/link tunnels have been provided within this challenging section to connect HRT-1 and HRT-2 each D-shaped, 30 m in length, with dimensions 5.5m in width by 6.0m in height.

3.3 Topographical Setting

Both Head Race Tunnels (HRTs) run generally North-South along the right bank of the Teesta River. However, this critical remaining section shifts to a NW-SE alignment, positioned approximately 550m to 650m into the hillside from the river's edge. The tunnel alignment traverses a rugged topography of low-to-high mountain terrain, with surface elevations varying between EL 500M to EL 650M. In areas where the alignment intersects deeply incised perennial streams, the super-incumbent vertical cover drops to approximately 150m. Furthermore, the tunnels directly underlie a dense footprint of surface infrastructure and human settlement including residential areas, schools, agricultural land, power transmission towers, and state road networks with vertical cover ranging from 130m to 300m.

3.4 Regional Geology

The project area is situated within the dynamic Lesser Himalayan zone, characterized by rugged hills, steep mountain ranges, and deeply incised valleys shaped by active tectonics and fluvial processes. Geologically, the site predominantly exposes the Gorubathan Formation of the Daling Group, which features an intensely folded and faulted phyllite–quartzite sequence indicative of severe tectonic deformation. Structurally, the area is highly influenced by major regional features: it lies approximately 15 km west of the Main Central Thrust (MCT), 36 km north of the Main Boundary Thrust (MBT), and falls under the structural influence of the regional Teesta lineament/fault aligned along the Teesta River. As per seismic zoning map of India, the project area falls within Seismic Zone-IV and has records of seismicity in adjacent areas.

3.5 Geological Setup at Tunnel Grade

The critical section of HRT tunnel alignment passes through low to medium grade meta-sedimentary argillaceous rock of dominantly Phyllite with their variants belonging to Gurubathan Formation of Daling Group of Pre-Cambrian age. Phyllitic rockmass is often associated with competent thinly bedded Phyllitic Quartzite rock. Due to alternative arrangement of high-competence Phyllitic Quartzite / Quartzite and low-competence Phyllites, tunnelling provide a typical geological setting. Beside this, multiple deformation processes of the Himalayan orogeny have characterised the rockmass in the project area to be intense folded, altered rockmass, fractured making tunnelling works very challenging.

3.6 Current Status

The heading excavations of four critical HRT Faces reveals a significant variance between scheduled targets and actual execution rates. While the critical Faces 3A and 3B under Lot 1 are progressing at a moderate pace but faces 4A and 4B under Lot 2 are experiencing severe delays. The latter are falling significantly behind their monthly targets, resulting in high "Asking Rates" to meet the scheduled heading excavation completion timeline of June 2028. The status of heading excavation at the critical faces executed after taking over the project is as under:

HRT Face 3A: Out of the total 1492m stretch, about 550m heading excavation has been completed, and balance excavation of 942m currently remains to be completed. The working face of 3A is at RD 1045m. The actual average rate of progress over the last 5months (Jan-May 2026) stands at 15.2 m/month against an asking rate of 37-40 m/month.

HRT Face 3B: Out of the total 1540m stretch, about 626m heading excavation has been completed, and balance excavation of 914m currently remains to be completed. The working face of 3A is at RD 1153m. Its last 05months (Jan-May2026), actual average progress is 17.64 m/month against an asking rate of 36-40 m/month.

HRT Face 4A: Out of the total 1361m stretch, about 560m heading excavation has been completed, and balance excavation of 801m currently remains to be completed. The working face of 4A is at RD 1274m. This face has experienced an almost complete standstill from February through May 2026 and the actual average progress over the last 5 months (Jan-May 2026) is critically low at 1.65 m/month, requiring an asking rate of 31-35 m/month to finish on time.

HRT Face 4B: Out of the total 1468m stretch, about 628m heading excavation has been completed, and balance excavation of 840m currently remains to be completed. The working face of 4A is at RD 1240m.The 5-month (Jan-May 2026) actual average progress is 10.72m/month, with an asking rate of 35-40 m/month.

Sl. No	Face	Total length (lm)	Excavated by Previous Developer (in m)	Executed by NHPC (in m)	Total Excavated (in m)	Balance (in m)
1	Face-3A (Lot 1)	1984.8	493	550	1043.0	941.8
2	Face-3B (Lot 1)	2063.3	523.3	626	1149.3	914
3	Face-4A	2075.2	714.5	560	1274.5	800.7

	(Lot 2)					
4	Face-4B (Lot 2)	2079.8	612	628	1240	839.8

3.7 Rockmass Classification Adopted

In the project, the rock classification system has been adopted as per the geomechanical classification system i.e., Rock Mass Rating (RMR) developed by Z. T. Bieniawski. The RMR class has been assigned to the whole of the excavation cross section i.e. heading and benching zone.

3.8 Geological Investigations Carried Out (2025–2026)

During the 2025–2026 period, a series of focused surface and subsurface geological, geophysical, and geotechnical investigations were undertaken. These studies aimed to address severe ground complexities encountered within critical sections of the HRT Faces 3A-4A (HRT-1), & 3B-4B (HRT-2), facilitating safe, optimal support design and timely project execution.

3.8.1 Topographical Survey and Surface Geological Mapping

To address systemic inaccuracies and a lack of detail in the legacy datasets provided by the previous project developer, NHPC alongside the Project Investigation Division (PID) executed an advanced, high-resolution topographical survey in February 2026.

Utilizing long-range laser scanners alongside modern geodetic techniques, the team generated precise, updated surface data with a strict 2m contour interval. This survey extended 120 meters laterally on both sides of the centrelines for both HRT-1 and HRT-2, establishing a highly accurate topographic baseline for these critical zones. Based on this enhanced dataset, detailed surface geological mapping was carried out to directly correlate prominent surface features with deep subsurface conditions, effectively refining the structural geological model along the alignment of the tunnels.

3.8.2 Investigations by the Geological Survey of India (GSI)

Following an intensive site investigation in August 2025 led by Sh. D. P. Dangwal, Director of the Engineering Geology Division, Shillong, the Geological Survey of India (GSI) issued crucial engineering recommendations to safely navigate highly weak and deformed Phyllitic rockmass. To prevent tunnel face collapses and manage intense side pressures, the GSI advocated for a strict top heading and bench excavation method paired with staggered workflows. Their safety framework relies heavily on real-time risk mitigation, combining 12–15m exploratory probe drilling, face mapping, and advanced structural instrumentation. To counteract water-softening and rock squeezing, they recommended keeping the phyllite dry with leak-free piping, drilling horizontal and stress-release drainage holes, and utilizing fiberglass bolts alongside potential circular rib supports. Finally, by adopting a dual RMR and Q-system rock classification, the GSI determined that steel rib spacing could be safely increased, paving the way for a return to full-face excavation once these complex fold and low-cover zones are stabilized.

3.8.3 Subsurface Investigation using Tunnel Seismic Prediction (TSP)

To look ahead of active excavation faces and proactively manage geological risks, a non-destructive Tunnel Seismic Prediction (TSP) campaign was carried out by specialized agency M/s Amberg Engineering (India) using the TSP-303 Plus system. Major surveys conducted in February 2026 at Face 3B (RD 1093) and Face 4A (RD 1268) successfully identified impending weak zones, joint discontinuities, and shifting lithological boundaries within a 100- to 150-meter predictive window ahead of the face. This crucial geophysical data allowed the project team to anticipate adverse ground anomalies before physical exposure, with mechanical excavation currently advancing safely through these critical predicted sections.

3.8.4 Gas Emission Studies by CSIR-CIMFR

To manage hazardous gas emissions during tunnelling, a specialized team from the CSIR-Central Institute of Mining and Fuel Research (CIMFR), Dhanbad, headed by Chief Scientist Dr. V. A. Mendhe, conducted multi-dimensional inspections of critical underground faces (4A, 4B, 3A, and 3B) and a surface reconnaissance of the Head Race Tunnel (HRT) alignment in March and May 2026. Following four days of continuous baseline monitoring and laboratory analysis of gas and rock samples, the team determined that the unpressurized methane releasing from pockets in the Phyllitic formation can be safely managed. Consequently, excavation has resumed at Face 4A under strict safety mandates. These directives require keeping methane levels below 1% using approved mobile monitoring units, positioning ventilation ducts within 15 meters and exhaust fans at least 25 meters from the active face and utilizing suction pumps to extract gas from cavities during pipe roofing. Additionally, operations must include a mandatory one-hour gas dilution observation period after every fresh excavation—during which all hot work is prohibited—along with immediate face sealing using shotcrete and grouting to ensure a safe construction environment.

3.8.5 In-House Deep Electrical Resistivity Geophysical Surveys

To evaluate the slow progress and uncertain subsurface conditions ahead of the excavation faces, a specialized geophysical team from the Corporate Office, Faridabad, conducted a detailed Electrical Resistivity Tomography (ERT) survey along the tunnel alignment in May 2026. This investigation comprised two profiles: the 1 km long profile ERT-1, executed over the HRT Face 4A-4B side (Lot II), achieved a maximum penetration depth of 200 m at its central portion (positioned 30 m above the tunnel grade), while the 400 m long profile ERT-2, conducted over the HRT Face 3A-3B side (Lot I), reached a maximum depth of 80m at its centre (approximately 150 m above the tunnel grade). The deeper central portion of ERT-1 is dominated by moderate resistivity values (200 Ω-m to 1000 Ω-m) reflecting a heterogeneous, moderately altered, and fractured rock mass with variable moisture, though an increase in resistivity between RD±340m and RD±720m points to a relatively dry rock mass.

In contrast, ERT-2 displays a significant drop in resistivity with depth, decreasing from 1800 Ω-m to 700 Ω-m which indicates altered and fractured rock with higher moisture retention. Across both profiles, several localized low-resistivity anomalies (100 Ω-m to 400 Ω-m) were delineated, indicating poor quality fractured rock, shear zones, or groundwater-saturated pockets that pose a high risk for localized weak zones, excavation boundary deformation, groundwater ingress, and increased support requirements during tunnelling.

3.8.6 Department of Mines & Geology-Sikkim Survey (March 2023)

In January 2024, the Department of Mines and Geology, Government of Sikkim, released findings from a joint geological mapping initiative conducted with NHPC in March 2023 along the Head Race Tunnel (HRT) alignment. The survey identified the critical section as a high-risk zone, characterized by a thick, loosely compacted soil overburden containing variable-sized boulders. Due to the area's weak geology and existing landslides including past cavity formations at Lower Maneydara the slopes are at a threshold condition for instability. Consequently, the team recommended highly cautious tunnel excavation. Furthermore, the Department advised installing geo-phones in moderate-to-high-risk areas like Karek, Maneydara, and Kabrey wards, emphasizing the need for prior coordination with district authorities, local Panchayats, and residents to prevent public grievances.

3.9 Geological Characteristics of Phyllitic rockmass

As per construction point of view, the dominant Phyllitic rockmass having typical engineering properties has influenced the overall progress of the excavation works. Phyllite is a fine-grained, foliated low grade metamorphic rock characterized by its distinct grey to greenish-grey coloration. It exhibits well-developed schistosity with thinly foliated and crenulated surfaces, giving it a notably flaky nature. On its foliation surfaces, phyllite displays a characteristic silky sheen and feels soapy to the touch. When saturated with water, the rock emits a distinct earthy smell. Compositionally, it is primarily made up of kaolinite and illite, with subordinate amounts of chlorite, and is notably free from swelling clays, though it can be carbonaceous in certain locations.

3.9.1 Engineering Properties and Strength

From an engineering perspective, phyllite is inherently soft and highly altered, making laboratory testing for strength parameters exceptionally difficult. Its soft nature even prevents accurate strength assessments using a Schmidt hammer. The rockmass exhibits a dry density ranging from 2.01gm/cc to 2.21gm/cc, coupled with a high porosity of 30.6% to 33.5%. Furthermore, its second cycle slake-durability index is remarkably low, registering at just 4% to 11%, which highlights its high susceptibility to weathering and disintegration.

3.9.2 Slake Durability Investigation

In response to tunnelling difficulties encountered in Phyllitic rockmass, particularly noted in the HRT Face 4A & 4B, Slake Durability Index tests were conducted during July 2024 by IIT (ISM) Dhanbad & in April 2025 at NHPC Geotechnical Laboratory, Faridabad.

The laboratory testing confirms that the Phyllitic rockmass traversing HRT Face 4A and Face 4B falls strictly under the Low to Very Low Durability classification as per ISRM guidelines. Rocks exhibiting low to very low slake durability pose severe geotechnical challenges during underground excavation, primarily due to their rapid weathering and accelerated degradation when exposed to atmospheric moisture and changing environmental conditions. This swift deterioration structurally undermines the newly exposed rock surfaces, leading to an immediate loss of cohesion, rapid softening, and a significantly reduced stand-up time. Consequently, such formations create highly unstable ground conditions that drastically increase the risk of progressive ravelling, unravelling of the tunnel crown, and spontaneous rock falls if immediate primary support is not applied.

Given that this highly altered, thinly foliated phyllite formation is projected to continue along the remaining tunnel alignment, the laboratory data must be considered into the future excavation / design for the balance work.

3.9.3 Seismic Velocity Profiles & Rock Competency (As per TSP)

The primary wave velocity (Vp) and shear wave velocity (Vs) inferred from the recently conducted Tunnel Seismic Prediction (TSP) study at HRT Faces 3B and 4A serve as direct indicators of rock mass competency, fracturing intensity, and structural stiffness. The seismic velocities (Vp and Vs) drop significantly from Face 3B to Face 4A, pointing to a severe change in rock mass competence.

- **Face 3B (RD 1093–1193 m):** This section shows higher structural stiffness. The primary wave velocity (Vp) stays consistently high, averaging around 2800 to 3190 m/s, while the shear wave velocity (Vs) ranges between 1600 to 1790 m/s. This indicates a more stable, compact rock mass.
- **Face 4A (RD 1268–1370 m):** There is a sharp decline in seismic velocity across this entire stretch. Vp drops to a range of 1930 to 2240 m/s, and Vs drops to 1077 to 1264 m/s. These low velocities strongly suggest that Face 4A consists of highly fractured, heavily jointed, or altered rock mass.

3.10 Observed Rock mass behaviour during excavation

3.10.1 HRT Face 3A & 3B.

Both Head Race Tunnel (HRT) faces, 3A and 3B, are currently being driven toward the downstream side along a bearing of 136°N. A major structural challenge is that both tunnels run almost parallel to the strike of the rockmass, which dips steeply at 70° to 80°. This alignment relative to the geological structure creates highly unfavorable excavation conditions.

The encountered rock mass is predominantly soft in nature, grey, and consists of thinly foliated phyllite. Intermittent bands of moderately strong phyllitic quartzite are present, featuring a maximum width of 10 to 15 cm. The rock mass is characterized by thin foliation and crenulation, and it completely lacks blockiness. Furthermore, the ground is traversed by multiple shear seams packed with clayey gouge material.

The intermittent phyllitic quartzite bands frequently act as primary hydrogeological conduits, triggering groundwater inflows that range from minor dripping to heavy flowing conditions. Upon saturation, the phyllite rockmass degrades significantly, softening to the point where it can be picked up by hand and feeling soapy to the touch. This rapid degradation results in an extremely low stand-up time.

Due to the saturated, soft rock conditions, standard primary support measures such as rock bolts, full steel rib sections, and full-face heading excavations proved ineffective. The tunnel face experienced frequent instability immediately after excavation, even when reinforced with a 50mm thick Steel Fiber Reinforced Shotcrete (SFRC) application, despite the rear span being stabilized with steel ribs and shotcrete. To counter these adverse conditions, heading excavation was shifted to a multi-segmental erection method. This involves installing a regular canopy of 89mm diameter, 21m long pipe roofing (fore poling) and restricting face advancement to a strict 0.5m to 1.0m per cycle.

To prevent further destabilization of the fragile rock face, excavation is being carried out entirely by non-explosive, mechanical means. However, this method generates muck in the form of fine chips. When mixed with the heavy seepage, this material transforms into a slushy, sticky slurry on the tunnel floor, creating severe hindrances for mucking equipment and haulage activities.

Actual ground condition confirms poor rock quality across both faces. In HRT Face 3A (excavated by NHPC), the rock mass is predominantly poor to very poor, consisting of roughly 94% Class-V and 6% Class-IV rock, with Rock Mass Rating (RMR) values consistently below 29. Similarly, HRT Face 3B predominantly traverses Class-V ground (approx. 69%) and Class-IV ground (approx. 31%), with RMR ratings generally staying below 35.

In February 2026, a Tunnel Seismic Prediction (TSP) study was conducted by M/s Amberg Engineering India at HRT 2 Face 3B near RD: ±1093m. The geophysical findings projected 100m ahead, indicating that no immediate improvement in ground conditions should be expected up to RD: 1193m. Currently, the working face of HRT Face 3B has progressed to RD: 1153m, and the actual altered and degraded rock mass encountered on-site remains completely aligned with the TSP findings.

3.10.2 HRT Face 4A & 4B.

The Head Race Tunnel (HRT) Faces 4A and 4B are currently being driven upstream (Northerly) and against the steep dip 30° to 45° of the rock formation under highly unfavourable conditions. Excavation is primarily carried out using non-explosive hydraulic breakers within a highly altered, sheared, and thinly foliated phyllitic rock mass. This rock mass exhibits crenulation, lacks blockiness, and features irregular, sugar-cube-textured, quartz-rich bands.

Furthermore, multiple shear seams filled with clayey gouge material traverse the formation. Upon saturation, the phyllite degrades rapidly, exhibiting a soapy texture and softening to a degree where it can be easily picked up by hand. This drastically reduces the stand-up time of the rock mass.

Due to the saturated and soft nature of the rock, conventional full-heading excavation and standard primary supports such as rock bolts and full steel rib sections proved unviable. Even after applying a 50mm thick Steel Fibre Reinforced Shotcrete (SFRC) layer directly at the face, frequent instability was observed, requiring the rear span to be stabilized with steel ribs and shotcrete.

To overcome these adverse geological conditions, the multi-segmental tunnelling has been adopted. This also involves installing a continuous canopy of 21-meter-long, 89mm diameter pipe roofing and restricting face advancement to a strict 0.5m to 1.0m per cycle. Additionally, because the mechanical hydraulic breaking generates fine rock chips, the floor conditions quickly deteriorate into a slushy, sticky mud upon water saturation, severely hindering mucking and haulage operations.

Based on actual site mapping, the rock mass encountered at HRT Face 4A is overwhelmingly poor, consisting of approximately 93% Class-V (Very Poor) and 7% Class-IV (Poor) rock, with Rock Mass Rating (RMR) values consistently below 24. Similarly, HRT Face 4B has been excavated predominantly in Class-V rock (85%) and Class-IV rock (15%), with RMR rating values likewise remaining below 27.

A Tunnel Seismic Prediction (TSP) investigation was conducted at HRT-1 Face 4A (RD 1268 m) in February 2026 by M/s Amberg Engineering (India). The TSP data confirms that the existing, highly unfavorable Class-V geological conditions are projected to persist ahead of the face for the next 100m (up to RD 1365 m). The tunnel will continue to negotiate highly sheared and crushed phyllite characterized by poor stand-up time when wet. Crucially, the forecast also identifies few distinct water-bearing zones anticipated, which will require stringent probing and drainage control.

3.10.3 JOINT SET PARAMETERS

Progressive geological mapping reveals a structural contrast between the different tunnel faces. In HRT Faces 3A and 3B, the rock mass is characterized by alternating bands of soft nature of phyllite and medium strong phyllitic quartzite, which have given rise to more than three distinct, pronounced joint sets. Conversely, the highly altered and sheared phyllitic rock mass encountered in HRT Faces 4A and 4B lacks any such clearly visible or well-defined joint sets due to its heavily crushed, thinly foliated, and unblocky nature. The specific engineering parameters recorded for the joint sets observed across these sections are detailed in the table below.

HRT FACE 3A-3B

Joint Set No.	Avg. Orientation	Persistence	Spacing
S1	190-240°N/40°-80°	10-20m	<60mm
S2	110-190°N/45°-70°	1-3m	6-20cm
S3	040-090°N/60°	1-3m	20-60cm
S4	250-330°N/40°-60°	1-3m	0.6-2m

HRT FACE 4A-4B

Joint Set No.	Avg. Orientation	Persistence	Spacing
S1	120-200°N/30°-45°	10-20m	<60mm
S2	240°N /40°	1-3m	20-60cm

3.11 Expected Geological condition

Based upon the various investigation programme taken up recently and understanding the encountered geological conditions for the already excavated sections; now these balance section of the both the HRTs can be predicted with more certainties.

Geotechnical forecasting indicates that the both the tunnels are about to be driven severely degraded ground, with a 68% (2,366m) of the remaining alignment categorized under RMR Class V (Very Poor) rock mass parameters, exhibiting Rock Mass Ratings dropping below 20 and, in critical zones, below 10. The balance 32% (1131m) shall be driven in RMR Class IV (Poor Rock) with maximum RMR rating shall be below 30. Overall, this entire critical section is conservatively classified as Class IV (Poor) to Class V (Very Poor) ground, with an expected Rock Mass Rating (RMR) below 30; no competent bedrock is anticipated.

The table below breaks down the balance tunnel length by contractual lots and predicted Rock Mass Rating (RMR) classes:

Contractual Lot	Tunnel Heading	RMR Class V Length (Very Poor)	RMR Class IV Length (Poor)	Total Balance Length
LOT I	HRT Face 3A	743 m	199 m	942 m
	HRT Face 3B	757 m	157 m	914 m
TOTAL		**1500m (81%)**	**356m (19%)**	**1856m**

Contractual Lot	Tunnel Heading	RMR Class V Length (Very Poor)	RMR Class IV Length (Poor)	Total Balance Length
LOT II	HRT Face 4A	426 m	375 m	801 m
	HRT Face 4B	440 m	400 m	840 m
TOTAL		**866 m (53%)**	**775 m (47%)**	**1641 m**

The balance tunnel section shall be expected in highly adverse geological condition dominated by soft, altered and thinly foliated phyllite. This rock mass is highly susceptible to slaking, crumbling, and rapid degradation upon saturation, with an associated risk of encountering hazardous & flammable gas such as Methane. Intermittent bands of moderately strong Phyllitic quartzite are expected to act as primary hydrogeological conduits, facilitating groundwater inflows ranging from minor dripping to heavy flowing conditions.

3.12 List of Enclosures:

i. Annexure-1 Location Map of the Project Area
ii. Annexure-2 Regional Geological Map – Source: Bhukosh
iii. Annexure-3 Surface Geological map Between Critical HRT Faces
iv. Annexure-4 Anticipated Geological Section Between Critical HRT Faces
v. Annexure-5 'TSP report'
vi. Annexure-6 'Geophysical report'

vii. Annexure-7 'Relevant Drawings'
viii. Annexure-8 'The average cycle time'
ix. Annexure- 9 Relevant Photographs of tunnel faces

4. Progress and Timelines

Excluding the hindrances caused by cavity formation and excessive seepage, an average progress of about **13–15 m per month** is being achieved when excavation is carried out in **4–8 segments**. In stretches where excavation can be undertaken in a **full-heading face**, the average progress achieved is about **20–22 m per month**. The average cycle time observed during excavation is enclosed as

For scheduled successful completion of project, the balance HRTs heading excavation is required to be completed within 24 months.

5. Requirement of Expert Agency

NHPC Limited, a leading public sector enterprise under the Ministry of Power, Government of India, and a premier organization in the hydropower sector, is pleased to invite Expression of Interest (EOI). NHPC intends to engage a competent, specialized agency possessing proven expertise in tunnelling through Himalayan or poor rock-mass formations and gassy ground conditions. The selected agency will provide specialized technical inputs, alternative or innovative excavation technologies, and continuous engineering supervision to expedite HRT excavation progress at all the active faces.

Applicants are advised, in their own interest, to inspect and examine the site and its surroundings before submitting their applications. They must satisfy themselves regarding all site conditions, including but not limited to: site access, existing means of transport and communication; geological, geotechnical, hydrogeological, meteorological, and topographical features; the extent of surface and sub-surface water; expected gas conditions; and all other information required to perform the work. This includes assessing risks, contingencies, and other circumstances that may influence or affect the work or its cost.

Any information regarding site and local conditions provided in these documents is furnished merely for assistance and is not warranted to be complete or accurate. The Employer bears no responsibility for any lack of site acquaintance by the applicants. Additionally, applicants shall submit a comprehensive site inspection report to the client (NHPC Ltd) along with their proposal.

6. SCOPE OF SERVICES

Following shall be the scope of services for the consultancy works to suggest new technique/ methodology to enhance the progress of Head Race tunnel (HRT) in very poor geological conditions while **adopting the same tunnel sizes & alignments*:***

1. **Detailed Review:** Detailed review of all available data (Tender Documents, Construction Drawings, Geological data / report, Geotechnical investigations / Test Reports, record of issues / incidences at site & their treatment, other reports etc.) and construction methodologies and instrumentation data provided by the Client and assessment of the present excavation methodology / practices, support system and progress at the four faces.

2. **Technological Innovation:** Recommendation and introduction of new / alternative excavation technologies, methodologies and sequencing suited to the prevailing poor rock-mass and gassy conditions, so as to expedite the progress of tunneling at the four faces by optimizing resources, manpower & equipment deployment etc. and prepare a schedule for early completion of balance works.
3. **Numerical Analysis:** Carrying out / overseeing appropriate numerical analysis (continuum and/or dis-continuum modelling) to validate the proposed excavation sequence, support design, ground-improvement measures and cavity / collapse rehabilitation schemes.
4. **Ground Improvement Designs:** Design and recommendation of suitable ground-improvement, pre-support and rehabilitation measures (such as face sealing, grouting, pipe roofing, fore-poling, pre-drainage, multi-drifting, rib / lattice-girder support, dewatering system etc.) for the weak and collapsing reaches.
5. **Methane Gas Management:** Recommendation and supervision of a comprehensive methane-gas management strategy, including gas detection / monitoring instrumentation, adequate ventilation and dilution, flame-proof / explosion-protected equipment and safe-working protocols to eliminate the risk of fire during the works.
6. **Geotechnical Testing:** Specifying and where required conducting, the geotechnical / geological field and laboratory tests necessary to resolve the current geotechnical issues (e.g. rock-mass characterization, probe-hole drilling, TSP / geophysical surveys, in-situ and laboratory rock testing, instrumentation and monitoring).
7. **Continuous Supervision:** Regular and periodic site visits by the Agency's experts and continuous supervision of the construction contractors' work at the two faces to ensure correct and timely implementation of the recommended measures. Assistance in resolving geological surprises encountered during excavation by providing immediate recommendations.
8. **Progress Monitoring:** Review of the contractors' work plans, monitoring of progress, identification of bottlenecks and provision of timely engineering solutions to accelerate excavation while ensuring safety and stability.
9. **Reporting:** Preparation and submission of periodic technical reports, recommendations, drawings and progress reviews and participation in review meetings with the Client.
10. **Others:** Any other allied engineering / geotechnical activity necessary to achieve safe and expedited progress of the HRT excavation at the two faces.

7. DATA / INPUTS TO BE PROVIDED BY THE CLIENT (NHPC)

All the data necessary for carrying out the assignment shall be provided by the Client (NHPC), including but not limited to:

- Tender Documents
- Construction Drawings

- Geological data / report, Geotechnical investigations / Test Reports, Face logs, RMR records, TSP / geophysical survey data, gas-monitoring records etc.
- Record of issues / incidences at site & their treatment
- Any other relevant data / reports
- Current construction methodologies
- Instrumentation data
- The present status and progress of the HRT works.

8. DELIVERABLES

The Agency shall provide actionable technical and management solutions aimed at:

- Reducing project delays.
- Enhancing construction productivity.
- Optimizing resource utilization.
- Managing project risks.
- Achieving timely completion of the remaining tunnel works while maintaining safety and quality standards.

9. ELIGIBILITY CRITERIA FOR PROSPECTIVE BIDDERS

To be considered eligible for this Expression of Interest, prospective Bidder(s) / Expert Agency(s) must meticulously demonstrate their qualifications and capabilities across several key areas. Prospective Bidder(s) / Expert Agency(s) are required to essentially visit the Teesta-VI HE Project within 15 days of the issue of this EOI for crucial on-ground assessment and fully acquaint themselves regarding all the aspects of the work. Based on various relevant implementation inputs the bidder(s) / Expert Agency(s) should ensure submission of an optimized, practical and justified EOI proposal. To be considered eligible for this Expression of Interest, prospective Bidder(s) / Expert Agency(s) must meticulously demonstrate their qualifications and capabilities across following key areas:

- **Experience in Similar Projects**: A fundamental requirement is a proven track record in the successful execution of tunneling through Himalayan or poor rock-mass formations and gassy ground conditions. Bidders must be able to substantiate their claims with relevant project documentation.
- **Technical Capability and Expertise**: The Bidder / Expert Agency(s) must unequivocally possess the requisite technical expertise to undertake such a complex operation. This encompasses a thorough understanding of various design & construction methodology of hydro tunnels in poor rock strata, and access to a highly skilled and experienced manpower pool. Furthermore, the Bidder /Expert Agency(s) should demonstrate the availability of other essential resources necessary for efficient and effective project execution. This

includes, for instance, access to relevant software, project management tools, and safety equipment.

- **Financial Capability and Stability**: Demonstrating financial stability and capability is paramount. While detailed financial statements are not required at this juncture, Bidder(s) / Expert Agency(s) should be prepared to provide evidence of their financial soundness upon request in subsequent stages of the tender process. This could include, but is not limited to, audited financial reports, lines of credit, or other verifiable financial instruments that demonstrate the ability to fund a project of this magnitude. This ensures that the selected firm has the necessary capital to sustain operations throughout the project lifecycle.

10. REQUIRED SUBMISSIONS FOR EOI

Interested Bidder(s) / Expert Agency(s) are essentially required to visit the site (Teesta-VI HE Project) within 15 days of the issue of this EOI. This site visit is crucial for a thorough understanding of the project's complexities and challenges. Following the site visit, Bidder(s) / Expert Agency(s) must submit their EOI, complete in all respects, within the next 30 days. The submission should include comprehensive details as outlined below:

(a) **EOI Letter and Company Profile**: A formal EOI letter accompanied by a detailed company profile. This profile should meticulously outline the company's background, core competencies, organizational structure, and overall experience and expertise relevant to tunneling through Himalayan or poor rock-mass formations and gassy ground conditions.

(b) **Project Experience Documentation**: Relevant and verifiable documents justifying project experience. This section should specifically highlight successful past projects that are directly comparable to tunneling through Himalayan or poor rock-mass formations and gassy ground conditions, providing details on project scale, challenges overcome, and outcomes achieved. Case studies, completion certificates, and client testimonials would be highly beneficial.

(c) **Technical Capability and Proposed Approach**: A comprehensive description of technical capabilities, including a brief yet insightful note on the proposed approach, methodology, and tentative timeline for execution. Furthermore, a detailed profile of key technical personnel intended to be deployed on the project, highlighting their relevant experience and qualifications, is required.

(d) **Detailed Methodology:** The Bidder / Expert Agency(s) shall propose a detailed methodology for the execution of the work. The methodology should demonstrate a clear understanding of the project's challenges and proposed solutions.

(e) **Tentative Timeline for Execution**: A well-structured tentative timeline for the execution of the work. This timeline should outline key milestones, phases, and estimated durations for each activity, providing a realistic roadmap for project completion. The schedule of activities should clearly reflect the activities which shall be in parallel and in series so as to ensure benchmarking for effective monitoring till completion of the work.

(f) **Submission Method**: All required documents as outlined above shall be furnished by the Bidder / Expert Agency exclusively through email to the designated email ID. Ensure all attachments are clearly labeled and in easily accessible formats.

(g) **Email Subject Line**: It is imperative that the interested Bidders / Expert Agency(s).

submit the information / documents with the subject line clearly stating: "**Tunneling through Himalayan or poor rock-mass formations and gassy ground conditions**." This ensures proper classification and timely processing of your submission.

11. EVALUATION CRITERIA FOR SHORTLISTING

NHPC will rigorously evaluate the submitted EOIs based on the following comprehensive criteria, aiming to identify the most suitable and capable partners for this critical project:

(a) **Relevant Experience and Track Record**: The evaluation will heavily weigh the Bidder / Expert Agency(s) experience in successfully executing similar projects, as defined and detailed in Section 9.0 (Eligibility Criteria). This includes the scale, complexity, and outcomes of past Tunneling through Himalayan or poor rock-mass formations and gassy ground conditions.

(b) **Technical Capability and Resource Availability**: This criterion assesses the Bidder / Expert Agency(s) demonstrated technical expertise, and the presence of skilled and experienced manpower for optimized operations. The proposed methodologies and personnel profiles will be key factors here.

(c) **Work Execution Approach and Suitability**: The evaluation shall consider the proposed work execution approach, specifically assessing its suitability for the project in totality, considering the optimal benefits and advantages for NHPC Ltd. This will involve assessing the efficiency, cost-effectiveness, and overall alignment of the proposed strategies with the project objectives.

12. PROJECT TIMELINE AND KEY DATES

The indicative timeline for this Expression of Interest process and subsequent project phases is as follows:

- **Site Visit**: Prospective Bidder(s) / Expert Agency(s) are required to complete their site visit to Teesta-VI HE Project within 15 days of the issue of this EOI. This allows for crucial on-ground assessment.

  Contact detail for site visit and related queries:

  Name: Sh. Sanjay Sengupta

  Designation: Deputy General Manager (Civil)

  Address of NHPC Office: Teesta-VI HE Project Balutar, Singtam, Distt. Gangtok, Sikkim

Mobile Number: **8811071178**

Email Address: **ssengupta@nhpc.nic.in**

- **EOI Submission:** The complete Expression of Interest document must be submitted by interested parties within next 30 days of the above-mentioned site visit i.e within 45 days from date of publication of as elaborated at serial no 10 followed by a preliminary assessment presentation within 15 days of EOI submission which will be followed by discussion on the question/queries of NHPC and replies thereof.

13. CLARIFICATION ON EOI DOCUMENTS

Prospective applicants requiring any clarification on the EOI document may request to EOI Inviting Authority within 14 days of issue of EOI in writing or by e-mail at the address indicated in the EOI Document. The Employer will respond to such requests for clarification which are received within the deadline for the same

14. NO CONTRACTUAL OBLIGATION

It is important to note that the issuance of this Expression of Interest (EOI) does not create any contractual obligation, explicit or implied, between NHPC Limited and any Bidder / Expert Agency(s) submitting an EOI. NHPC shall not be bound contractually or in any other way to any Expert Agency(s) submitting this EOI, and expressly disclaims any liability for any costs, expenses, or compensations incurred by the Bidder / Expert Agency(s) in relation to the preparation, submission, or consideration of this EOI. All EOI documents and accompanying information submitted by the Bidder / Expert Agency(s) shall become the sole property of NHPC Limited.

15. DISCLAIMER

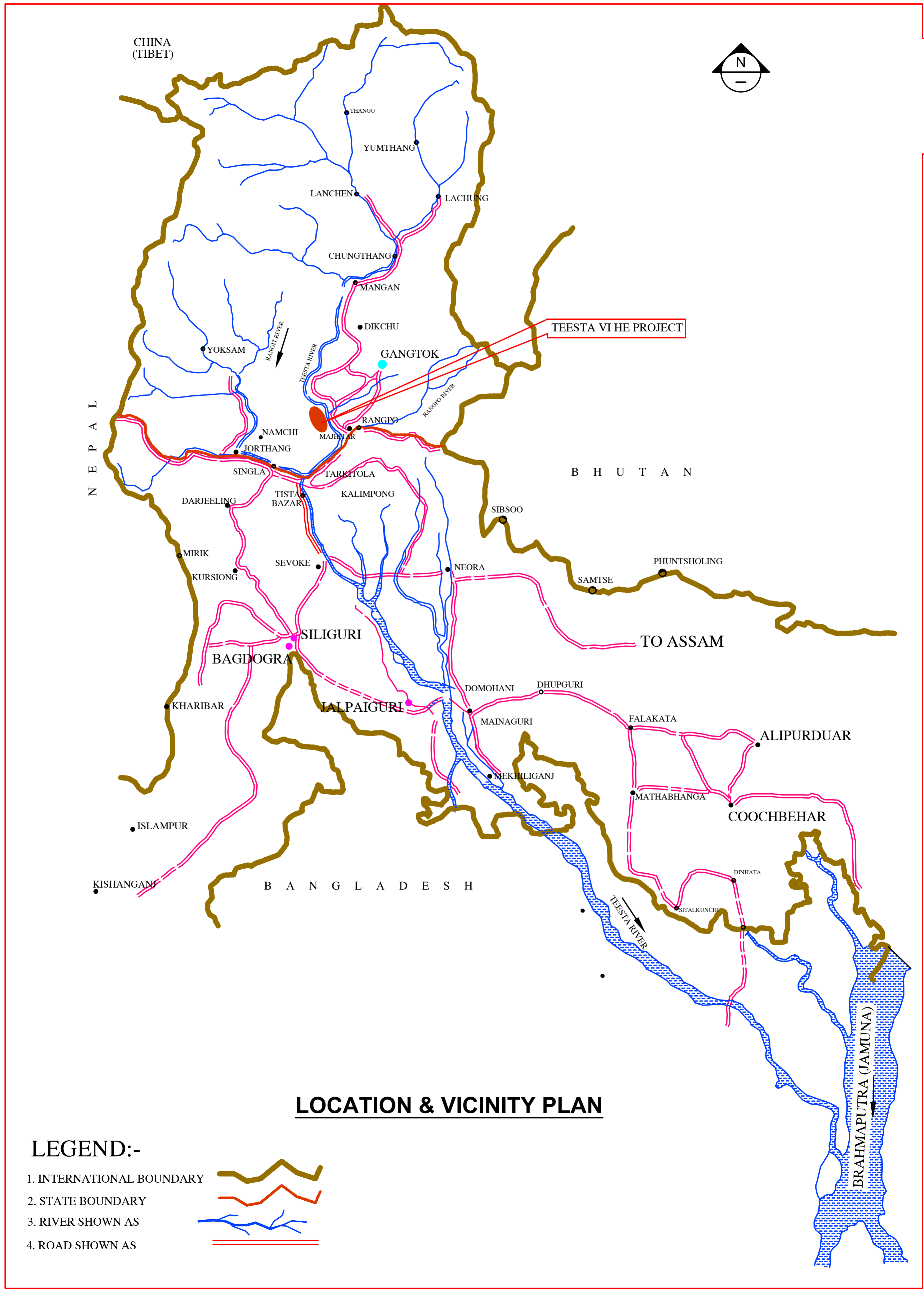
This document serves as an Expression of Interest and does not, in any manner, commit or otherwise oblige NHPC Limited to proceed with all or any part of a formal tender process. This EOI request is explicitly not the subject of any process contract or any contractual obligations between NHPC Limited and the Bidder / Expert Agency(s).

Furthermore, NHPC Limited reserves the absolute right, at its sole discretion, to either modify or abandon any part or the entirety of this document and/or the EOI process at any time, without providing prior notice to any or all of the Bidder/Expert Agency(s). NHPC's decision in this regard shall be final and binding.

Annexure-1

Location Map of the Project Area

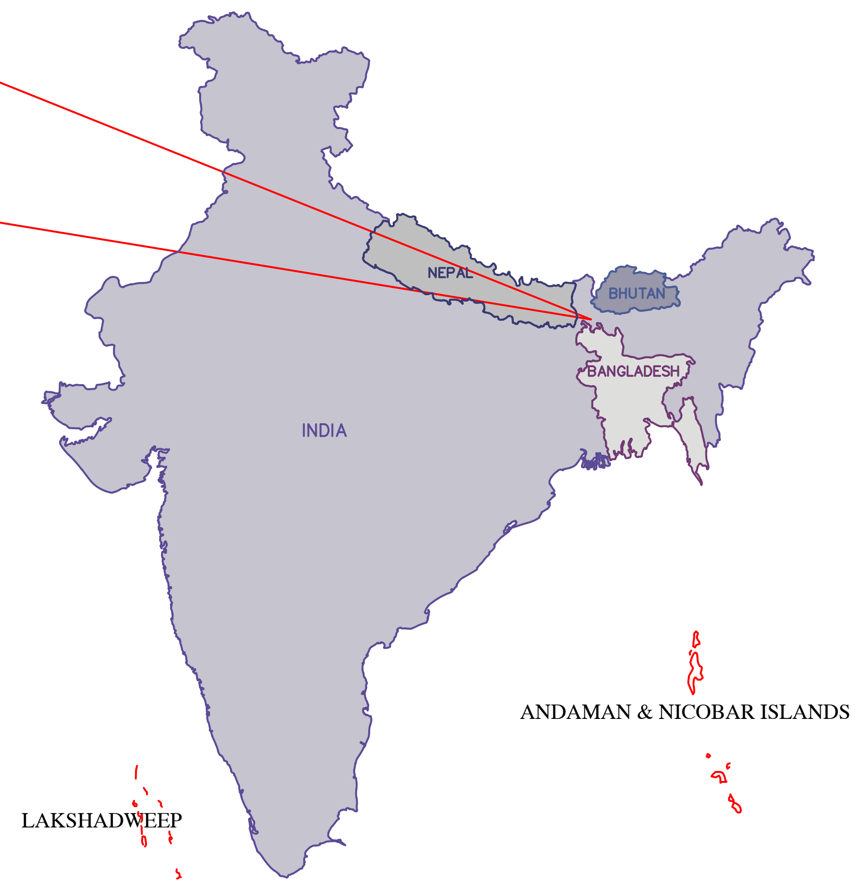
ANNEXURE-1



LOCATION & VICINITY PLAN

LEGEND:-

1. INTERNATIONAL BOUNDARY
2. STATE BOUNDARY
3. RIVER SHOWN AS
4. ROAD SHOWN AS



MAP OF INDIA
AND LOCATION OF THE PROJECT

NOT TO SCALE

NHPC LIMITED

TEESTA VI HE PROJECT

LOCATION & VICINITY PLAN

Annexure-2

Regional Geological Map – Source: Bhukosh

Annexure-2 Regional Geological Map – Source: Bhukosh

Annexure-3

Surface Geological map Between Critical HRT Faces

ANNEXURE -3

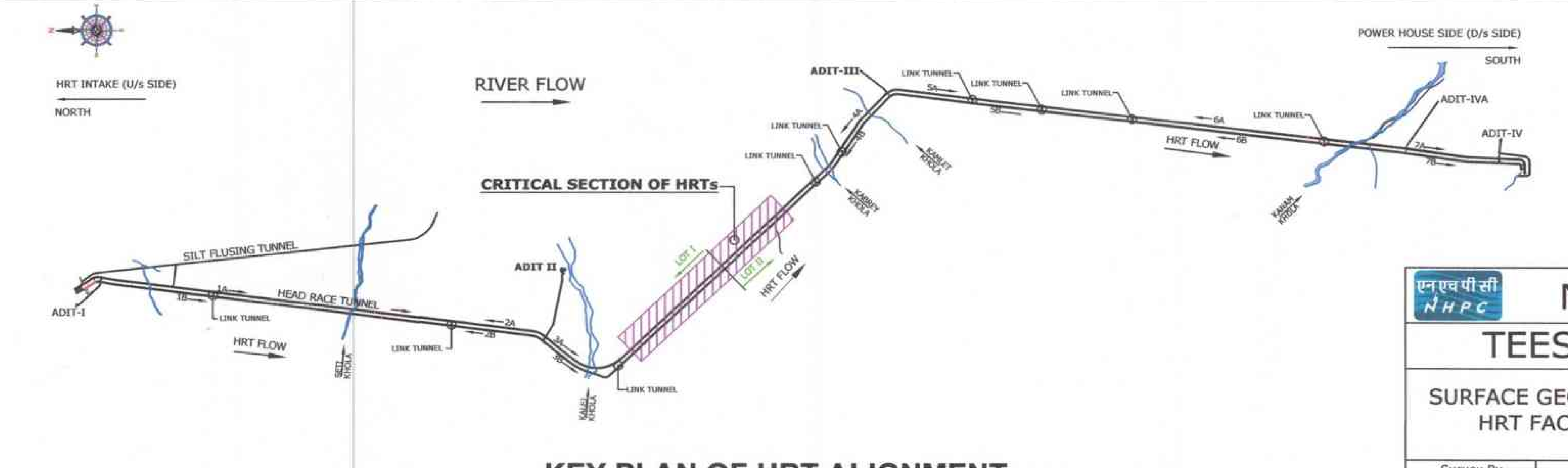
Legends

- State Road Networks (Unmettaled)
- Perennial Stream / Nala / Khola
- Seasonal Stream / Nala
- Culvert
- House / Pvt. Buildings
- Human habitations / cultivation
- High Power Transmission Towers
- Slope Wash Materials
- Rock Expoures: Phyllitic Quartzite
- Rock Exposures: Phyllite
- Foliation Joints
- Prominent Joints
- Shear Seams / Fractured Zones
- Geological Traverses Taken
- Heading Excavation Completed in HRT
- Incidence of Methane Gas Release at Tunnel Grade
- Incidence of Seepage at tunnel Grade (> 50LPM)
- HRT Face RD
- Electrical Resistivity Survey (May 2026)

NOTE

1. This contour plan has been developed by PID, CO for which ground survey was done using a high-precision long-range scanner during February 2026. This effort was performed concurrently with detailed geological mapping by the Project Geology Division to ensure a complete and accurate surface features along the alignment of HRT particulary between the critical HRT Faces 3A-4A & 3B-4B.

2. This refernce drawing has been prepared for publication within the Expression of Interest (EOI) and should be referenced concurrently with the geotechnical information provided in the EOI.



KEY PLAN OF HRT ALIGNMENT
(Not to Scale)

NHPC LIMITED

TEESTA VI HE PROJECT

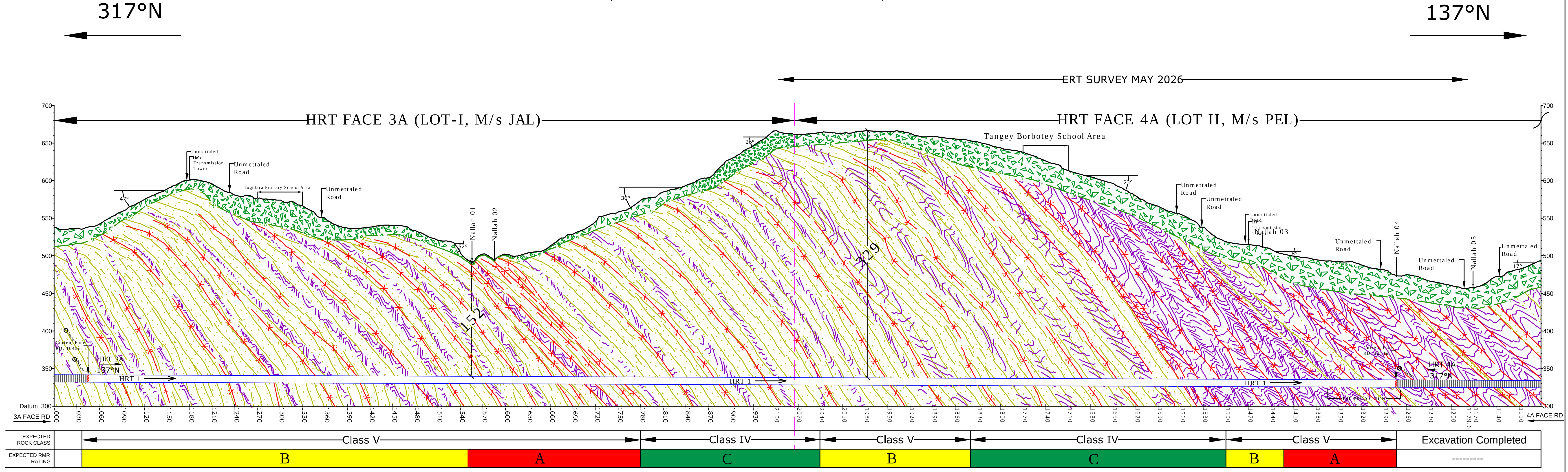
SURFACE GEOLOGICAL MAP BETWEEN CRITICAL HRT FACES-(HRT FACE 3A-4A & 3B-4B)

Survey By	Mapped, Prepared & Submitted By						Recc. By
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Date: June 2026	Dwg. No: NH/ T-VI/ GEO/ PLAN/2026						(Sheet 1 OF 2)

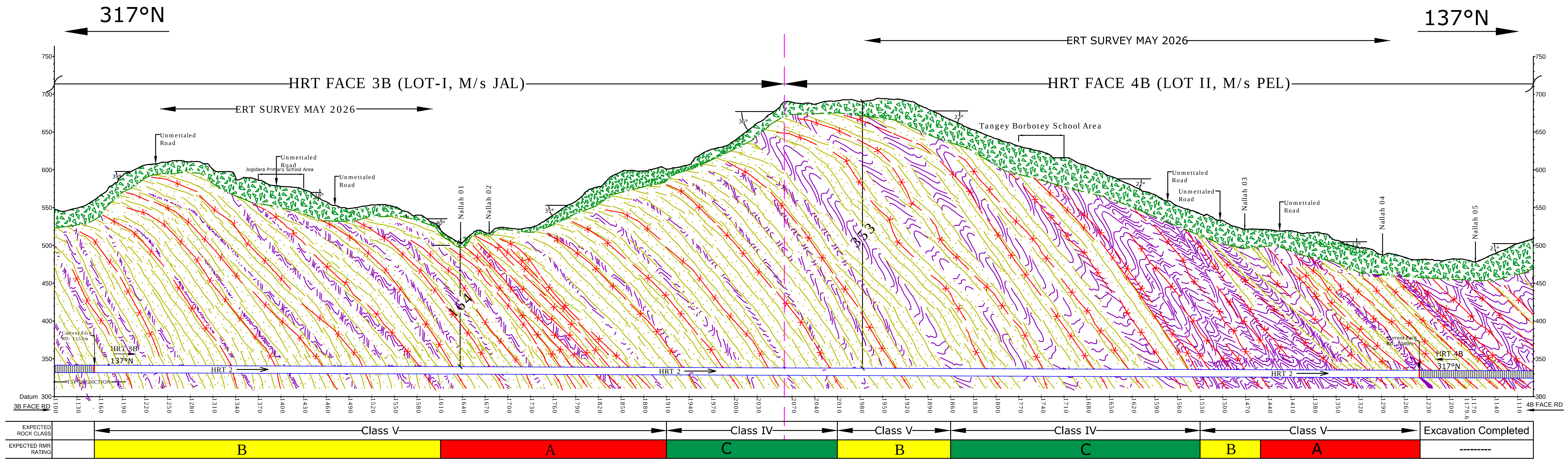
Annexure-4

Anticipated Geological Section Between Critical HRT Faces

GEOLOGICAL SECTION OF HRT 1 & 2
(HRT FACE 3A-4A & 3B-4B)



Geological Section Along HRT 2 (from Face 3A RD 1000.00 towards HRT Face 4A)



Geological Section Along HRT 2 (from Face 3B RD 1100.00 towards Face 4B)

ANNEXURE-4

- Slope Wash Materials
- Bedrock of Phyllite with interbands of Phyllitic Quartzite
- Bedrock of Soft nature of Phyllite
- Foliation Joints
- Shear Seams / Fractured Zones
- Expected Overburden-bedrock Contact
- Heading Excavation Completed

Expected Geological condition

The balance tunnel section shall be expected in highly adverse geological condition dominated by soft, altered and thinly foliated phyllite. This rock mass is highly susceptible to slaking, crumbling, and rapid degradation upon saturation, with an associated risk of encountering hazardous & flammable gase such as Methane. Intermittent bands of moderately strong phyllitic quartzite are expected to act as primary hydrogeological conduits, facilitating groundwater inflows ranging from minor dripping to heavy flowing conditions. Consequently, this entire stretch is conservatively classified as Class IV (Poor) to Class V (Very Poor) ground, with an expected Rock Mass Rating (RMR) below 30; no competent bedrock are anticipated. Furthermore, the alignment directly underlies a dense footprint of public and private infrastructures including human habitation, schools, cultivated lands, transmission towers, and state road networks with a vertical cover ranging from 130m to 300m.

Expected RMR/Q Rating

	RMR Values	Q Values
A	<10	<0.02
B	10-20	0.02-0.1
C	21-30	0.1-0.3

The conversion from Q to RMR has been carried out using the empirical correlation **RMR=9ln(Q)+44** .

The recorded for the joint sets observed across these sections are detailed in the table below:

HRT FACE 3A-3B

Joint Set No	Avg. Orientation	Persistence	Spacing
S1	190-240°N/ 40°-80°	10-20m	< 60mm
S2	110-190°N/ 45°-70°	1-3m	6-20cm
S3	040-090°N/ 60°	1-3m	20-60cm
S4	250-330°N/ 40°-60°	1-3m	0.6-2m

HRT FACE 4A-4B

Joint Set No	Avg. Orientation	Persistence	Spacing
S1	120-200°N/ 30°-45°	10-20m	< 60mm
S2	240°N/40°	1-3m	6-20cm

NOTE:-

1. This section has been developed from contour Plan freshly surveyed and prepared by Project Investigation Division, CO using a long-range scanner in February 2026 on the request of project.
2. The geological section in the intended stretch been updated after a detailed surface geological mapping by the Project Geology Division, Geophysical Survey conducted by CO during May 2026 and TSP conducted during Feb 2026 in HRT Face 3B & 4A.
3. To optimize drawing clarity, the discontinuity sets tabulated above are not shown in the geological sections.
4. For Geological Plan, Please refer to Dwg. No: NH/ T-VI/ GEO/ PLAN/2026. (Sheet 1 OF 2)
5. This refernce drawing has been prepared for publication within the Expression of Interest (EOI) and should be referenced concurrently with the geotechnical information provided in the EOI.

0 50 100 150 200M

NHPC LIMITED

TEESTA VI HE PROJECT

ANTICIPATED GEOLOGICAL SECTION OF HRT 1 & 2 (CRITICAL HRT FACE 3A-4A & 3B-4B)

Survey By	Mapped, Prepared & Submitted By						Recc. By
Satish Kr Dhatwalia, AM (Survey) Jatan Malik, AM (Survey) Project Investigation Division, CO	Manoj Brahma AM (Survey) Teesta VI HEP	Sunil Kr Dass TO (Geology) Teesta VI HEP	Prateeksha Patel TO (Geology) Teesta VI HEP	Anish Mohan SM (Geology) Teesta VI HEP	Anoop Kr. Patel SM (Geology) Teesta VI HEP	Shishir Rath SM (Geology) Teesta VI HEP	Sailendra Singh Bariha Dy. GM (Geology) Teesta VI HEP
Date:JUNE 2026	Dwg. No: NH/ T-VI/ GEO/ PLAN/2026						(Sheet 1 OF 2)

Annexure-5

'TSP report'

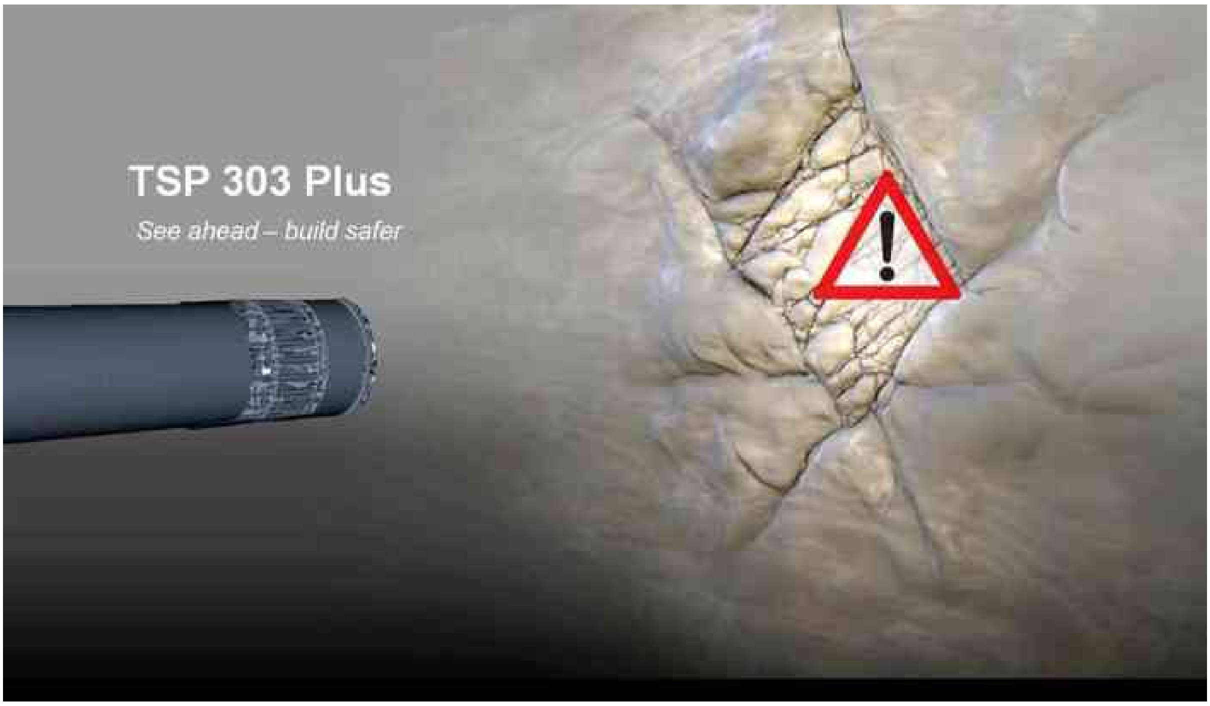
Jaiprakash Associates Pvt Ltd,
Teesta H.E. Project – VI, Sirwani,
Singtam, East Sikkim - 737134, India

AMBERG Engineering (India)
Unit No. 321-329 3rd Floor
Vipul agora, MG Road
Gurgaon (HR) - 122002
Phone +91-124-4881000
www.amberg.ch

Teesta-VI Hydroelectric Power Project

Result Report of Tunnel Seismic Prediction - TSP 303 Plus

Campaign location: #6 HRT2 FACE 3B_RD 1,093
Campaign date: 16th Feb 2026



1. Preface

The Teesta Stage-VI Hydroelectric Project, located in Sikkim, is a run-of-river scheme with a diversion barrage situated approximately 100 m downstream of L.D. Kazi Bridge at Sirwani, near Singtam, Sikkim. Jaiprakash Associates is responsible for the balance civil works, including the barrage, desilting basins, silt flushing tunnel (SFT), intake structure, parts of HRT-1 and HRT-2, and other associated structures.
As part of Lot-I of the Teesta VI HEP (500 MW) project, Jaiprakash Associates awarded the Tunnel Seismic Prediction (TSP) services to Amberg Engineering India. One TSP measurement was planned and carried out in HRT-2. A schematic diagram of the project layout is provided in Figure 1.
The primary objective of this investigation was to assess the rock mass condition ahead of and around the tunnel face within a prediction range of 100–150 m. This report provides a summary of the operational work, measurement procedures, and results of the TSP survey conducted at HRT-2 Face 3B, where the tunnel face was located at RD1,093 at the time of measurement. The horizontal distance between the two parallel tunnels at current chainage is 30m.

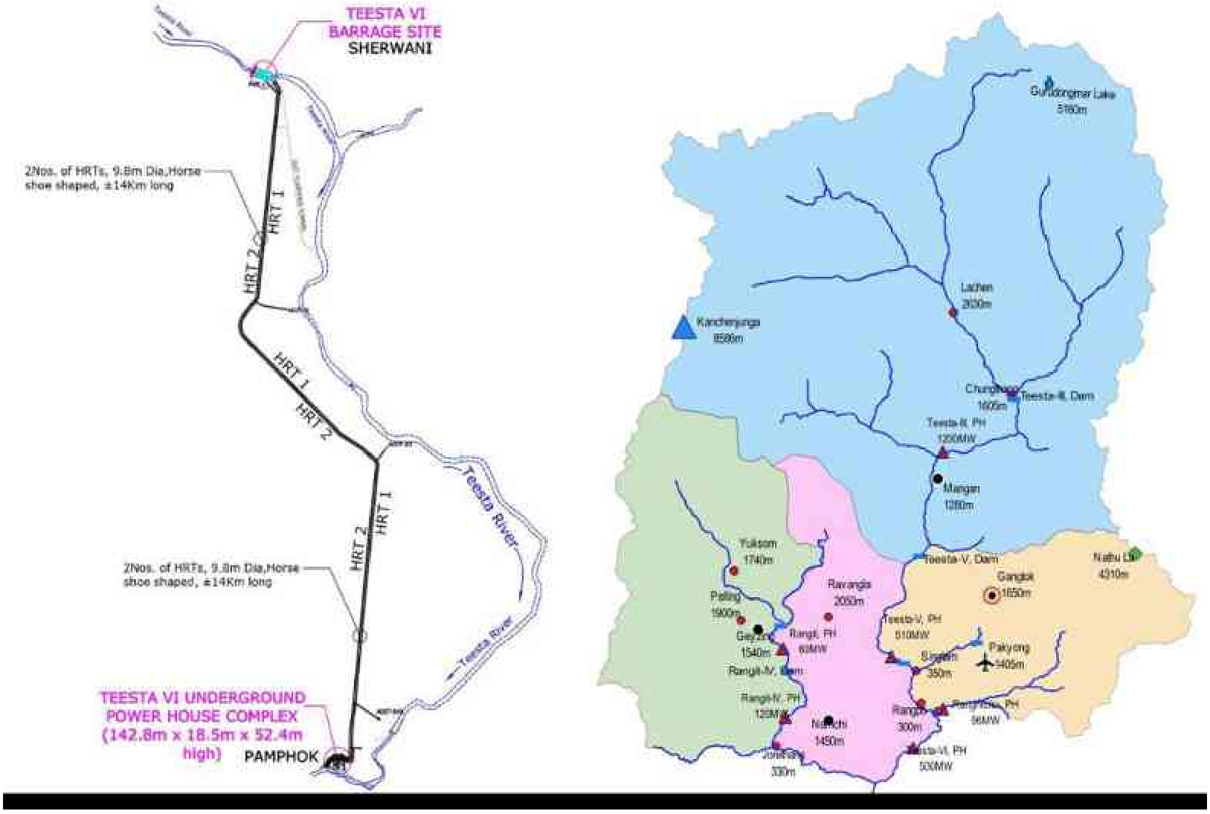


Figure 1 Project Layout

2. The TSP Method

2.1. Principal concept

The Tunnel Seismic Prediction method developed by AMBERG Technologies AG detects changes in rock mass such as irregular bodies, discontinuities, fault and fracture zones ahead of the tunnel face. Employed as a predictive method during excavation process for both drill &

blast and TBM headings, no access to the face is required to perform measurements, which are taken in tunnelling production breaks of around 60 minutes. Acoustic signals are produced by a series of 24 shots of usually 50 to 100 grams of detonation cord aligned along one tunnel wall side and having an additional shot line along the opposite tunnel wall side in cases of more complex geology. Four sensor probes, consisting of highly sensitive tri-axial receivers, are contained in protection tubes whose tips are firmly cemented into boreholes of 45-50 mm in both sidewall (Figure 2).

Figure 2. Standard TSP measuring layout. 24 explosive charges are being shot one by one along right or/and left tunnel wall close to the tunnel face. Four receivers arranged further back pick up arriving waves.

The 3-component receivers pick up the seismic signals, which were being reflected from any kind of discontinuity in the rock mass ahead. A highly sophisticated processing & evaluation software has been devised for ease of operation. The capability of the system to record the full wave field of compressional and shear waves in conjunction with the intelligent analysis software enables a determination of rock mechanical properties such as Poisson's ratio and Young's Modulus within the prediction area. The final 2D- and 3D-summary results produced by the system software present as well detected events and boundary planes crossing the tunnel axis coordinates ahead of the face.

2.2. Operation

The TSP 303 system is an easy-to-operate system. The system setup and installation of the four sensitive tri-axial sensors is simple and comparable with the setting of a rock bolt as shown in Figure 3.

The seismic acquisition geometry is restricted to source and receiver positions at or close to the tunnel. As a result, reflection and scattering angles are small and the spatial resolution while imaging obstacles ahead is not optimum. Resolution is further decreased by seismic attenuation, which is notably strong at the required high frequencies. Hence, careful data processing is very important in order to avoid inaccurate seismic predictions ahead of the tunnel, which may lead to misinterpretations. For example, discontinuities, which are structural or geological features that changes the homogeneity in the rock mass, may not being imaged to full scale, because only constricted portions of these zones could reflect waves towards the receiver due to the physical Snell's law of reflection.

Figure 3 Simple installation of receiver and recording unit of the TSP 303 system.

The image will be enhanced by the use of more receivers such as two at both tunnel wall sides. Moreover, it could become quite meaningful to provide a second source line along the opposite tunnel wall side when the rock mass is very complex in terms of alternating strike angles or irregular obstacles such as cavities or Karst features. By all means, any increase of acquisition data quantity produces higher quality result images, in particular when it comes to 3D data processing.

The TSP 303 system integrates 3D data acquisition and processing software containing routines for optimal seismic imaging with respect to tunnelling requirements. It exploits the information in the seismic wave field by separate compression (P) and shear (S) wave analysis and the 3D-Velocity based Migration & Reflector Extraction technology (3D-VMR). The 3D-VMR technology provides an adequate and detailed 3D image of the ground leading to a more reliable interpretation compared to conventional 2D approaches.

2.3. Wave velocity and related parameters

Elastic body waves passing through homogeneous, isotropic media have well-defined equations of motion. Utilizing these equations, computations of geomechanical properties of the rock mass can be done. Field surveys can readily obtain wave velocities, V_P and V_s as with the TSP method; velocities are in units of length per time, usually meters/second (m/s).
A homogeneous, isotropic medium's engineering properties such as: Young's or elastic modulus (E), shear modulus (G) and Poisson's ratio can be determined, if V_P and V_s are known as well as accounting with a representative density value.

$\sigma = \frac{1}{2} (V_P^2 - 2V_S^2) / (V_P^2 - V_S^2)$ Poisson's ratio

$E = \rho\ V_P^2\ (1\text{-}2v)(1+v)/(1\text{-}v)$ Young's or elastic modulus

$G = E/[2(1+v)]$ Shear modulus

2.4. Limitations conditional upon geology

The TSP method like every seismic method is subject to certain geological conditions. We are confident in the applicability of TSP® 303 for any underground project if the following preconditions are fulfilled:

- Adequate rock physical property contrasts will exist in conjunction with fault zones or changes in rock formation. Seismic applications employ the parameter of acoustic impedance (the products of body wave velocity and rock density) that is a measure of quality determining the reflection coefficient. An acoustic impedance contrast of at least 20% ensures sufficient strong reflection signals in order to seismically detect geological discontinuities.
- The usual TSP® layout works most accurately for rock boundary orientations that intersect the tunnel axis at moderate to high angles. Thus, a certain strike and dip angle (>25°) with reference to the tunnel axis has to be expected to be predictable by TSP®. Best results are being achieved at steeply dipping or striking boundaries (> 45°). Boundaries ahead of the tunnel face showing lower angles (< 25°) aren't able to reflect signals to the receivers due to the receivers' back arrangement of approx. 50 m behind the tunnel face. This restriction is related to the physical Snell's law of reflection and refraction.
- Standard TSP data processing and modelling has been developed for data acquired in tunnels with high overburden (> 50 m). Although not restricted, results analysis and interpretation can be carefully done for tunnel with lower overburden (< 50 m) considering result extrapolation beyond the actual surface.

3. Geology along TSP layout

The Project area falls in the Outer and Lesser Himalayas, exposing varied rock types belonging to different tectono-stratigraphic units, thrown into complex fold system, and tectonically distributed by faults and thrusts of different dimensions.

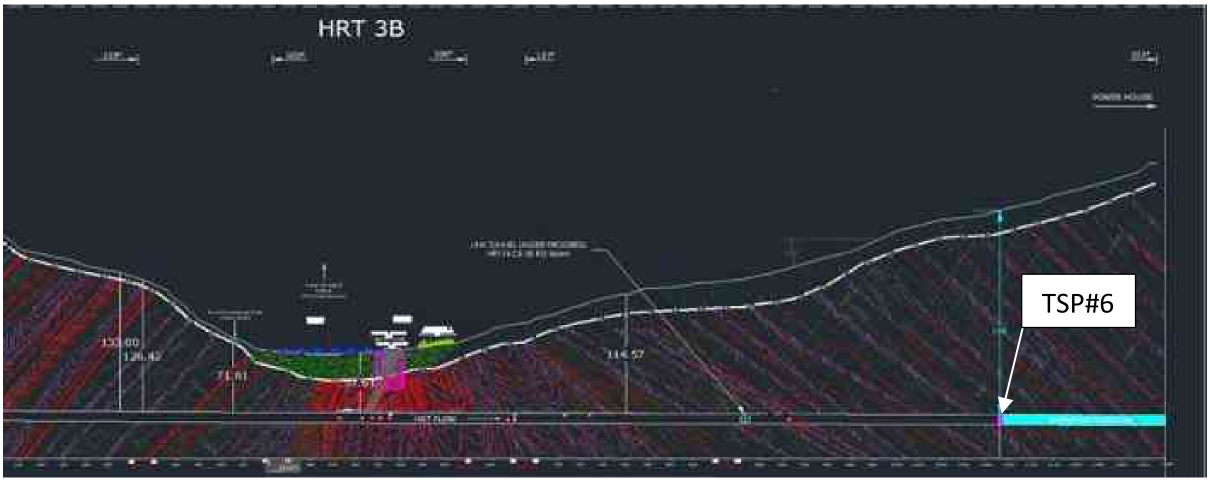


Figure 4 Geological L section showing TSP Location

As per the geological face log information, the geology along the TSP layout between the reference point at RD1,028 and the face location at RD1,093 consists of sheared, exceptionally very poor (Class-V) rock mass, primarily composed of Phyllite and Phyllitic Quartzite, (RMR ~ 10-17). The groundwater condition along this layout indicates a flowing regime. The overburden at the face is approximately 180 meters. The location where TSP was performed is marked in the L section in Figure 4.

4. Operational Commentary

Data acquisition of the TSP campaign was carried out on February 16, 2026. A total of 46 shot holes and 4 receiver holes were drilled using the available drill jumbo. As the rock mass condition along the TSP layout was very poor, it was decided to use two shot lines (23 shot holes on each side), as shown in Figure 6.

Figure 5 Detonator cap with wrapped round wire (white) that gives the accurate recording trigger in the moment of blast.

As per AMBERG's TSP standard procedure, the shot and receiver boreholes of the TSP layout along the tunnel walls were checked upon correctness of length, diameter, alignment and access. It had been agreed on the use of delay electric detonators. The use of delayed detonators implies the use of the wire Break Trigger mode (WBT) of the TSP 303 Recording Unit as shown in Figure 5. The WBT mode allows the use of delay detonators despite the request for very high accuracy of the trigger time of each shot. This can be ensured by using an active wire wrapped round the cap's tip of each detonator that give highly accurate trigger time of recording while it breaks in the moment of the blast. At the same time as the system was installed, the blasting team also received a brief explanation of how to prepare the explosive charge. The first shot hole was charged with 100 g of explosive (SL1 and SL2) and sandbags were used for tamping which generated magnitudes of 111 mV and 160 mV, respectively, i.e above the recommended value of 100mV. However, as the measurement progressed towards the tunnel face, a higher attenuation of energy was observed. Based on recorded magnitude, charge size has been increased stepwise towards face, and their details is given below in table 1.

Table 1 Charge size details

Shot Line (LHS)		Recording Time
Shot hole	Charge size (gram)	
1-5	100	16:50 hr - 17:50 hr (1 hour approximately)
6-10	150	
11-15	200	
16-20	250	
21-23	300	
Shot Line (RHS)		Recording Time
Shot hole	Charge size (gram)	
1-5	100	18:10 hr - 19:10 hr (1 hour approximately)
6-10	150	
11-15	200	
16-20	250	
21-23	300	

Figure 6 depicts the seismic layout reproduced in the AMBERG TSP Ease software. The tunnel model exactly resembles the geometry of the tunnel at the moment of the measurement.

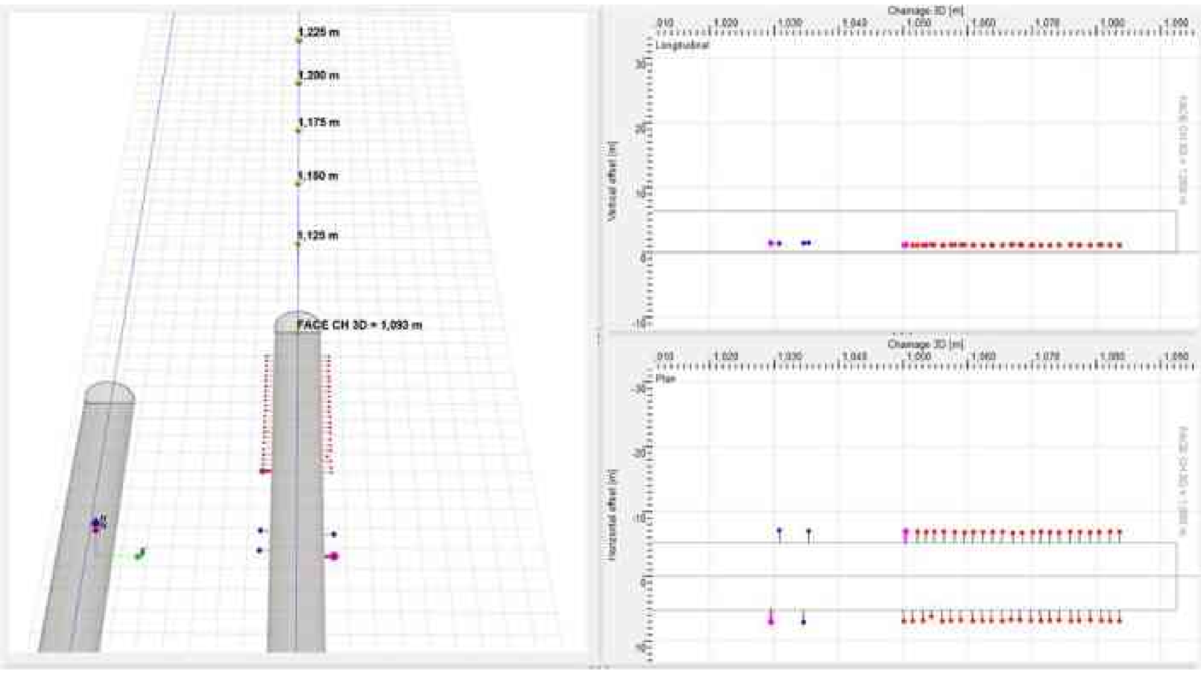


Figure 6: Actual TSP layout at campaign site. Blue dots: receivers, red dots: shots.

Specification about shot and receiver holes as well as the seismic source are presented in Table 2.

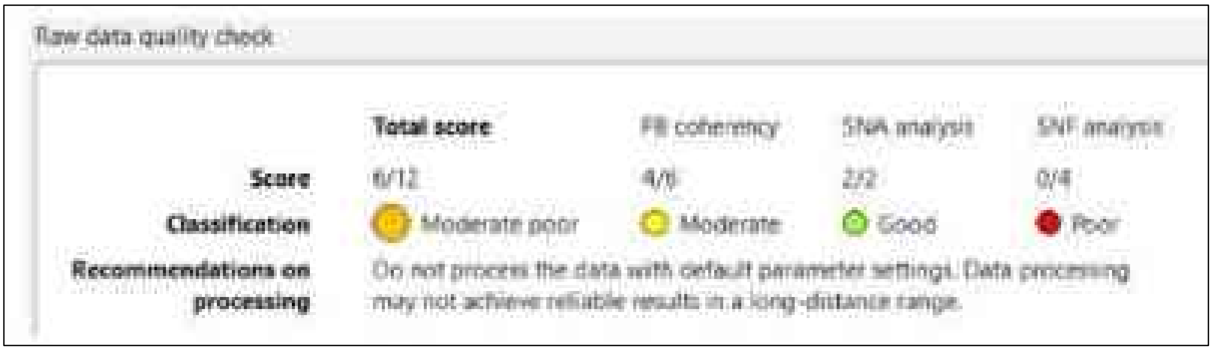
Table 2: TSP layout specification

Data Acquisition date		**February 16, 2026**
Layout in direction of investigation		
Shot holes	No. drilled	46
	Diameter	45 mm
	Depth / Location	1.4m to 1.9 m / along both walls
	Inclination from horizontal	-2° to -7° upwards
	Spacing	1.3 – 1.8 m
	Performed shots	46
	Explosive charges	100 - 300 g (stepwise increasing twds face)
Receiver holes	Number	4
	Diameter	51 mm
	Depth / Location	RCV1 & RCV2 – 1.8/1.9 m (right) RCV3 & RCV4 – 1.8/1.9 m (left)
	Inclination from horizontal	7° to 10°
	Nearest offset to first shot hole	15.0m
	Distance between receiver holes	4. 5m (left) and 5m (right)
Seismic Source		
Blasting machine	Electric blasting machine	
Detonators	Delay electronic detonators	
Explosive type	Powergel 80	
Min detonation velocity	3,500 - 4000 m/s	
Type of Triggering	WBT	

5. Raw data Analysis & Processing

5.1. Raw data Analysis

After input the geometry data of the tunnel profile, receivers and shots, the software Amberg TSP Plus is ready to present the recorded raw data arranged in the three components of directions X, Y and Z for each receiver. An additional data check per receiver component gather is now possible as shown in Appendix -1.



Raw data quality check

	Total score	FB coherency	SNA analysis	SNF analysis
Score	6/12	4/6	2/2	0/4
Classification	Moderate poor	Moderate	Good	Poor
Recommendations on processing	Do not process the data with default parameter settings. Data processing may not achieve reliable results in a long-distance range.			

Figure 7 Raw data quality check (RQDC)

Raw data quality for this campaign is categorized as moderate poor shown in Figure 7 (total score 6 out of 12). The raw data quality analysis comprises three major procedures: First Break coherency (FB coherency), Signal/Noise Amplitude (SNA analysis) and Signal/Noise Frequency analysis (SNF analysis). Each analysis delivers a content specific scoring and classification. The overall analysis is then summarized in a Total score and a Classification representing the quality of the whole data set.
In this campaign, the signal amplitude varies from 200 mV to 25 mV, indicating very high energy attenuation along the TSP layout. The noise caused by the airborne wave is moderately high for crossline receivers. The data is characterized by a low frequency content (25 – 300 Hz).

5.2. Seismic data processing

After the selection of proper seismic data, the subsequent seismic data processing per receiver immediately started to run through several primary steps controlled by a given flow chart as shown in Figure 8.
The aim of seismic data processing is the extraction and enhancement of the reflected wave field. For this purpose, the data run through specially designed processing steps where intermediate results are stored enabling a review during processing at any time. The wave separation process of Amberg TSP Ease separates the recordings into wave types (P, SV and SH waves) according to their polarization type via rotating the coordinate system as function of recording time. All pre-processed data are passed onto the 3D processing, where a velocity distribution of a user-defined 3D-model is presented. Finally, extracted reflectors are interpreted and rock property calculations of relevant reflectors are presented in the evaluation.
For the current dataset, data from 3 receivers and 35 shots (18 from SL1 and 17 from SL2) were used for processing. Due to the high content of noise interference in the recorded signals, SH-2, SH-3, SH-5, SH-8, and SH-17 from SL1 and SH-4, SH-8, SH-9, SH-14, SH-15, and SH-

20 from SL2 were deactivated from processing. The excessive noise is most likely attributed to poor shot coupling during detonation, possibly caused by very poor rock mass conditions along layout.
The full model size of 200 m in the longitudinal direction and 100 m in lateral directions was used in 3D data processing.

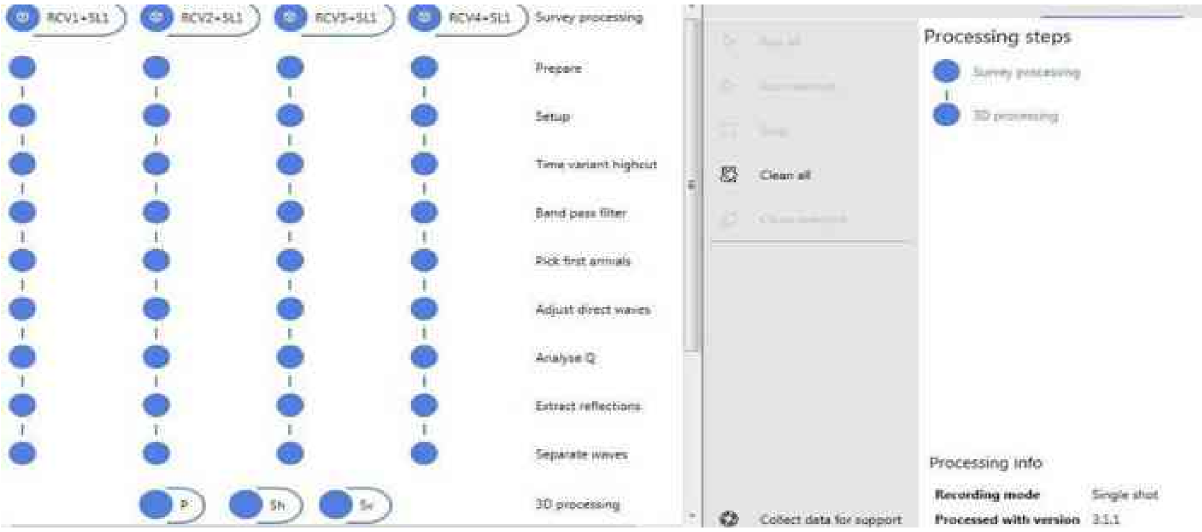


Figure 8 Processing Flow Chart of AMBERG TSP Ease Software

6. Result of TSP Campaign #6 FACE 3B RD 1093

6.1. 3D Velocity Models

P wave Velocity Model:

Figure 9 depicts 2D longitudinal and plan sections (top and bottom, respectively) which were extracted from the 3D model of the P-wave velocity (Vp) along the seismic axis. Varying colouring in Figure 9 indicates velocity variation, in which blue and red areas correspond to increasing and decreasing P-wave velocity, respectively. The description of the velocities & estimated parameters is given in Table 3.

The estimated P-wave velocity along the seismic axis ranges between 2,750 m/s to 3,200 m/s with a reference value of 2,966 m/s. The reference value is estimated from the first arrival of direct P–wave and it is used as an input parameter in the 3D processing. It also corresponds to a representative velocity of the prevailing lithology along the TSP layout, that is poor/sheared rock mass.

Table 3: 3D model description and features

2D sections						
Model start (RD): 1028			**Model end (RD): 1228**	**Tunnel face at the time of recording (RD): 1093**		
Vp (m / s)			**Vs (m / s)**			
Min.	**Ref.**	**Max.**	**Min.**	**Ref.**	**Max.**	**comment**
2,750	2,966	3,200	1,600	1,715	1,800	• Reference velocity along the TSP layout

2D sections				
Comparatively Identified Low Velocity Zones (LVZ) *				
Zone	**RD (Approx.)**	**Vp (m / s)**	**Location**	**comment**
i	1120 - 1140	2,750 - 2850	• Cutting the tunnel axis	
* LVZs are commonly associated with changes in rock properties. These changes may be due to increased fracturing or jointing, the appearance of fault or shear zones. * Identified LVZs are marked in Figure 9.				

According to the 2D chart and 3D Vp model, a drop in P-wave velocity (Vp) has been observed between approximately RD 1120 to RD1140, where Vp decreases to its lowest observed value 2,750 to 2,850 m/s, this low velocity zone is cutting the tunnel axis.
LVZs are commonly associated with changes in rock properties, which may result from increased fracturing, jointing, or the presence of fault or shear zones.

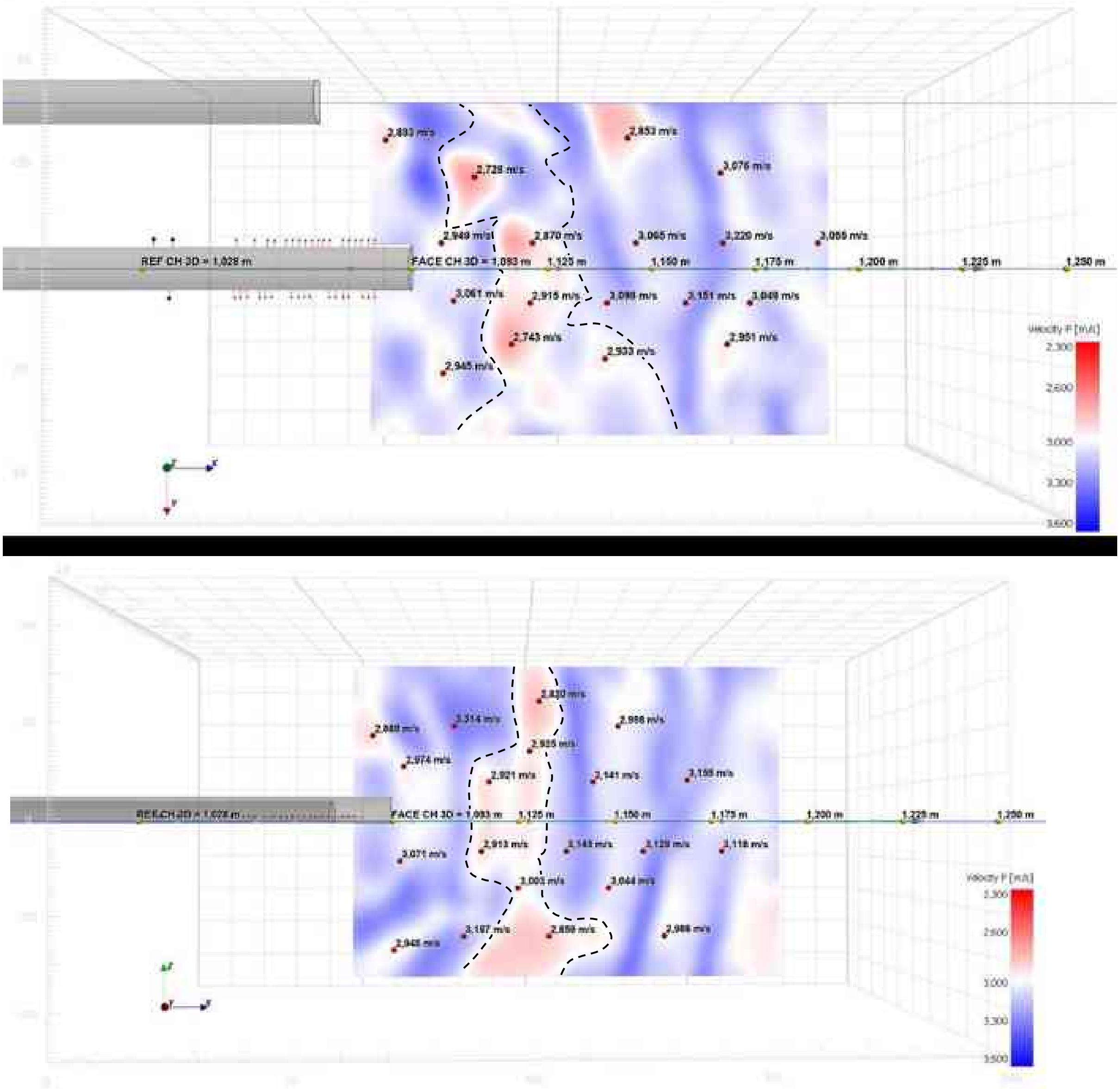


Figure 9: Plan & Longitudinal view of the 3D P-wave velocity model along the tunnel axis including the tunnel model with the location of the shot holes (red dots) and the receivers (blue dots). The red dot markings indicate values of Vp at the selected position.

S wave velocity model:

Figure 10 depicts perspective 2D plan & longitudinal sections, which were extracted from the 3D model of the S-wave velocity (Vs) along the seismic axis. The Vs model indicates lower velocities between RD1100 to RD1120, where Vs drops to its lowest observed value ranging from 1,600 to 1,650 m/s, which is cutting across and surrounding the tunnel axis. The low velocity zones in S wave can be associated with a deterioration in rock mass conditions and the possible influence of fracturing, shearing.

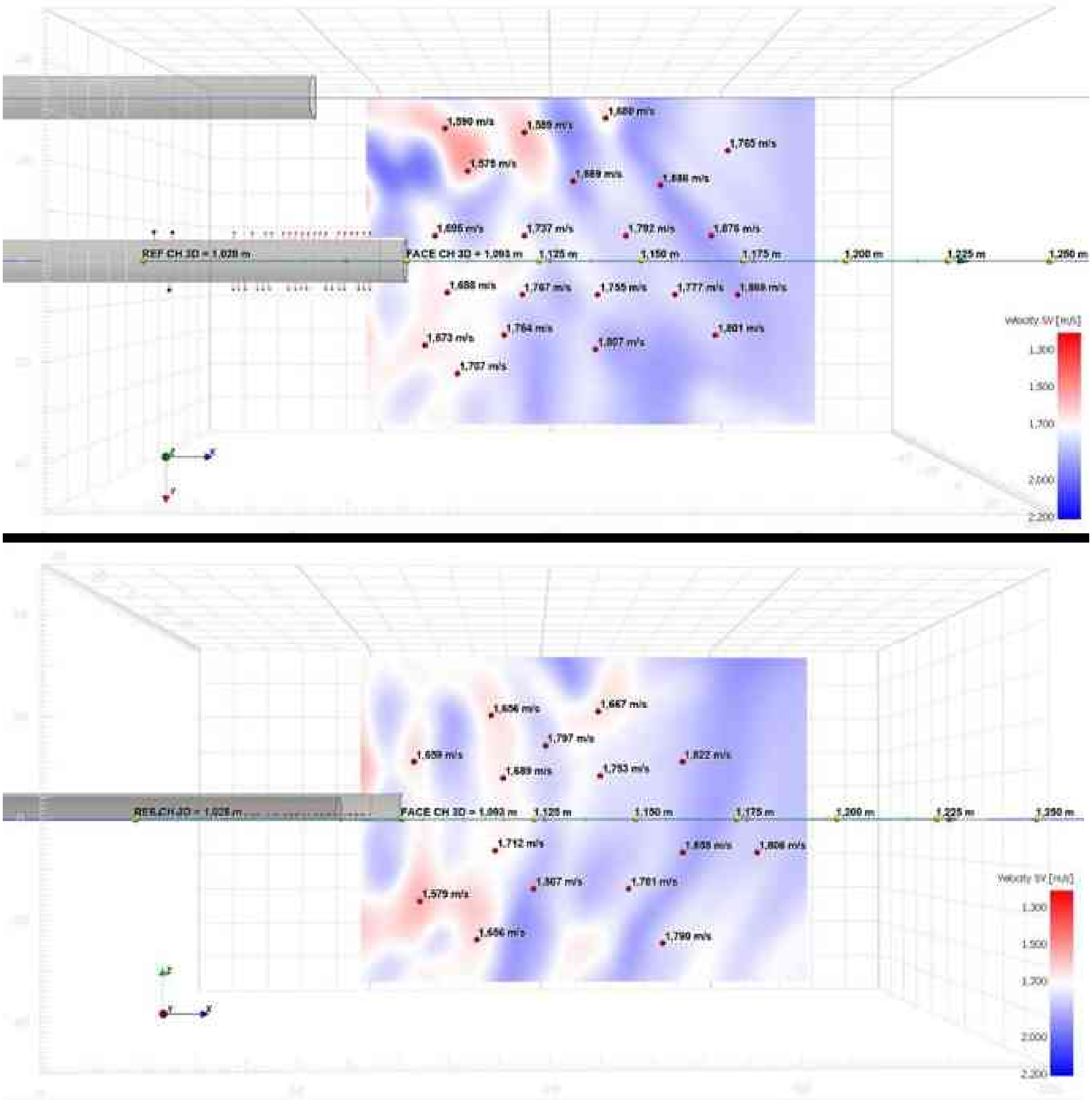


Figure 10 Plan & Longitudinal view of the 3D S-wave velocity model along the tunnel axis including the tunnel model with the location of the shot holes (red dots) and the receivers (blue dots). The red dot markings indicate values of Vs at the selected position.

6.2. Poisson's ratio

The Poisson's ratio is an elastic parameter that is a measure of the compressibility of material perpendicular to applied stress, or the ratio of latitudinal to longitudinal strain. Poisson's ratio (σ) can be expressed in terms of derived velocities of P-waves (Vp) and S waves (Vs) as follows:

$\sigma = \frac{1}{2} (VP2 - 2VS2) / (VP2 - VS2)$

Figure 11 illustrates the variation in the estimated Poisson's ratio along and around the tunnel axis. Notably, high Poisson's ratio values (>0.29) are observed at approximately RD1100 - 1121 and RD1138 - 1145. These high values may indicate the presence possible water-bearing zones or increased shearing in the rock mass. The detailed prognosis is given in chapter 6.3.

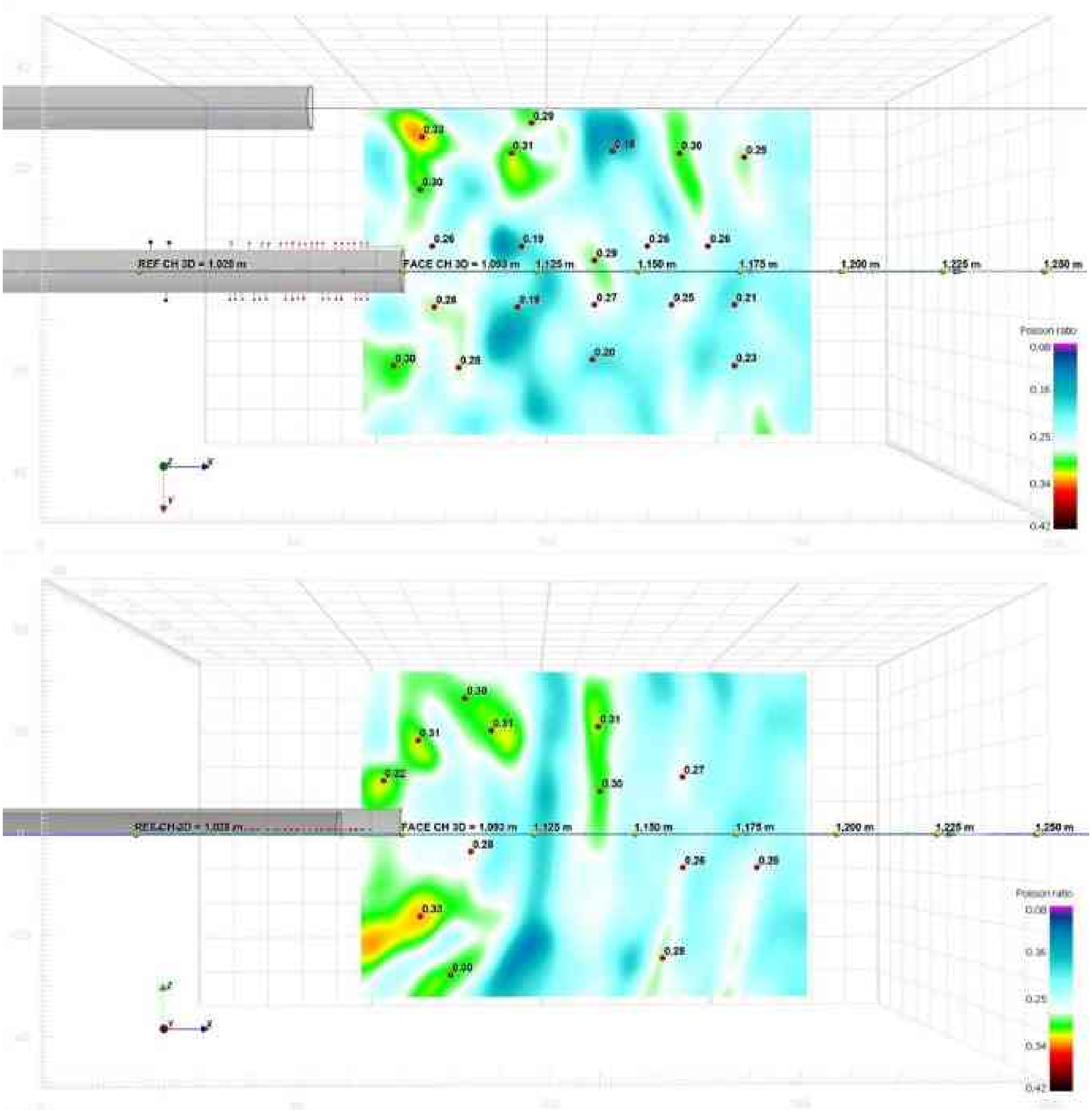


Figure 11 Plan & longitudinal view of Poisson ratio along & around tunnel axis. The red dot markings indicate values of Vs at the selected position.

6.3. Prognosis along tunnel axis

The fundamental of the interpretation based on the TSP results relies on the contrast between the reference values, i.e. seismic velocities and geomechanical parameters estimated within the TSP layout and the values of these parameters associated to the reflectors extracted along the prediction range. In addition, geological observations along the TSP layout and existing geological model allow for an initial correlation of these values.

RD1028 to 1093 (Reference values)

This section corresponds to the TSP seismic layout where a single reference value for each parameter is estimated based on the velocity of the direct waves and an empirical density formula selected from the rock catalogue included in the software Amberg TSP Ease for the most predominant type of rock along the TSP layout.

Table 4: Reference values & estimated parameters

Parameter	Campaign # 6 HRT 2 FACE 3B RD 1093
Vp (m / s)	2,966
Vs (m / s)	1,715
Poisson ratio (-)	0.25
Edyn (GPa)	15
Bulk mod. (GPa)	10
Geology	Very poor rock mass, Quarzitic phyllite

a) RD1093 to RD1101

Parameter	Vp [m / s]	Vs [m / s]	Bulk mod. [Gpa]	Poisson	Edyn [GPa]
values	3,020	1,780	11	0.24	17
Tendency from reference value	Slight Increase	Slight Increase	Slight Increase	Slight Decrease	Slight Increase
Interpretation	Continuation of almost similar rock mass				
Remarks					

b) RD1101 to RD1119

Parameter	Vp [m / s]	Vs [m / s]	Bulk mod. [Gpa]	Poisson	Edyn [GPa]
values	3,000 – 3,100	1,600 – 1,650	12 - 13	0.29 – 0.30	15
Tendency from reference value	Comparable	Decreasing	Slight Increase	Increasing	Decreasing
Interpretation	Comparative slight decrease in stiffness; Increase in shearing / fracturing / Possible water bearing zone				
Remarks					

c) RD1119 to RD 1137

Parameter	Vp [m / s]	Vs [m / s]	Bulk mod. [Gpa]	Poisson	Edyn [GPa]
values	2,800 - 2,850	1,650 - 1,750	8 - 9	0.17 - 0.22	14 - 15
Tendency from reference value	Decreasing	Slight Increase	Decreasing	Decreasing	Decreasing
Interpretation	Further decrease in rock mass stiffness.				
Remarks					

d) RD1137 to RD1159

Parameter	Vp [m / s]	Vs [m / s]	Bulk mod. [Gpa]	Poisson	Edyn [GPa]
values	3,170 – 3,190	1,757 – 1,683	13 - 14	0.28 – 0.31	16 - 17
Tendency from reference value	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing
Interpretation	Comparative Slight improvement in rock mass stiffness ~ Still very poor				
Remarks	As per 3D, a higher Poisson’s ratio value is estimated, which might indicate a water-bearing zone or increased shearing/fracturing				

e) RD1159 to RD1193

Parameter	Vp [m / s]	Vs [m / s]	Bulk mod. [Gpa]	Poisson	Edyn [GPa]
values	2,950 – 3,170	1,720 – 1,790	10 - 13	0.24 – 0.28	16 - 17
Tendency from reference value	Decreasing	Decreasing	Decreasing	Decreasing	Decreasing
Interpretation	Continuation of almost similar ground conditions.				
Remarks	End of prediction				

7. Concluding Remarks & Recommendation

- The 6th TSP campaign was conducted at HRT 2 Face 3B at RD1093, achieving a rock mass prediction ahead of the tunnel face up to 100m.

- The raw data quality is classified as moderate poor. However, high energy attenuation indicates very poor rock mass conditions along the TSP layout.

- As per estimated TSP parameters no major improvement is observed, however localized low velocity zones were observed such as, approximately RD1,119 to RD1,137 which may be associated with further decrease in rock mass stiffness or an increase in shearing and jointing.

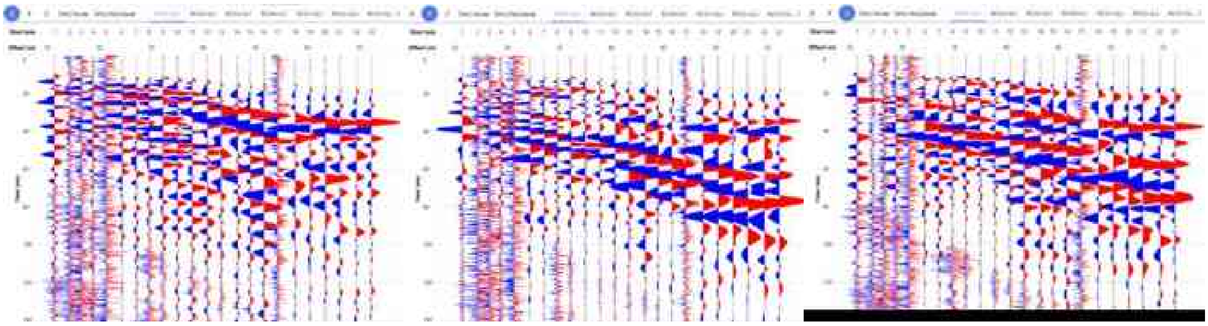
- As per 3D distribution of Poisson's ratio, higher values have been estimated at approximately RD1,100 - RD1,121, and RD1,137 – 1,145 which can be associated with possible water-bearing zones or increased shearing and fracturing.

Kripal Choudhary
Dept head Geophysicist
AMBERG Engineering India

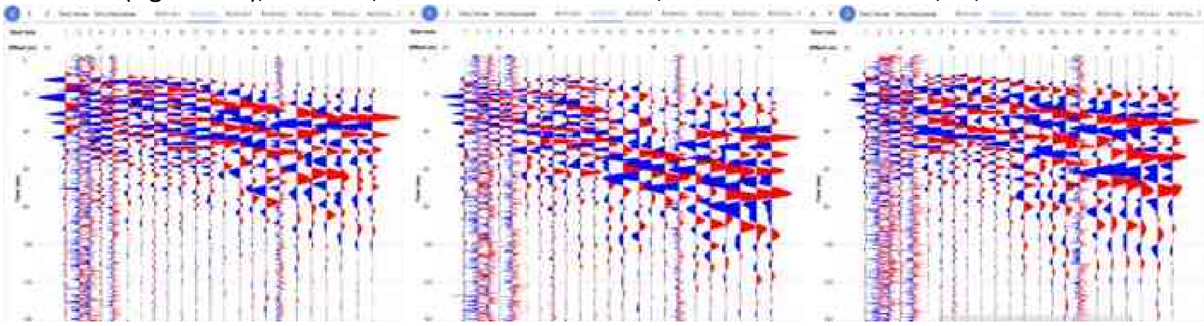
Amol Verma
Senior Geophysicist
AMBERG Engineering India

8. Appendix 1: Seismic raw data

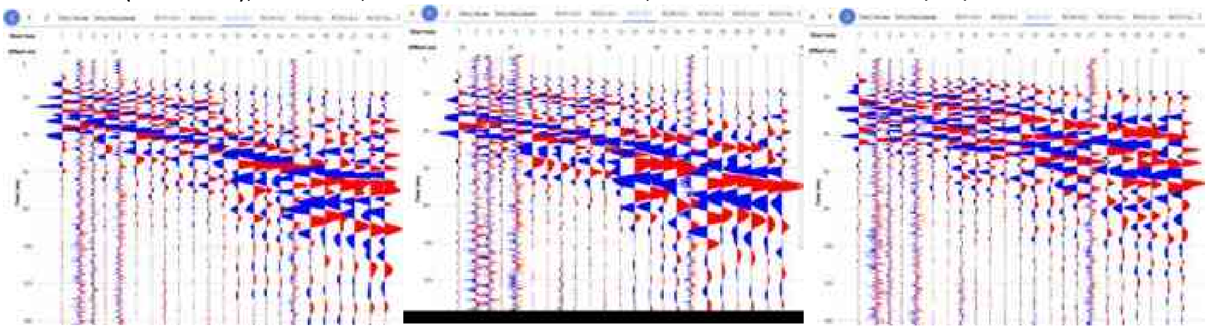
RCV1-SL1 (right front), 23 shots, between 0 and 140 ms, trace Normalization X / Y / Z



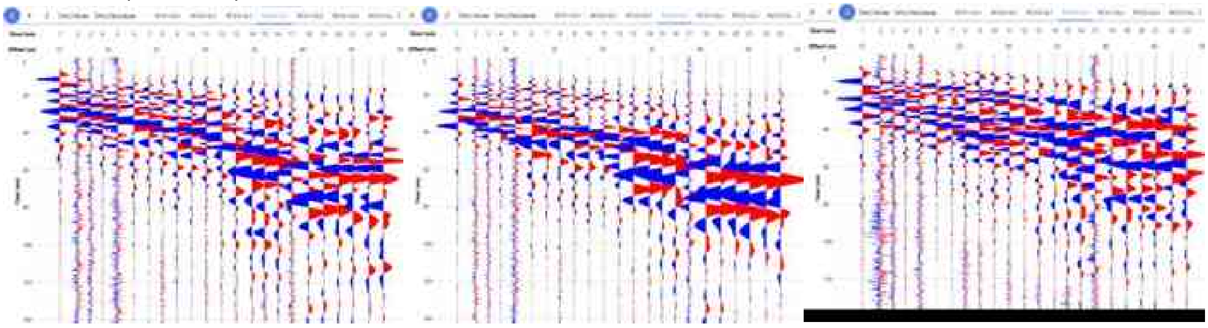
RCV2-SL1 (right back), 24 shots, between 0 and 140 ms, trace Normalization X / Y / Z



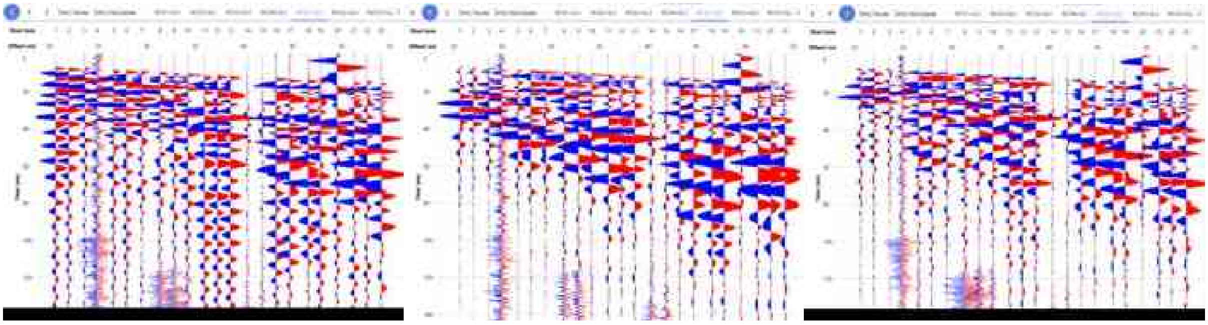
RCV3-SL1 (left front), 24 shots, between 0 and 140 ms, trace Normalization X / Y / Z



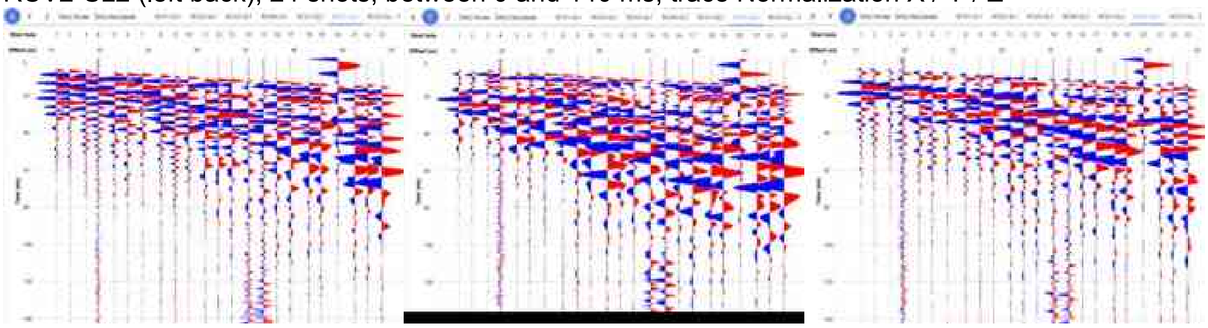
RCV4-SL1 (left back), 24 shots, between 0 and 140 ms, trace Normalization X / Y / Z



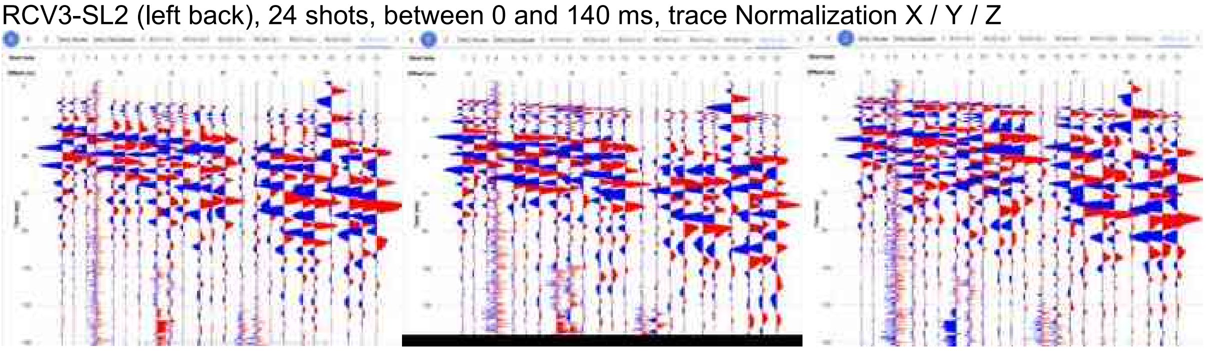
RCV1-SL2 (left back), 24 shots, between 0 and 140 ms, trace Normalization X / Y / Z



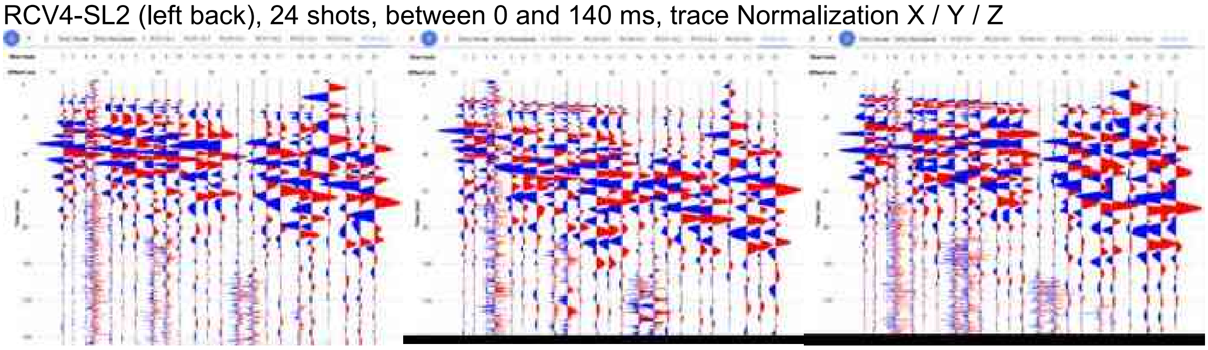
RCV2-SL2 (left back), 24 shots, between 0 and 140 ms, trace Normalization X / Y / Z



RCV3-SL2 (left back), 24 shots, between 0 and 140 ms, trace Normalization X / Y / Z



RCV4-SL2 (left back), 24 shots, between 0 and 140 ms, trace Normalization X / Y / Z



9. Appendix 2: Results

- ✓ Rock properties charts / longitudinal and plan view of colour shaded rock zones
- ✓ 2D plan view of P-Wave velocity model and Rock properties table.

TSP - Tunnel Seismic Prediction: TEESTA-VI_JP

Campaign name:	HRT2_FACE_3B_RD1092.5	Processing name:	#2V
Campaign type:	Sporadic measurement (single face)	Evaluation set:	Set 3
Face tunnelmeter:	593m	Processing type:	Ahead
Face stationing:	593m	Construction stage date:	16-02-2026 15:50:09 UTC+05:30
Face chainage:	1,093m	Creation date:	01-03-2026
Overburden:	190m	Operator:	AMBERG

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Rock properties table

Chainage 3D [m]	Velocity P [m/s]	Velocity S [m/s]	Poisson ratio	Stat. Young's mod. [GPa]	Dyn. Young's mod. [GPa]	Shear mod. [GPa]	Bulk mod. [GPa]	Remark
initial	2,966	1,715	0.25	5	15	6	10	Reference rock mass stiffness of fractured/ sheared Phyllite & Phyllitic quartzite ~ very poor rock mass
1,083	3,025	1,779	0.24	6	17	7	11	Continuation of similar rock mass conditions
1,101	3,110	1,657	0.30	5	15	6	13	Comparative slight decrease in stiffness; Increase in shearing / fractuing / Possible water bearing zone
1,111	3,070	1,680	0.29	5	15	6	12	

TSP - Tunnel Seismic Prediction: TEESTA-VI_JP

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Campaign name:	HRT2_FACE_3B_RD1092.5	Processing name:	#2V
Campaign type:	Sporadic measurement (single face)	Evaluation set:	Set 3
Face tunnelmeter:	593m	Processing type:	Ahead
Face stationing:	593m	Construction stage date:	16-02-2026 15:50:09 UTC+05:30
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Rock properties table

Chainage 3D [m]	Velocity P [m/s]	Velocity S [m/s]	Poisson ratio	Stat. Young's mod. [GPa]	Dyn. Young's mod. [GPa]	Shear mod. [GPa]	Bulk mod. [GPa]	Remark
1,119	3,045	1,627	0.30	4	14	6	12	Further decrease in rock mass stiffness
1,121	2,807	1,765	0.17	5	15	7	8	
1,135	2,862	1,721	0.22	5	15	6	9	
1,137	3,178	1,757	0.28	6	17	7	13	Comparative slight improvement in rock mass stiffness~ Still very poor
1,150	3,189	1,683	0.31	5	16	6	14	
1,159	3,011	1,718	0.26	5	16	6	11	Continuation of almost similar ground conditions.
1,171	2,956	1,740	0.24	5	16	6	10	
1,182	3,026	1,784	0.23	6	17	7	10	
1,186	3,171	1,739	0.28	6	17	6	13	
1,192	3,049	1,771	0.25	6	17	7	11	
1,193	3,038	1,783	0.24	6	17	7	11	End of Prediction

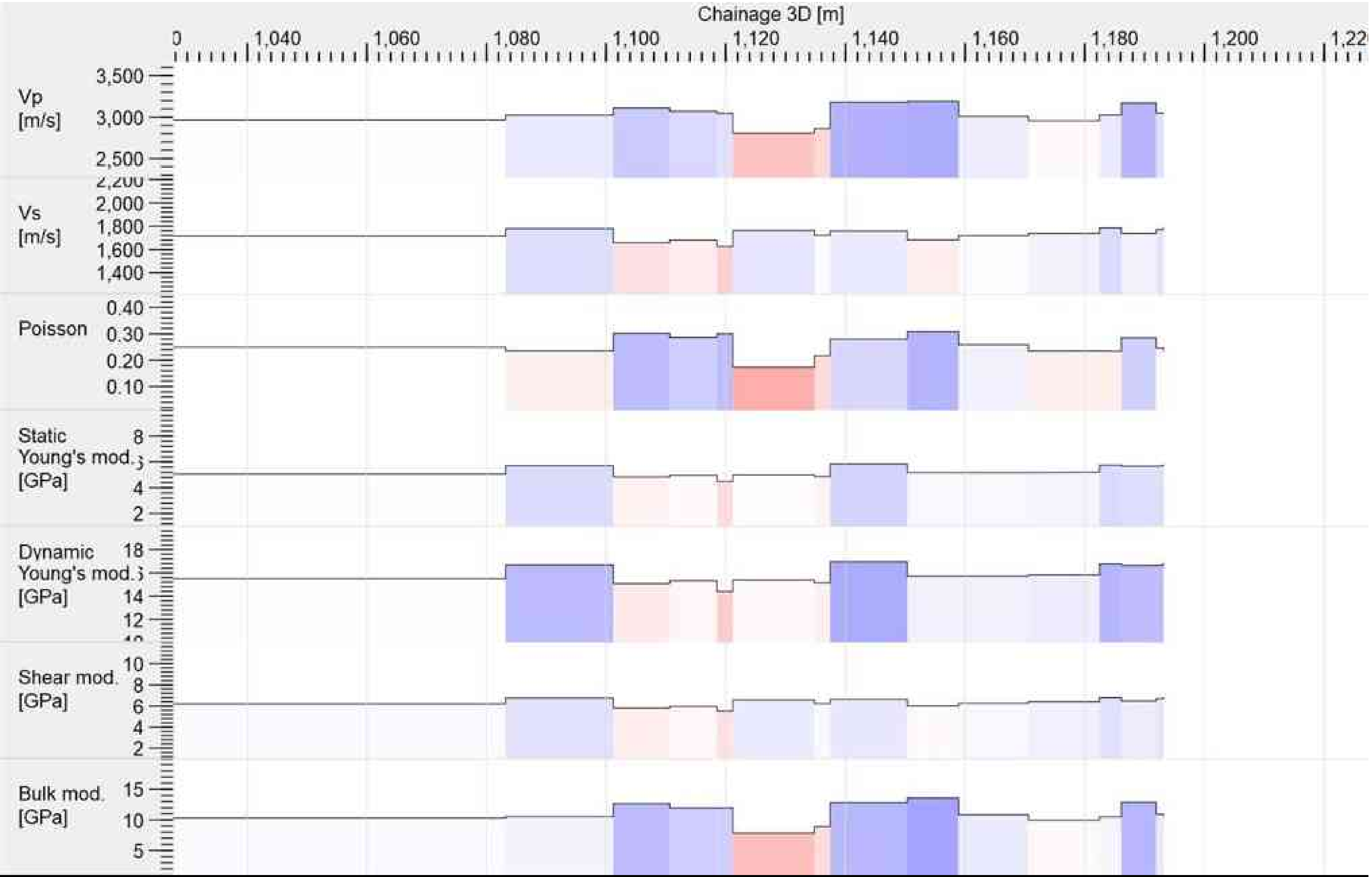
TSP - Tunnel Seismic Prediction: TEESTA-VI_JP

JAIPRAKASH ASSOCIATES LIMITED

Campaign name:	HRT2_FACE_3B_RD1092.5	Processing name:	#2V
Campaign type:	Sporadic measurement (single face)	Evaluation set:	Set 3
Face tunnelmeter:	593m	Processing type:	Ahead
Face stationing:	593m	Construction stage date:	16-02-2026 15:50:09 UTC+05:30
Face chainage:	1,093m	Creation date:	01-03-2026
Overburden:	190m	Operator:	AMBERG

Rock properties charts / longitudinal and plan view

Scale: 1 : 1000

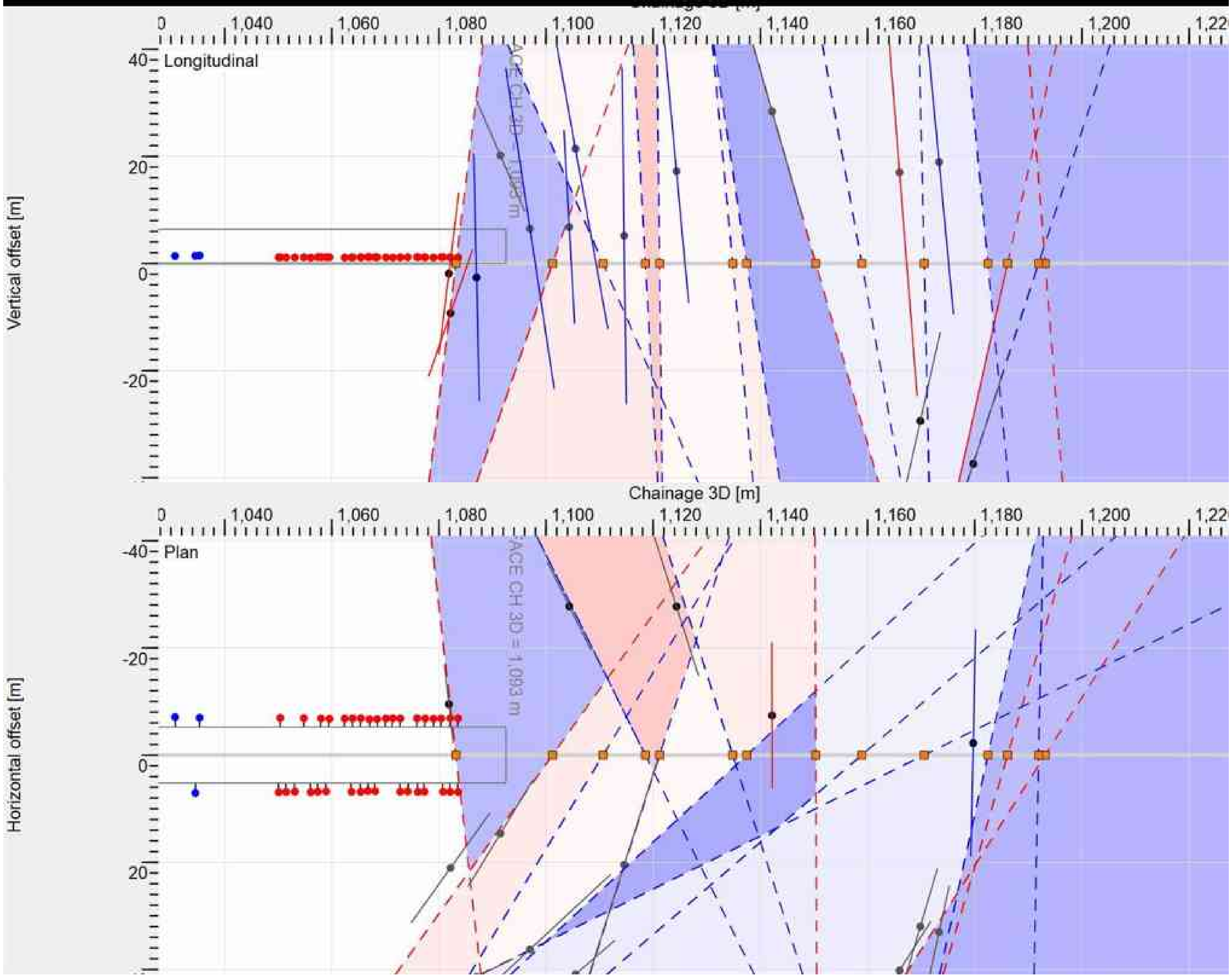


[redacted]

Legend:

- 2,266 m/s
- 2,966 m/s
- 3,666 m/s
- 1,215 m/s
- 1,715 m/s
- 2,215 m/s
- 0.01
- 0.25
- 0.45
- 1 GPa
- 5 GPa
- 10 GPa
- 10 GPa
- 16 GPa
- 20 GPa
- 1 GPa
- 6 GPa
- 12 GPa
- 1 GPa
- 10 GPa
- 20 GPa

[redacted]



Legend:

Dyn. Young's mod.

- 10 GPa
- 16 GPa
- 20 GPa

Reflector symbols:

- crossing long. or plan view, reflectivity pos.
- reflector plane intersection reflectivity pos.
- crossing long. or plan view, reflectivity neg.
- reflector plane intersection reflectivity neg.
- outside long. or plan view
- border of seismic zone
- border plane intersection
- reflector plane intersection with tunnel axis
- reflector plane intersection with seismic axis

TSP - Tunnel Seismic Prediction: TEESTA-VI_JP

Campaign name:	HRT2_FACE_3B_RD1092.5	Processing name:	#2V
Campaign type:	Sporadic measurement (single face)	Evaluation set:	Set 3
Face tunnelmeter:	593m	Processing type:	Ahead
Face stationing:	593m	Construction stage date:	16-02-2026 15:50:09 UTC+05:30
Face chainage:	1,093m	Creation date:	01-03-2026
Overburden:	190m	Operator:	AMBERG

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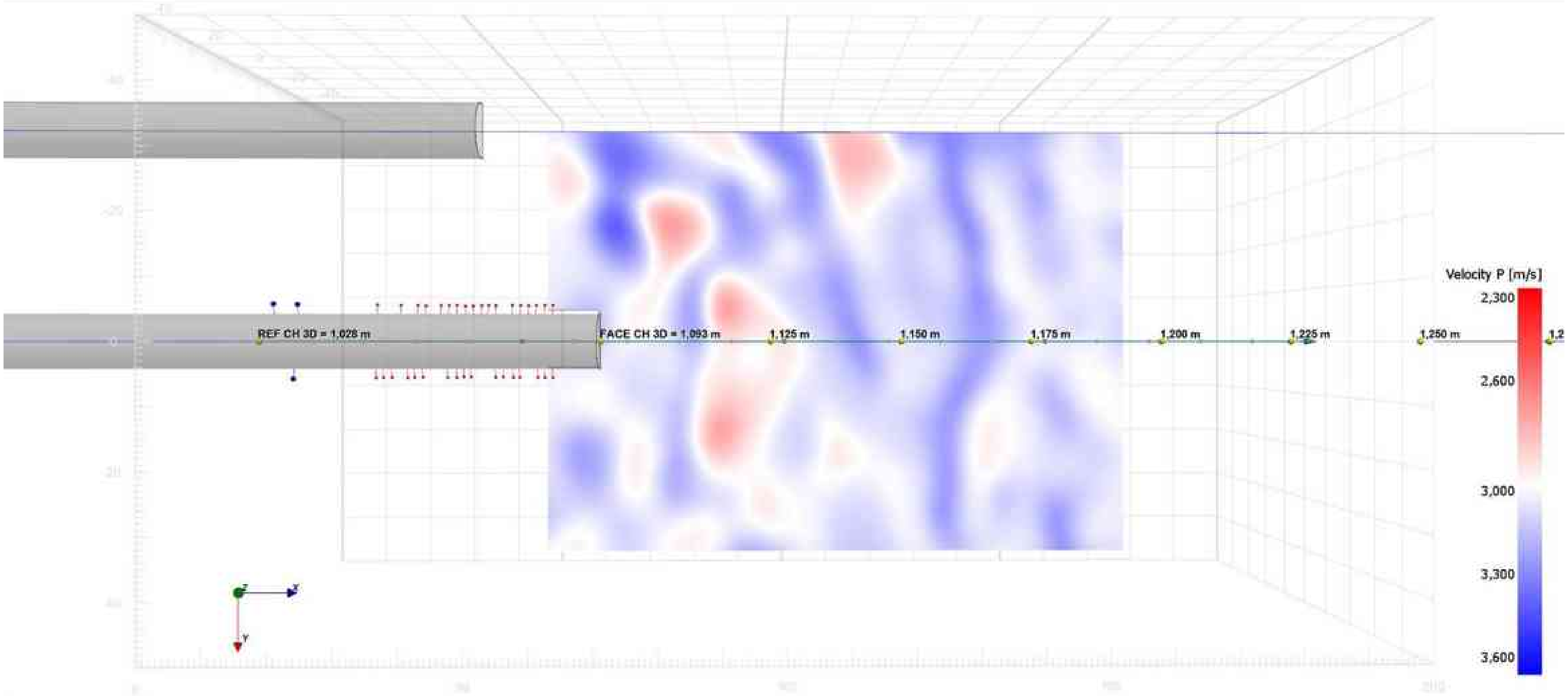
3D view - Velocity P



TSP - Tunnel Seismic Prediction: TEESTA-VI_JP			
Campaign name:	HRT2_FACE_3B_RD1092.5	Processing name:	#2V
Campaign type:	Sporadic measurement (single face)	Evaluation set:	Set 3
Face tunnelmeter:	593m	Processing type:	Ahead
Face stationing:	593m	Construction stage date:	16-02-2026 15:50:09 UTC+05:30
Face chainage:	1,093m	Creation date:	01-03-2026
Overburden:	190m	Operator:	AMBERG

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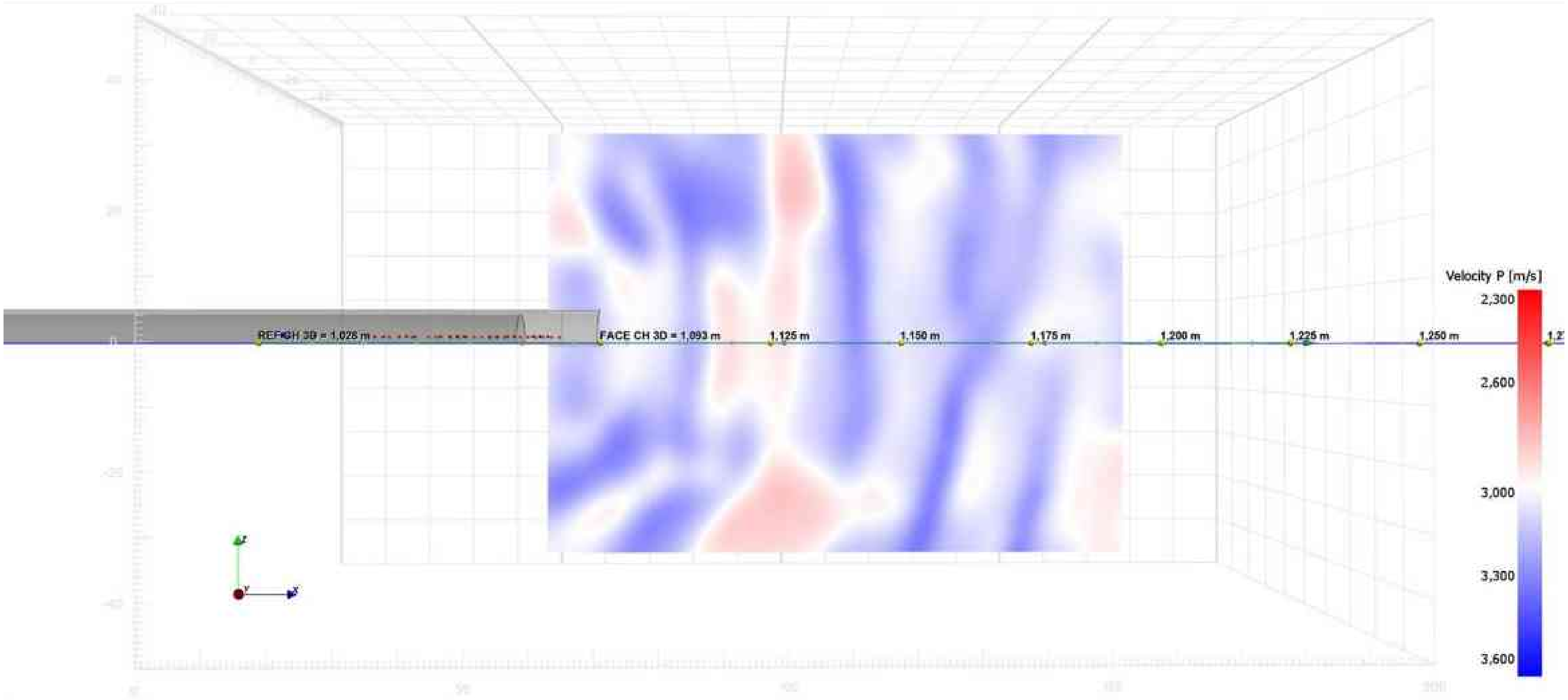
3D view - Velocity P

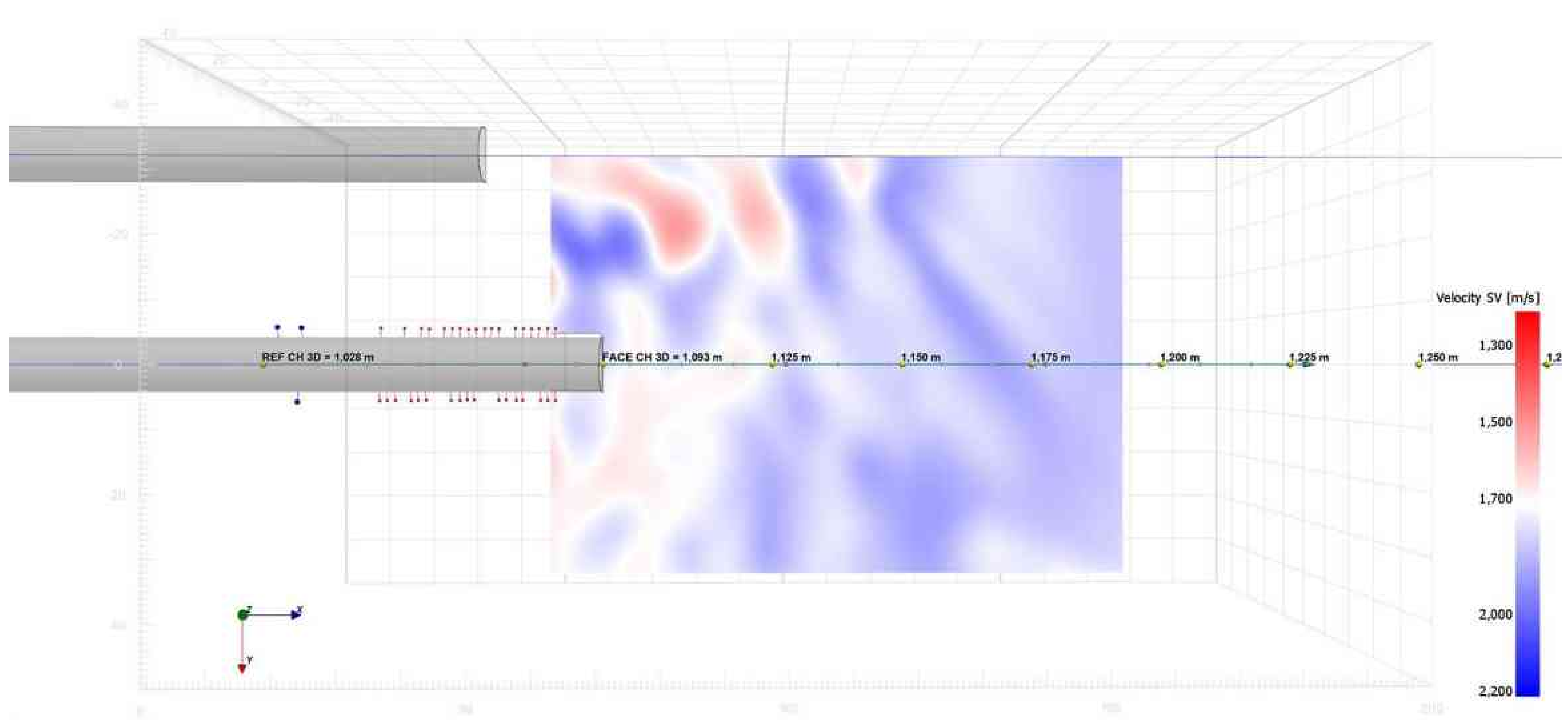


TSP - Tunnel Seismic Prediction: TEESTA-VI_JP

Campaign name:	HRT2_FACE_3B_RD1092.5	Processing name:	#2V
Campaign type:	Sporadic measurement (single face)	Evaluation set:	Set 3
Face tunnelmeter:	593m	Processing type:	Ahead
Face stationing:	593m	Construction stage date:	16-02-2026 15:50:09 UTC+05:30
Face chainage:	1,093m	Creation date:	01-03-2026
Overburden:	190m	Operator:	AMBERG

JAIPRAKASH ASSOCIATES LIMITED

3D view - Velocity SV

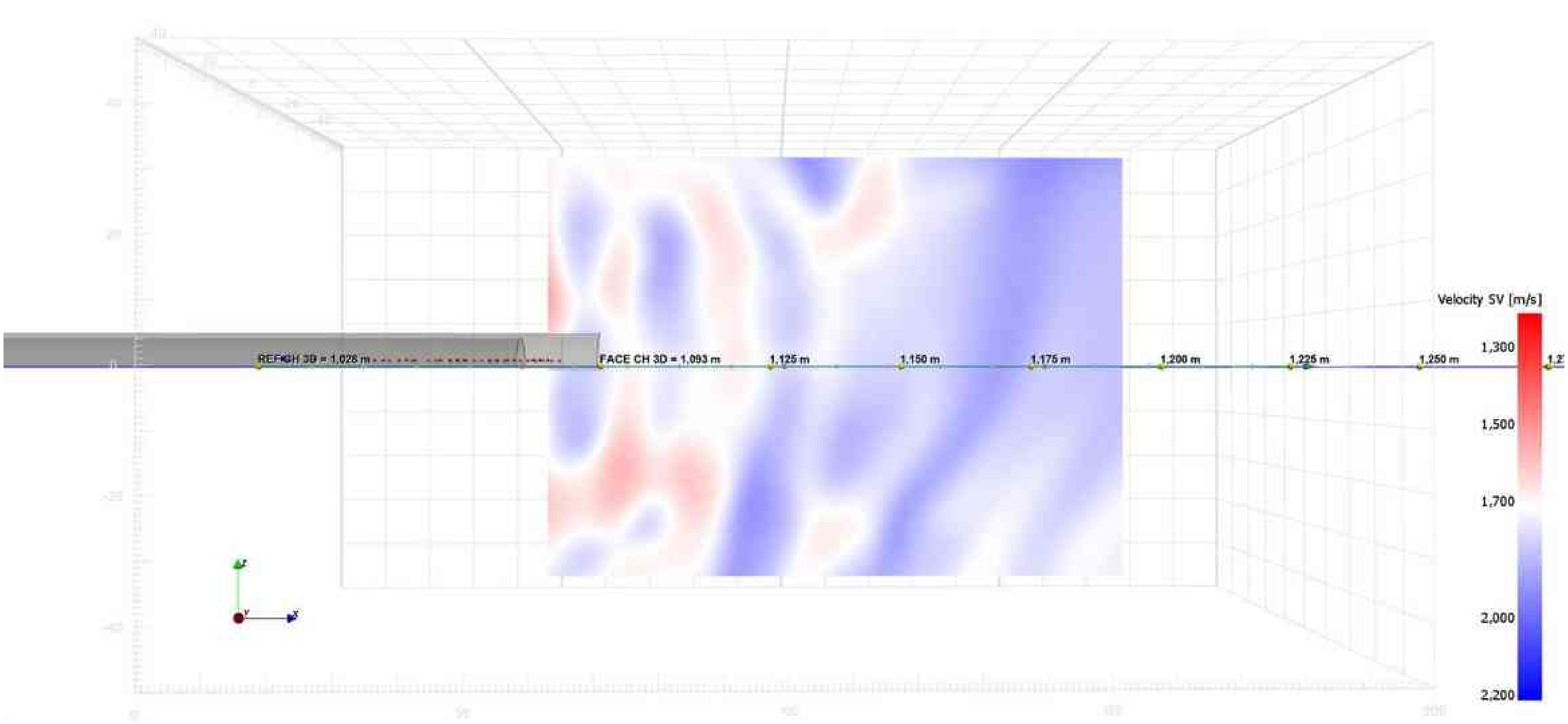


TSP - Tunnel Seismic Prediction: TEESTA-VI_JP

JAIPRAKASH ASSOCIATES LIMITED

Campaign name:	HRT2_FACE_3B_RD1092.5	Processing name:	#2V
Campaign type:	Sporadic measurement (single face)	Evaluation set:	Set 3
Face tunnelmeter:	593m	Processing type:	Ahead
Face stationing:	593m	Construction stage date:	16-02-2026 15:50:09 UTC+05:30
Face chainage:	1,093m	Creation date:	01-03-2026
Overburden:	190m	Operator:	AMBERG

3D view - Velocity SV



TSP - Tunnel Seismic Prediction: TEESTA-VI_JP

Campaign name:	HRT2_FACE_3B_RD1092.5	Processing name:	#2V
Campaign type:	Sporadic measurement (single face)	Evaluation set:	Set 3
Face tunnelmeter:	593m	Processing type:	Ahead
Face stationing:	593m	Construction stage date:	16-02-2026 15:50:09 UTC+05:30
Face chainage:	1,093m	Creation date:	01-03-2026
Overburden:	190m	Operator:	AMBERG

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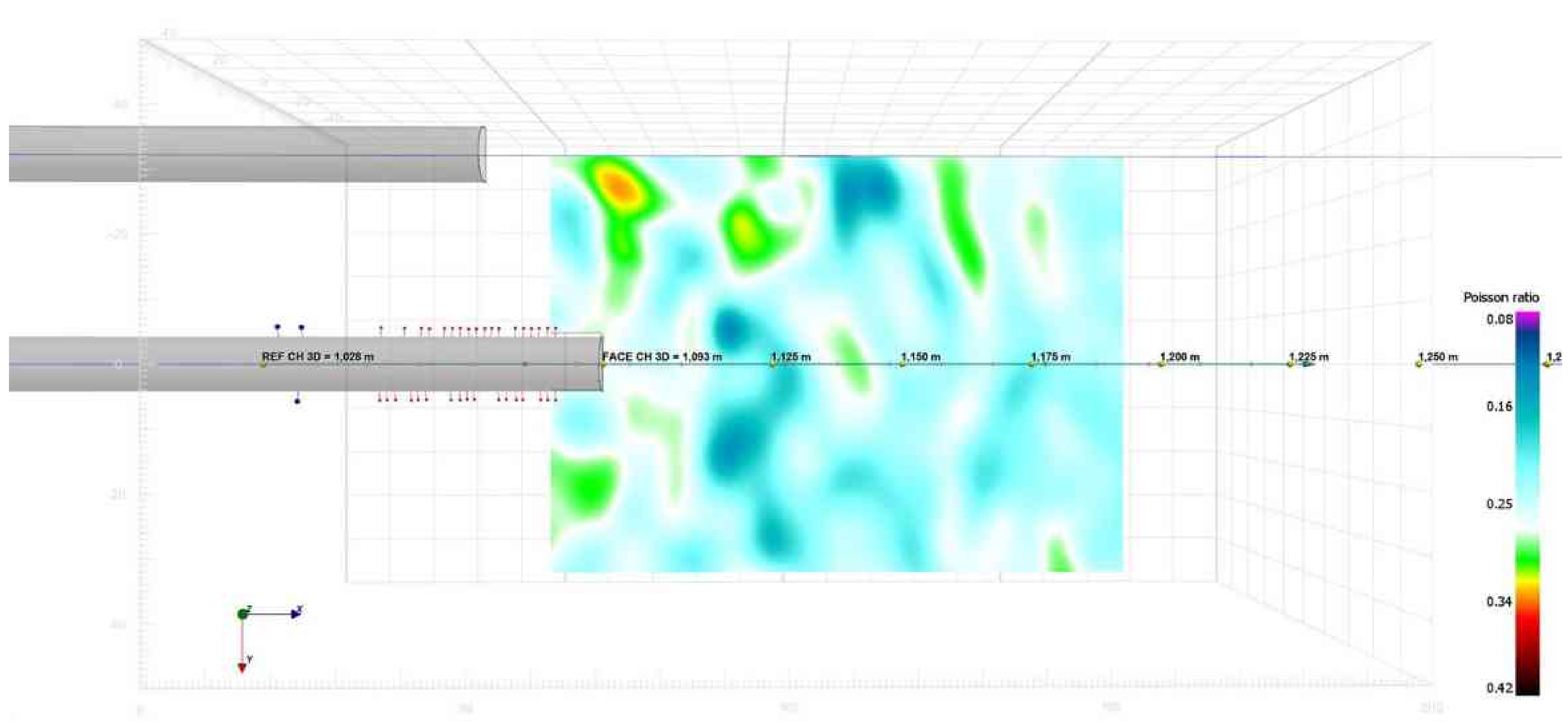
3D view - Poisson



TSP - Tunnel Seismic Prediction: TEESTA-VI_JP

Campaign name:	HRT2_FACE_3B_RD1092.5	Processing name:	#2V
Campaign type:	Sporadic measurement (single face)	Evaluation set:	Set 3
Face tunnelmeter:	593m	Processing type:	Ahead
Face stationing:	593m	Construction stage date:	16-02-2026 15:50:09 UTC+05:30
Face chainage:	1,093m	Creation date:	01-03-2026
Overburden:	190m	Operator:	AMBERG

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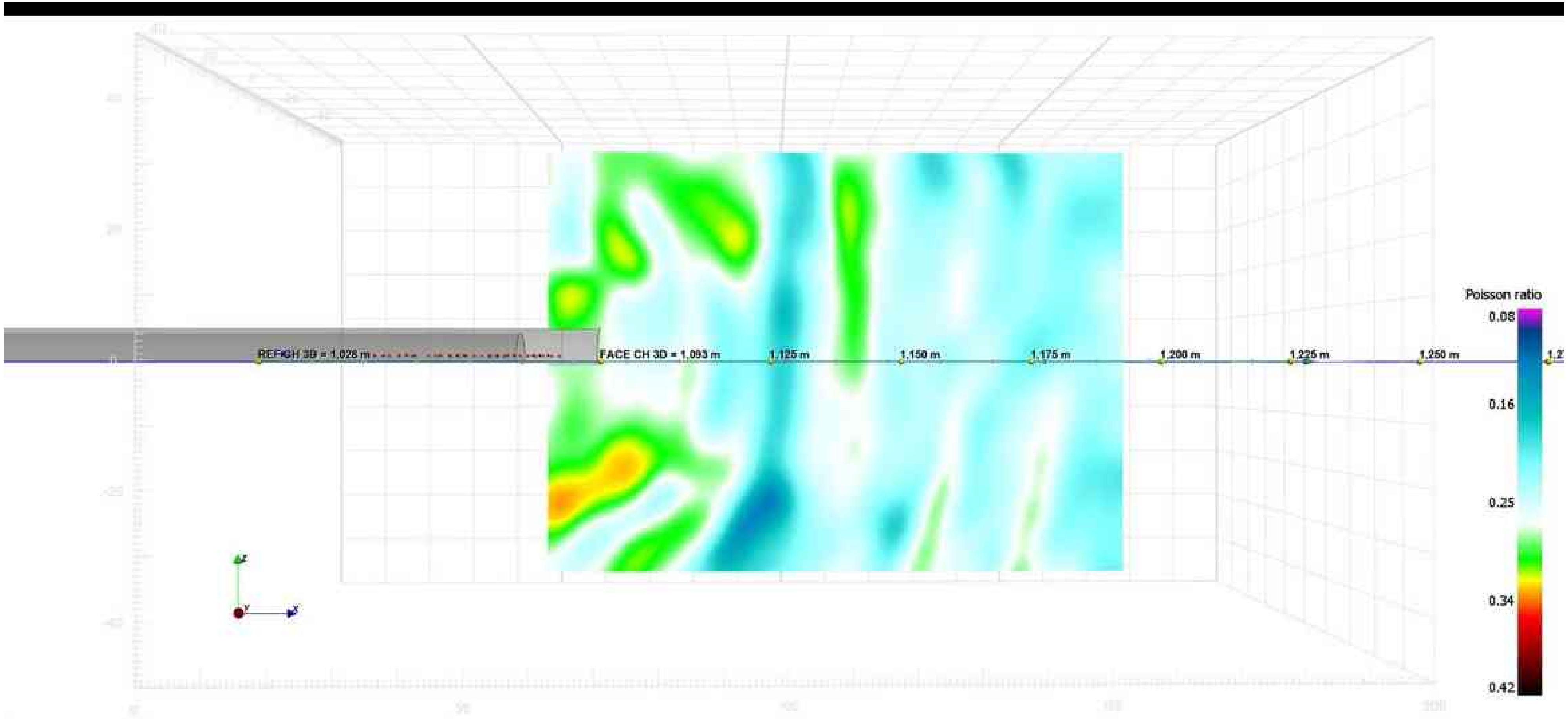
3D view - Poisson



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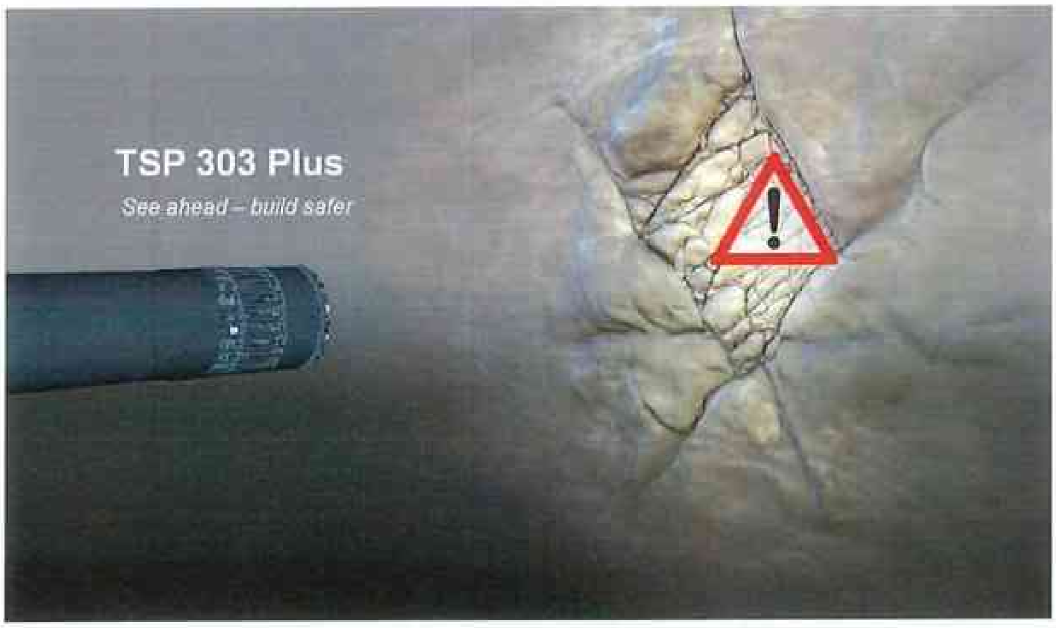
Teesta-VI Hydroelectric Power Project

Result Report
of
Tunnel Seismic Prediction - TSP 303 Plus

Campaign location: #4_HRT1 FACE 4A_RD 1268
Campaign date: 14th February 2026



PATEL ENGINEERING LTD.
TEESTA-VI HEP

PATEL ENGINEERING LTD. TEESTA-VI HEP

1. Preface

The Teesta Stage-VI Hydroelectric Project, located in Sikkim, is a run-of-river scheme with a diversion barrage situated approximately 100 meters downstream of L.D. Kazi Bridge at Sirwani, near Singtam, Sikkim. The civil works contract for the project was awarded to Patel Engineering, a leading infrastructure and construction services company in India. The contractual scope of work includes diversion works, barrage and spillway construction, penstocks, underground powerhouse, intake, pothead yard, and tail channel development.
As part of the project, Patel Engineering entrusted Amberg Engineering India with Tunnel Seismic Prediction (TSP) services to assess rock mass conditions ahead of tunnel excavation. The project comprises two parallel headrace tunnels, HRT-1 and HRT-2, with a wall-to-wall distance of 30 m. One TSP measurement was planned and executed at different locations along Head Race Tunnel (HRT-1) to provide geophysical insights critical for tunnel construction and safety. The schematic project layout is illustrated in **Error! Reference source not found.**. The objective of this investigation is to evaluate the rock mass condition ahead & around the tunnel face within a prediction range of 100-150m.
This report summarises the operational work description and results discussion of TSP measurement carried out at HRT-1 FACE-4A. At the time of measurement, the tunnel face was at RD1,268.

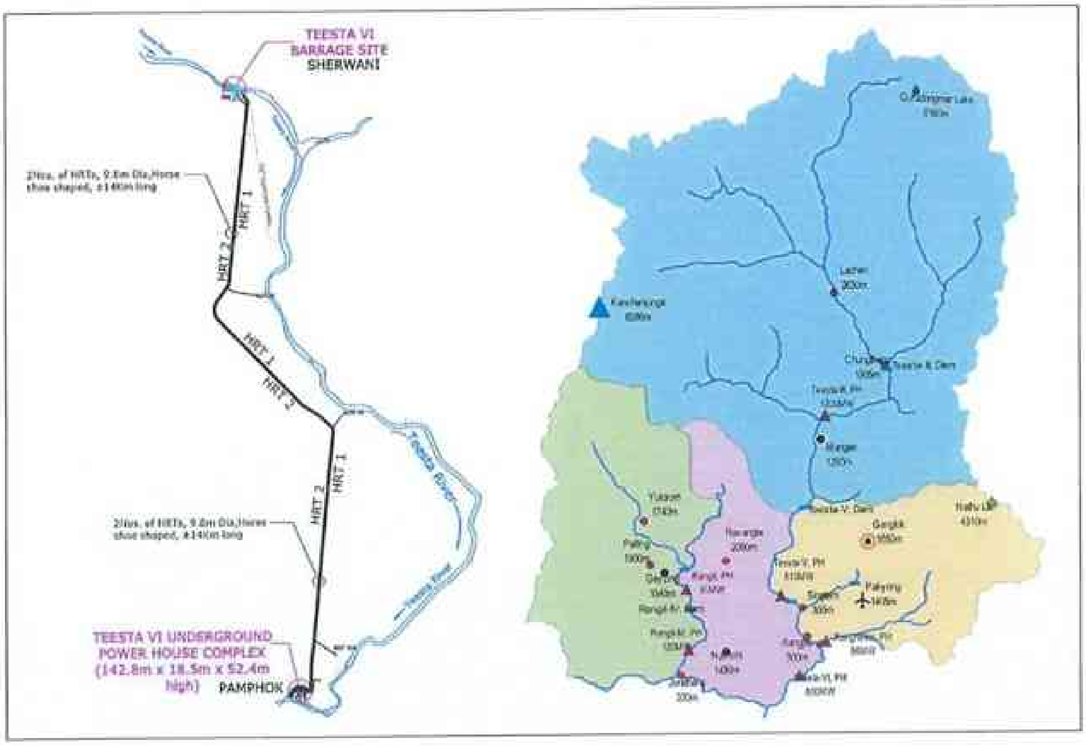


Figure 1 Project layout of Teesta-VI Hydroelectric Power Project

2. The TSP Method

2.1. Principal concept

The Tunnel Seismic Prediction method developed by AMBERG Technologies AG detects changes in rock mass such as irregular bodies, discontinuities, fault and fracture zones ahead of the tunnel face. Employed as a predictive method during excavation process for both drill & blast and TBM headings, no access to the face is required to perform measurements, which are taken in tunnelling production breaks of around 60 minutes. Acoustic signals are produced by a series of 24 shots of usually 50 to 100 grams of detonation cord aligned along one tunnel wall side and having an additional shot line along the opposite tunnel wall side in cases of more complex geology. Four sensor probes, consisting of highly sensitive tri-axial receivers, are contained in protection tubes whose tips are firmly cemented into boreholes of 45-50 mm in both side-wall (Figure 2).

Figure 2. Standard TSP measuring layout. 24 explosive charges are being shot one by one along right or/and left tunnel wall close to the tunnel face. Four receivers arranged further back pick up arriving waves.

The 3-component receivers pick up the seismic signals, which were being reflected from any kind of discontinuity in the rock mass ahead. A highly sophisticated processing & evaluation software has been devised for ease of operation. The capability of the system to record the full wave field of compressional and shear waves in conjunction with the intelligent analysis software enables a determination of rock mechanical properties such as Poisson's ratio and Young's Modulus within the prediction area. The final 2D- and 3D-summary results produced by the system software present as well detected events and boundary planes crossing the tunnel axis coordinates ahead of the face.

2.2. Operation

The TSP 303 system is an easy-to-operate system. The system setup and installation of the four sensitive tri-axial sensors is simple and comparable with the setting of a rock bolt as shown in Figure 3.

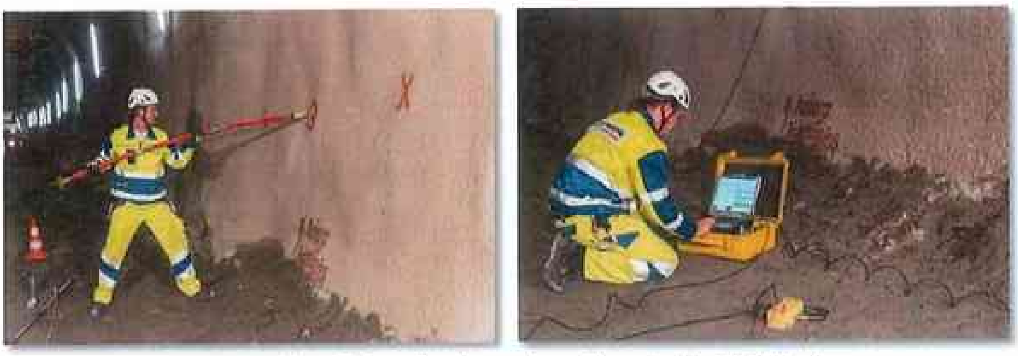


Figure 3 Simple installation of receiver and recording unit of the TSP 303 system.

The seismic acquisition geometry is restricted to source and receiver positions at or close to the tunnel. As a result, reflection and scattering angles are small and the spatial resolution while imaging obstacles ahead is not optimum. Resolution is further decreased by seismic attenuation, which is notably strong at the required high frequencies. Hence, careful data processing is very important in order to avoid inaccurate seismic predictions ahead of the tunnel, which may lead to misinterpretations. For example, discontinuities, which are structural or geological features that changes the homogeneity in the rock mass, may not being imaged to full scale, because only constricted portions of these zones could reflect waves towards the receiver due to the physical Snell's law of reflection.

The image will be enhanced by the use of more receivers such as two at both tunnel wall sides. Moreover, it could become quite meaningful to provide a second source line along the opposite tunnel wall side when the rock mass is very complex in terms of alternating strike angles or irregular obstacles such as cavities or Karst features. By all means, any increase of acquisition data quantity produces higher quality result images, in particular when it comes to 3D data processing.
The TSP 303 system integrates 3D data acquisition and processing software containing routines for optimal seismic imaging with respect to tunnelling requirements. It exploits the information in the seismic wave field by separate compression (P) and shear (S) wave analysis and the 3D-Velocity based Migration & Reflector Extraction technology (3D-VMR). The 3D-VMR technology provides an adequate and detailed 3D image of the ground leading to a more reliable interpretation compared to conventional 2D approaches.

2.3. Wave velocity and related parameters

Elastic body waves passing through homogeneous, isotropic media have well-defined equations of motion. Utilizing these equations, computations of geomechanical properties of the rock mass can be done. Field surveys can readily obtain wave velocities, V_P and V_s as with the TSP method; velocities are in units of length per time, usually meters/second (m/s).
A homogeneous, isotropic medium's engineering properties such as: Young's or elastic modulus (E), shear modulus (G) and Poisson's ratio can be determined, if V_P and V_s are known as well as accounting with a representative density value.

$\sigma = ½ (V_P^2 - 2V_S^2) / (V_P^2 - V_S^2)$ Poisson's ratio

$E = \rho\, V_P^2 (1\text{-}2v)(1+v)/(1\text{-}v)$ Young's or elastic modulus

$G = E/[2(1+v)]$ Shear modulus

2.4. Limitations conditional upon geology

The TSP method like every seismic method is subject to certain geological conditions. We are confident in the applicability of TSP® 303 for any underground project if the following preconditions are fulfilled:

- Adequate rock physical property contrasts will exist in conjunction with fault zones or changes in rock formation. Seismic applications employ the parameter of acoustic impedance (the products of body wave velocity and rock density) that is a measure of quality determining the reflection coefficient. An acoustic impedance contrast of at least 20% ensures sufficient strong reflection signals in order to seismically detect geological discontinuities.
- The usual TSP® layout works most accurately for rock boundary orientations that intersect the tunnel axis at moderate to high angles. Thus, a certain strike and dip angle (>25°) with reference to the tunnel axis has to be expected to be predictable by TSP®. Best results are being achieved at steeply dipping or striking boundaries (> 45°). Boundaries ahead of the tunnel face showing lower angles (< 25°) aren't able to reflect signals to the receivers due to the receivers' back arrangement of approx. 50 m behind the tunnel face. This restriction is related to the physical Snell's law of reflection and refraction.
- Standard TSP data processing and modelling has been developed for data acquired in tunnels with high overburden (> 50 m). Although not restricted, results analysis and interpretation can be carefully done for tunnel with lower overburden (< 50 m) considering result extrapolation beyond the actual surface.

3. Geology along TSP layout

The Project area falls in the Outer and Lesser Himalayas, exposing varied rock types belonging to different tectono-stratigraphic units, thrown into complex fold system, and tectonically distributed by faults and thrusts of different dimensions.
As per the geological face log information, the geology along the TSP layout between reference at RD1,194 and face location at RD1,268 corresponds to sheared, exceptionally poor (class-IV) rock mass of Phyllite (RMR ~ 10-15). The overburden at the face is about 150m.

4. Operational Commentary

Data acquisition of TSP campaign was carried out on February 14, 2026. Total 24 shot holes and 4 receiver holes were drilled with available Drill Jumbo. As per the site condition, the shot holes were drilled on left side of tunnel wall.

As per AMBERG's TSP standard procedure, the shot and receiver boreholes of the TSP layout along the tunnel walls were checked upon correctness of length, diameter, alignment and access.

Figure 4 Detonator cap with wrapped round wire (white) that gives the accurate recording trigger in the moment of blast.

It had been agreed on the use of delay electric detonators. The use of delayed detonators implies the use of the Wire Break Trigger mode (WBT) of the TSP 303 Recording Unit as shown in Figure 4. The WBT mode allows the use of delay detonators despite the request for very high accuracy of the trigger time of each shot. This can be ensured by using an active wire wrapped round the cap's tip of each detonator that give highly accurate trigger time of recording while it breaks in the moment of the blast.

At the same time as the system was installed, the blasting team also received a brief explanation of how to prepare the explosive charge. The first shot hole was charged with 100g of explosive, and sandbags were used for tamping, which generated a magnitude of 317mV, above the recommended value of 100mV. However, as the measurement progressed towards the tunnel face, a higher attenuation of energy was observed. Due to the very poor rock mass conditions, the charge size was not increased further to prevent excessive vibration or instability. The detailed specifications of the charge sizes and their corresponding energy magnitudes are provided in Table 1:

Table 1 Charge size details

Shot Line (LHS)		Recording Time
Shot hole	Charge size (gram)	
1 - 5	100	16:40 hr - 19:40 hr (3 hour approximately)
6 - 12	150	
13 - 14	200	
15 - 24	300	

Figure 5 depicts the seismic layout reproduced in the AMBERG TSP Ease software. The tunnel model exactly resembles the geometry of the tunnel at the moment of the measurement.

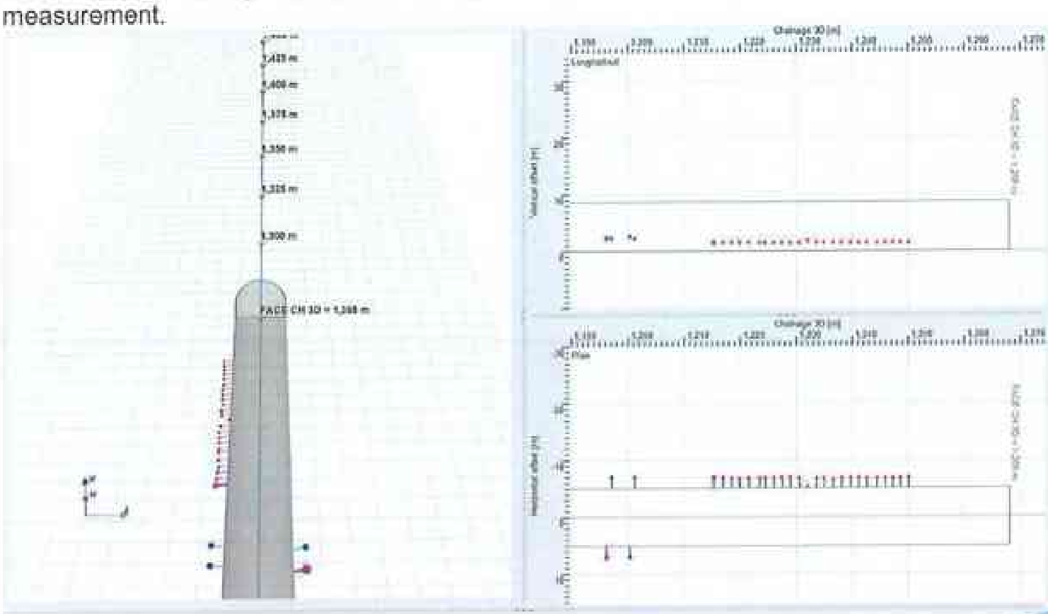


Figure 5: Actual TSP layout at campaign site. Blue dots: receivers, red dots: shots.

Specification about shot and receiver holes as well as the seismic source are presented in Table 2.

Table 2: TSP layout specification

Data Acquisition date		**February 14, 2026**
Layout in direction of investigation		
Shot holes	No. drilled	24
	Diameter	51 mm
	Depth / Location	1.50 m to 1.90 m / along left wall
	Inclination from horizontal	8° to 12° downwards
	Spacing	1.30 – 1.90m
	Performed shots	24
	Explosive charges	100 - 300 g
Receiver holes	Number	4
	Diameter	51 mm
	Depth / Location	RCV1 & RCV2 – 1.95/1.95 m (left) RCV3 & RCV4 – 1.95/1.95 m (right)
	Inclination from horizontal	9° to 13°
	Nearest offset to first shot hole	15.0m
	Distance between receiver holes	4.1m (left) and 4.1m (right)
Seismic Source		
Blasting machine	Electric blasting machine	
Detonators	Delay electronic detonators	
Explosive type	Powergel 80	
Min detonation velocity	3,500 - 4000 m/s	
Type of Triggering	WBT	

5. Raw data Analysis & Processing

5.1. Raw data Analysis

After input the geometry data of the tunnel profile, receivers and shots, the software Amberg TSP Plus is ready to present the recorded raw data arranged in the three components of directions X, Y and Z for each receiver. An additional data check per receiver component gather is now possible as shown in Appendix -1.

Raw data quality check

	Total score	FB coherency	SNA analysis	SNF analysis	Analysis date
Score	7/12	2/6	2/2	3/4	**Analyzed shots**
Classification	Moderate good	Poor	Good	Good	
Recommendations on processing	Do not process the data with default parameter settings. Most likely, data processing can also succeed reliably in the long-distance range. Details				

Figure 6 Raw data quality check (RQDC)

Raw data quality for this campaign is categorized as moderate poor shown in Figure 6 (total score 7 out of 12). The raw data quality analysis comprises three major procedures: First Break coherency (FB coherency), Signal/Noise Amplitude (SNA analysis) and Signal/Noise Frequency analysis (SNF analysis). Each analysis delivers a content specific scoring and

classification. The overall analysis is then summarized in a Total score and a Classification representing the quality of the whole data set.
In this campaign, the signal amplitude varies from 317 mV to 36 mV. However, only a few initial shots were recorded with magnitudes greater than 100mV (above the minimum recommended value), indicating high energy attenuation within the rock mass.
The noise caused by the airborne wave is moderately high for crossline receivers. The data is characterized by a very low frequency content (50 – 300 Hz).

5.2. Seismic data processing

After the selection of proper seismic data, the subsequent seismic data processing per receiver immediately started to run through several primary steps controlled by a given flow chart as shown in Figure 7.
The aim of seismic data processing is the extraction and enhancement of the reflected wave field. For this purpose, the data run through specially designed processing steps where intermediate results are stored enabling a review during processing at any time. The wave separation process of Amberg TSP Ease separates the recordings into wave types (P, SV and SH waves) according to their polarization type via rotating the coordinate system as function of recording time. All pre-processed data are passed onto the 3D processing, where a velocity distribution of a user-defined 3D-model is presented. Finally, extracted reflectors are interpreted and rock property calculations of relevant reflectors are presented in the evaluation. For the current dataset, data from 3 receivers and 24 shots were processed. However, shots 21,22,23 and 24 were deactivated from RCV-2 due to very poor S/N ratio in the signals. The Vp/Vs ratio was kept as 1.73 in all receivers to pick the direct S-wave velocity. This Vp/Vs ratio corresponds to the theoretical value for hard rock. In case that first arrivals of the S-wave are not identifiable in a dataset, which is normal when using explosive source, the theoretical value may be applied. Certainly, together with the direct P-wave velocity, the Vp/Vs ratio is also an important calibration parameter for this campaign. If necessary, these parameters could be modified after proper validation of TSP data as the excavations overlap the prediction range. The full model size of 200 m in the longitudinal direction was used in 3D data processing.

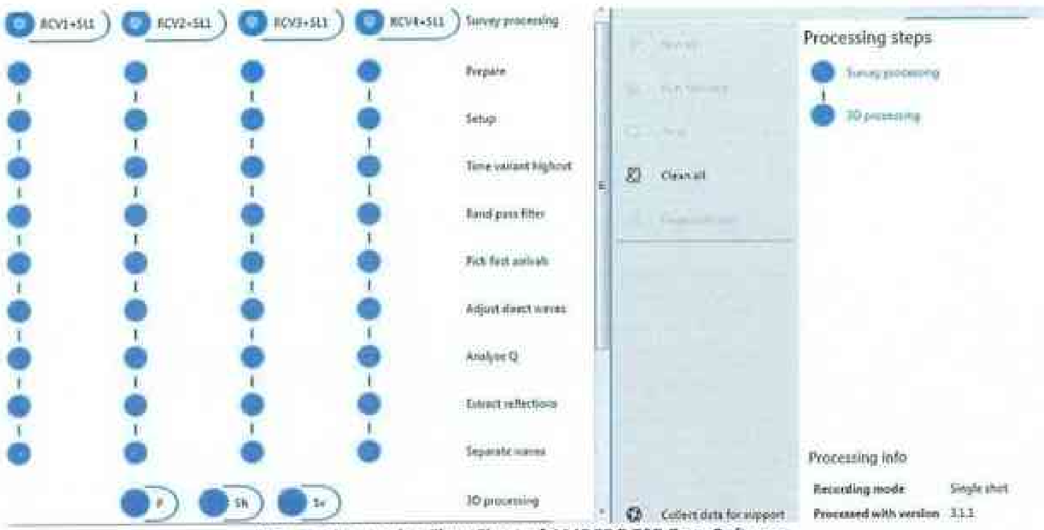


Figure 7 Processing Flow Chart of AMBERG TSP Ease Software

6. Result of TSP Campaign # 4_FACE 4A_RD 1268

6.1. 3D Velocity Models

P wave Velocity Model:

Figure 8 depicts 2D longitudinal and plan sections (top and bottom, respectively) which were extracted from the 3D model of the P-wave velocity (Vp) on the seismic axis. Varying colouring in Figure 8 indicates velocity variation, in which blue and red areas correspond to increasing and decreasing P-wave velocity, respectively. The description of the velocities & estimated parameters is given in Table 3.
The estimated P-wave velocity along the seismic axis ranges between 1,930 m/s to 2,240 m/s with a reference value of 2,021 m/s. The reference value is estimated from the first arrival of direct P–wave and it is used as an input parameter in the 3D processing. It also corresponds to a representative velocity of the prevailing lithology along the TSP layout, that is poor/sheared rock mass.

Table 3: 3D model description and features

2D sections							
Model start (RD): 1,194			**Model end (RD):** 1,394 **Tunnel face at the time of recording (Ch):** 1,268				
Vp (m / s)			**Vs (m / s)**				
Min.	**Ref.**	**Max.**	**Min.**	**Ref.**	**Max.**	**comment**	
1,930	2,021	2,240	1,070	1,168	1,270	• Reference velocity along the TSP layout	
Comparatively Identified Low Velocity Zones (LVZ) *							
Zone	**RD (Approx.)**		**Vp (m / s)**			**Location**	**comment**
i	1,302 – 1,312		1,900 – 1,930				
ii	1,319 – 1,330		1,950 – 2,000				
* LVZs are commonly associated with changes in rock properties. These changes may be due to increased fracturing or jointing, the appearance of fault or shear zones. * Identified LVZs are marked in figure 8.							

According to the 3D Vp model, a drop in P-wave velocity has been observed directly ahead of the face, approximately from RD1,268 to RD1,285, where Vp decreases to a value of about 1,900 m/s. This reduction likely corresponds to a continuation of weak rock mass stiffness. Additionally, two more low-velocity zones (LVZs) were identified between RD1,319 to RD1,330 and RD1,340 to RD1,357, which might cut across the tunnel axis.

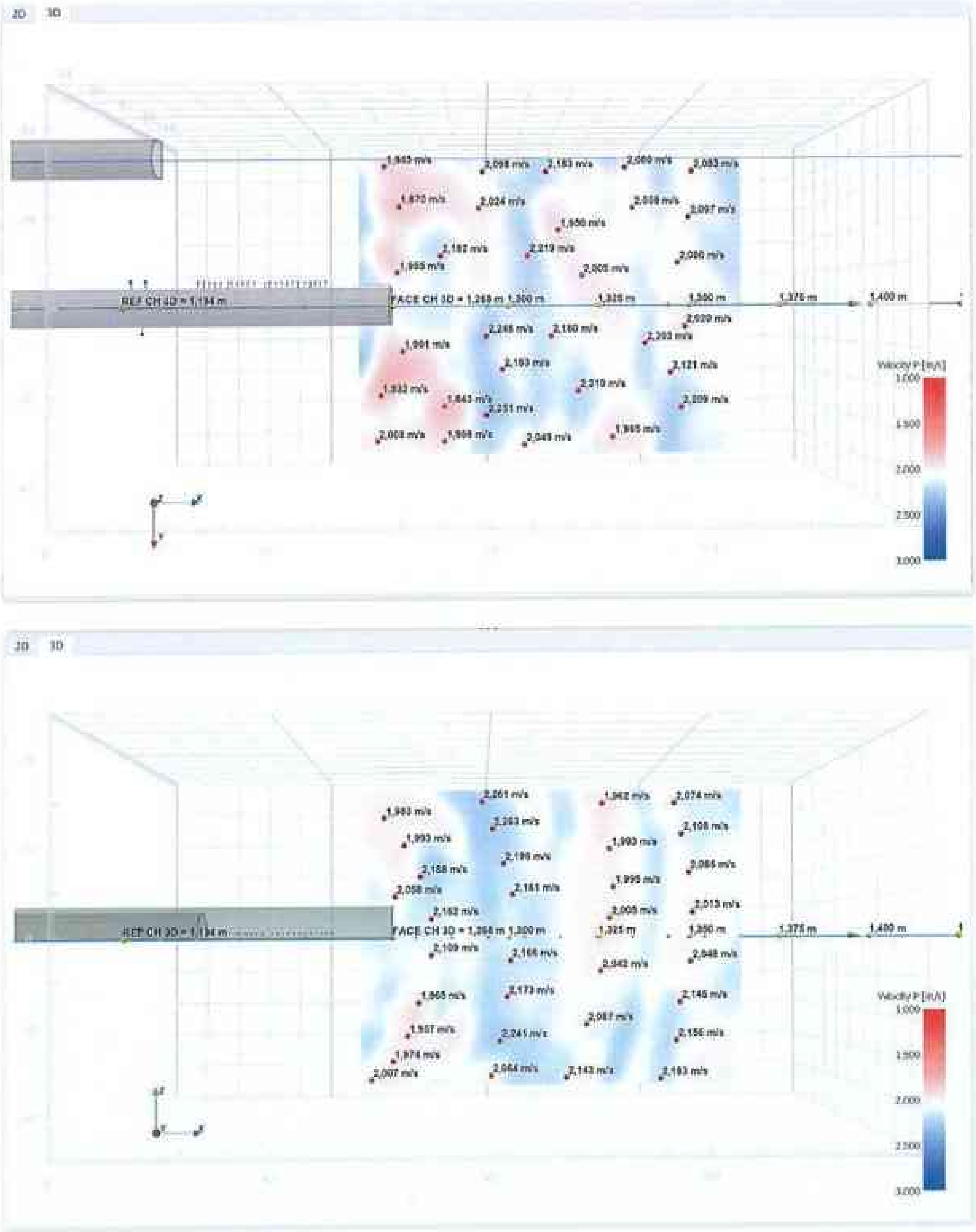


Figure 8: Plan & Longitudinal view of the 3D P-wave velocity model along the tunnel axis including the tunnel model with the location of the shot holes (red dots) and the receivers (blue dots). The red dot markings indicate values of Vp at the selected position.

S wave velocity model:

Figure 9 depicts perspective 2D plan & longitudinal sections, which were extracted from the 3D model of the S-wave velocity (Vs) on the seismic axis. Similar as in the Vp model, Vs model is also showing lower velocities from RD1,268 – RD1,280 and RD1,240 – RD1,250.

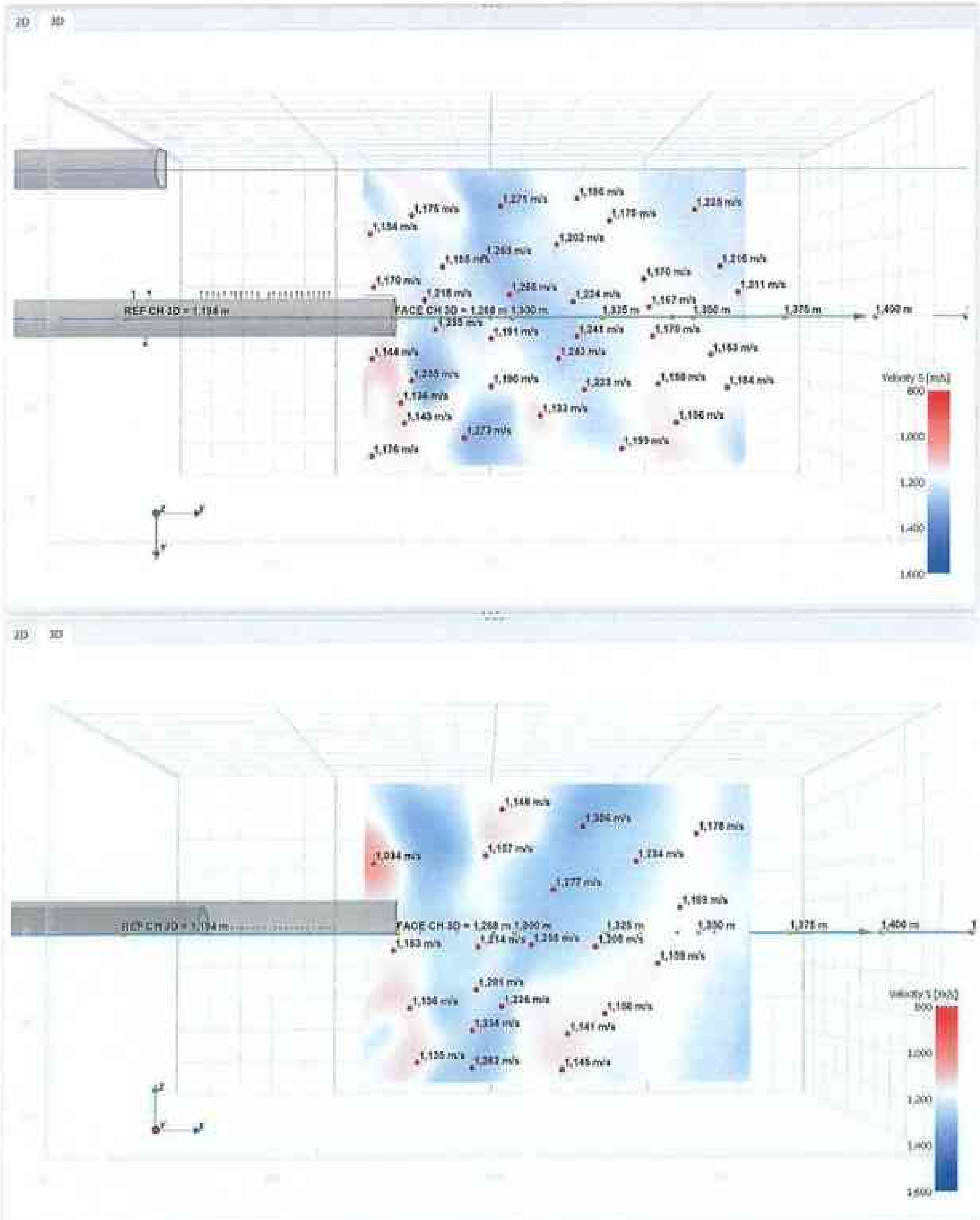


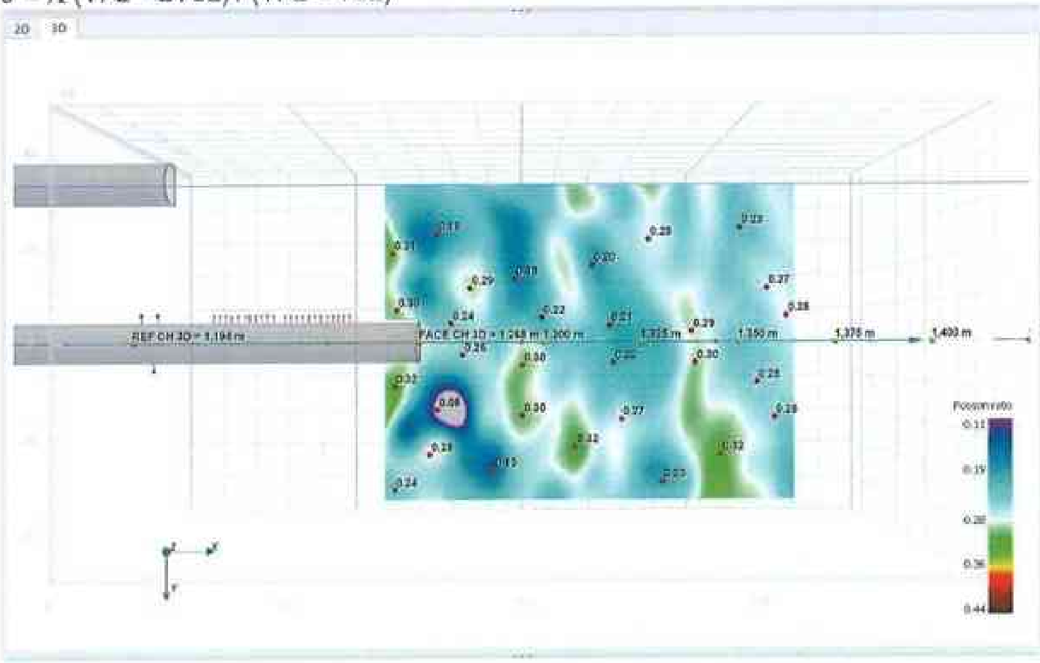
Figure 9 Plan & Longitudinal view of the 3D S-wave velocity model along the tunnel axis including the tunnel model with the location of the shot holes (red dots) and the receivers (blue dots). The red dot markings indicate values of Vs at the selected position.

The low velocity zones in S wave can be associated with a deterioration in rock mass conditions and the possible influence of fracturing, shearing.

6.2. Poisson's ratio

The Poisson's ratio is an elastic parameter that is a measure of the compressibility of material perpendicular to applied stress, or the ratio of latitudinal to longitudinal strain. Poisson's ratio (σ) can be expressed in terms of derived velocities of P-waves (Vp) and S waves (Vs) as follows:

σ = ½ (VP2 – 2VS2) / (VP2 – VS2)



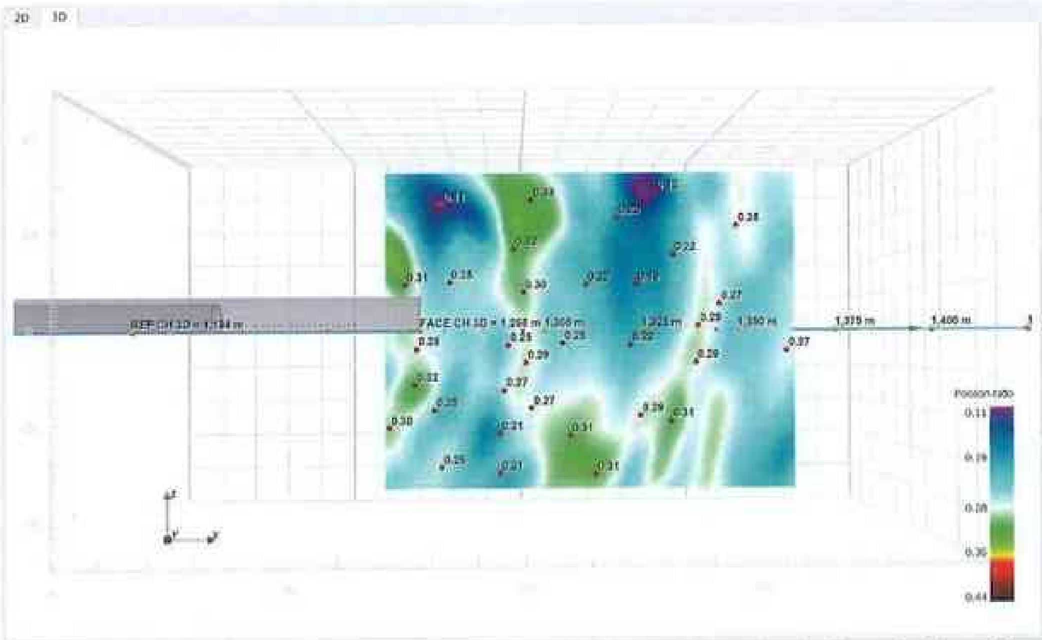


Figure 10 Plan & longitudinal view of Poisson ratio along & around tunnel axis. The red dot markings indicate values of Vs at the selected position.

The variation in the estimated Poisson's ratio along and around the tunnel axis is shown in Figure 10. Approximately at RD1,290, RD1,335 a high value of Poisson's ratio (>0.29) has been estimated at the crown and on the right side of the axis. The high Poisson's ratio may be associated with possible water-bearing conditions or increased shearing. The detailed prognosis is given in chapter 6.3.

6.3. Prognosis along tunnel axis

The fundamental of the interpretation based on the TSP results relies on the contrast between the reference values, i.e. seismic velocities and geomechanical parameters estimated within the TSP layout and the values of these parameters associated to the reflectors extracted along the prediction range. In addition, geological observations along the TSP layout and existing geological model allow for an initial correlation of these values.

RD1,096 to 1,160 (Reference values)

This section corresponds to the TSP seismic layout where a single reference value for each parameter is estimated based on the velocity of the direct waves and an empirical density formula selected from the rock catalogue included in the software Amberg TSP Ease for the most predominant type of rock along the TSP layout.

Table 4: Reference values & estimated parameters

Parameter	Campaign # 4_FACE 4A_RD1,268
Vp (m / s)	2,021
Vs (m / s)	1,167
Poisson ratio (-)	0.25
Edyn (GPa)	6
Bulk mod. (GPa)	4
Geology	Extremely Poor rock mass, Crushed Phyllite

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a) RD1,268 to RD1,280

Parameter	Vp [m / s]	Vs [m / s]	Bulk mod. [Gpa]	Poisson	Edyn [GPa]
values	2,100 – 2,132	1,077 – 1,144	5	0.32 – 0.30	6 - 5
Tendency from reference value	Slight increase	Slight Decrease	Slight increase	Increasing	Comparable
Interpretation	Continuation of almost similar rock mass condition as layout; very poor rock mass				
Remarks	Possible water bearing zone.				

b) RD1,280 to RD1,303

Parameter	Vp [m / s]	Vs [m / s]	Bulk mod. [Gpa]	Poisson	Edyn [GPa]
values	1,990 – 2,190	1,210 – 1,250	3 - 5	0.18 – 0.28	6 - 7
Tendency from reference value	Increase - Decrease	Increasing	Slight Decrease	Decreasing	Slight Increase
Interpretation	Comparatively increase in rock mass stiffness; Still very poor rock mass.				
Remarks	As per 3D, higher value of Poisson's ratio is observed approximately at RD1,290. Which is away from 10~15m away from tunnel axis				

c) RD1,303 to RD1,312

Parameter	Vp [m / s]	Vs [m / s]	Bulk mod. [Gpa]	Poisson	Edyn [GPa]
values	1,930	1,195	3	0.19	6
Tendency from reference value	Decreasing	Decreasing	Decreasing	Decreasing	Slight Decrease
Interpretation	Comparatively slight decrease in rock mass stiffness / Possible increase of rock mass fracturing or jointing.				
Remarks					

d) RD1,312 to RD1,320

Parameter	Vp [m / s]	Vs [m / s]	Bulk mod. [Gpa]	Poisson	Edyn [GPa]
values	2,139	1,264	5	0.23	7
Tendency from reference value	Increasing	Increasing	Increasing	Increasing	Increasing
Interpretation	Comparatively increase in rock mass stiffness; Still very poor rock mass.				
Remarks					

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e) RD1,320 to RD1,331

Parameter	Vp [m / s]	Vs [m / s]	Bulk mod. [Gpa]	Poisson	Edyn [GPa]
values	1,990	1,190	4	0.23	6
Tendency from reference value	Decreasing	Decreasing	Decreasing	Comparable	Decreasing
Interpretation	Comparative decrease in rock mass stiffness				
Remarks					

f) RD1,331 to RD1,341

Parameter	Vp [m / s]	Vs [m / s]	Bulk mod. [Gpa]	Poisson	Edyn [GPa]
values	2,090 – 2,150	1,180 - 1,190	4 - 5	0.26 – 0.29	6 - 7
Tendency from reference value	Increasing	Comparable	Slight Increase	Increasing	Slight Increase
Interpretation	Comparative slight improvement in rock mass stiffness~ Still very poor				
Remarks	As per 3D, higher value of Poisson's ratio is observed approximately at RD1,335.				

g) RD1,341 to RD1,358

Parameter	Vp [m / s]	Vs [m / s]	Bulk mod. [Gpa]	Poisson	Edyn [GPa]
values	2,030	1,160	4	0.26	6
Tendency from reference value	Increasing	Comparable	Slight Increase	Increasing	Slight Increase
Interpretation	Comparative slight decrease in rock mass stiffness.				
Remarks					

h) RD1,358 to RD1,370

Parameter	Vp [m / s]	Vs [m / s]	Bulk mod. [Gpa]	Poisson	Edyn [GPa]
values	2,160 – 2,240	1,160 – 1,200	5 - 6	0.27	7
Tendency from reference value	Increasing	Comparable	Slight Increase	Increasing	Slight Increase
Interpretation	Comparative slight improvement in rock mass stiffness~ Still very poor.				
Remarks					

Remarks	End of prediction

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7. Concluding Remarks & Recommendation

- One TSP campaign was carried out at RD 1,268 in Tunnel HRT-1 Face_4A, providing a prediction of rock mass conditions for approximately 102 m ahead of the tunnel face.
- Raw data quality is classified Moderate poor. The energy attenuation is moderately high, which might be due to poor rock mass condition along the layout.
- As per the estimated TSP parameters, no major Improvement is expected in ground conditions ahead of the face. However, localized drops in velocities are observed approximately from RD1,303 - 1,312, RD1,320 - 1,331 and RD1,341 - 1,358. These fluctuations in velocities can be associated with further decrease in rock mass stiffness.
- As per the 3D Poisson ratio distribution, higher values of Poisson's ratio (>0.29) are observed around the tunnel axis approximately at RD 1,290 and RD 1,335 in HRT-1. Additionally, elevated values of Poisson's ratio are also observed along HRT-2, approximately between RD 1,300 and RD 1,330, which can be associated with possible water-bearing zones or an increase in rock mass fracturing and shearing.

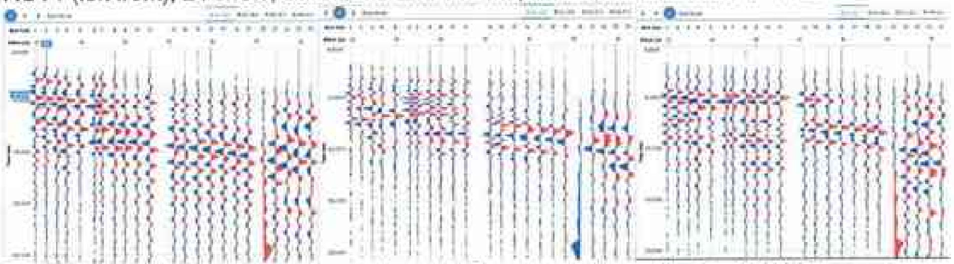
Amberg Engineering India

Kripal Choudhary
Geophysicist

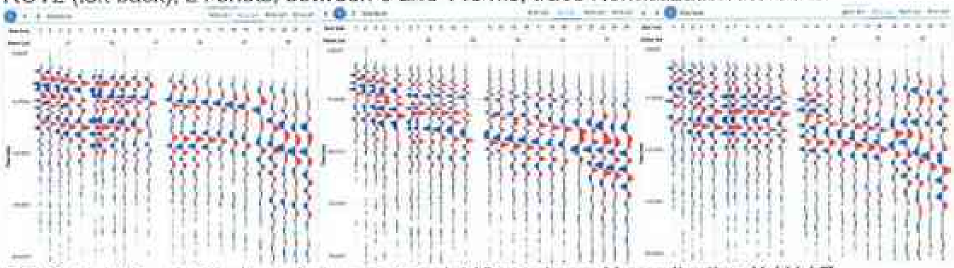
PATEL ENGINEERING LTD.

8. Appendix 1: Seismic raw data

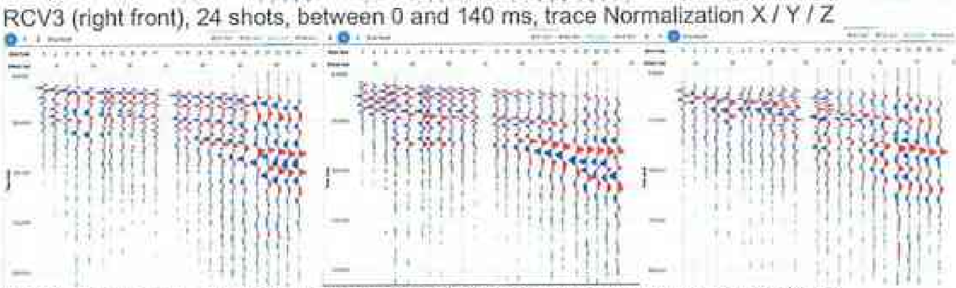
RCV1 (left front), 24 shots, between 0 and 140 ms, trace Normalization X / Y / Z



RCV2 (left back), 24 shots, between 0 and 140 ms, trace Normalization X / Y / Z



RCV3 (right front), 24 shots, between 0 and 140 ms, trace Normalization X / Y / Z



RCV4 (right back), 24 shots, between 0 and 140 ms, trace Normalization X / Y / Z

9. Appendix 2: Results

- ✓ Rock properties charts / longitudinal and plan view of colour shaded rock zones
- ✓ 2D plan view of P-Wave velocity model
- ✓ Rock properties table

TSP - Tunnel Seismic Prediction: TEESTA-VI_PATEL

Patel Since 1949

Campaign name:	HRT1_FACE 4A_RD1268	Processing name:	#1
Campaign type:	Sporadic measurement (single face)	Evaluation set:	Set 2
Face tunnelmeter:	268m	Processing type:	Ahead
Face stationing:	268m	Construction stage date:	14-02-2026 16:31:54 UTC+05:30
Face chainage:	1,268m	Creation date:	26-02-2026
Overburden:	150m	Operator:	AMBERG

Rock properties table

Chainage 3D [m]	Velocity P [m/s]	Velocity S [m/s]	Poisson ratio	Stat. Young's mod. [GPa]	Dyn. Young's mod. [GPa]	Shear mod. [GPa]	Bulk mod. [GPa]	Remark
initial	2,021	1,168	0.25	1	6	2	4	Refrence rock mass stiffness of crushed Quartzitic Phyllite
1,269	2,100	1,077	0.32	1	5	2	5	Continuation of almost similar rockmass condition as layout; very poor rock mass with poosible water bearing zone
1,273	2,132	1,144	0.30	1	6	2	5	
1,280	2,187	1,217	0.28	1	7	3	5	Comparativley increase in rock mass stiffness, Very poor rock mass
1,283	2,171	1,210	0.27	1	7	3	5	
1,286	1,992	1,244	0.18	1	7	3	3	

Created with Amberg TSP Ease Processing version 2.4.11221 (64 bit)

AMBERG ENGINEERING

PATEL ENGINEERING LTD.

TSP - Tunnel Seismic Prediction: TEESTA-VI_PATEL

Patel Since 1949

Campaign name:	HRT1_FACE 4A_RD1268	Processing name:	#1
Campaign type:	Sporadic measurement (single face)	Evaluation set:	Set 2
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Rock properties table

Chainage 3D [m]	Velocity P [m/s]	Velocity S [m/s]	Poisson ratio	Stat. Young's mod. [GPa]	Dyn. Young's mod. [GPa]	Shear mod. [GPa]	Bulk mod. [GPa]	Remark
1,298	1,994	1,211	0.21	1	6	3	4	
1,303	1,930	1,193	0.19	1	6	3	3	Comparative decrease in rock mass stiffness
1,305	1,932	1,198	0.19	1	6	3	3	
1,312	2,139	1,264	0.23	1	7	3	5	Comparativley increase in rock mass stiffness, Very poor rock mass
1,320	2,005	1,190	0.23	1	6	3	4	Comparative decrease in rock mass stiffness
1,328	1,992	1,189	0.22	1	6	3	4	
1,331	2,158	1,183	0.29	1	7	3	5	Almost similar to reference rock stiffness
1,338	2,089	1,189	0.26	1	6	3	4	
1,341	2,030	1,163	0.26	1	6	2	4	

TSP - Tunnel Seismic Prediction: TEESTA-VI_PATEL

Patel Since 1949

Campaign name:	HRT1_FACE 4A_RD1268	Processing name:	#1
Campaign type:	Sporadic measurement (single face)	Evaluation set:	Set 2
Face tunnelmeter:	268m	Processing type:	Ahead
Face stationing:	268m	Construction stage date:	14-02-2026 16:31:54 UTC+05:30
Face chainage:	1,268m	Creation date:	26-02-2026
Overburden:	150m	Operator:	AMBERG

Rock properties table

Chainage 3D [m]	Velocity P [m/s]	Velocity S [m/s]	Poisson ratio	Stat. Young's mod. [GPa]	Dyn. Young's mod. [GPa]	Shear mod. [GPa]	Bulk mod. [GPa]	Remark
1,345	2,156	1,219	0.26	1	7	3	5	Comparativley increase in rock mass stiffness, Very poor rock mass
1,358	2,160	1,207	0.27	1	7	3	5	
1,363	2,237	1,167	0.31	1	7	2	6	
1,370	2,094	1,252	0.22	1	7	3	4	End of prediction

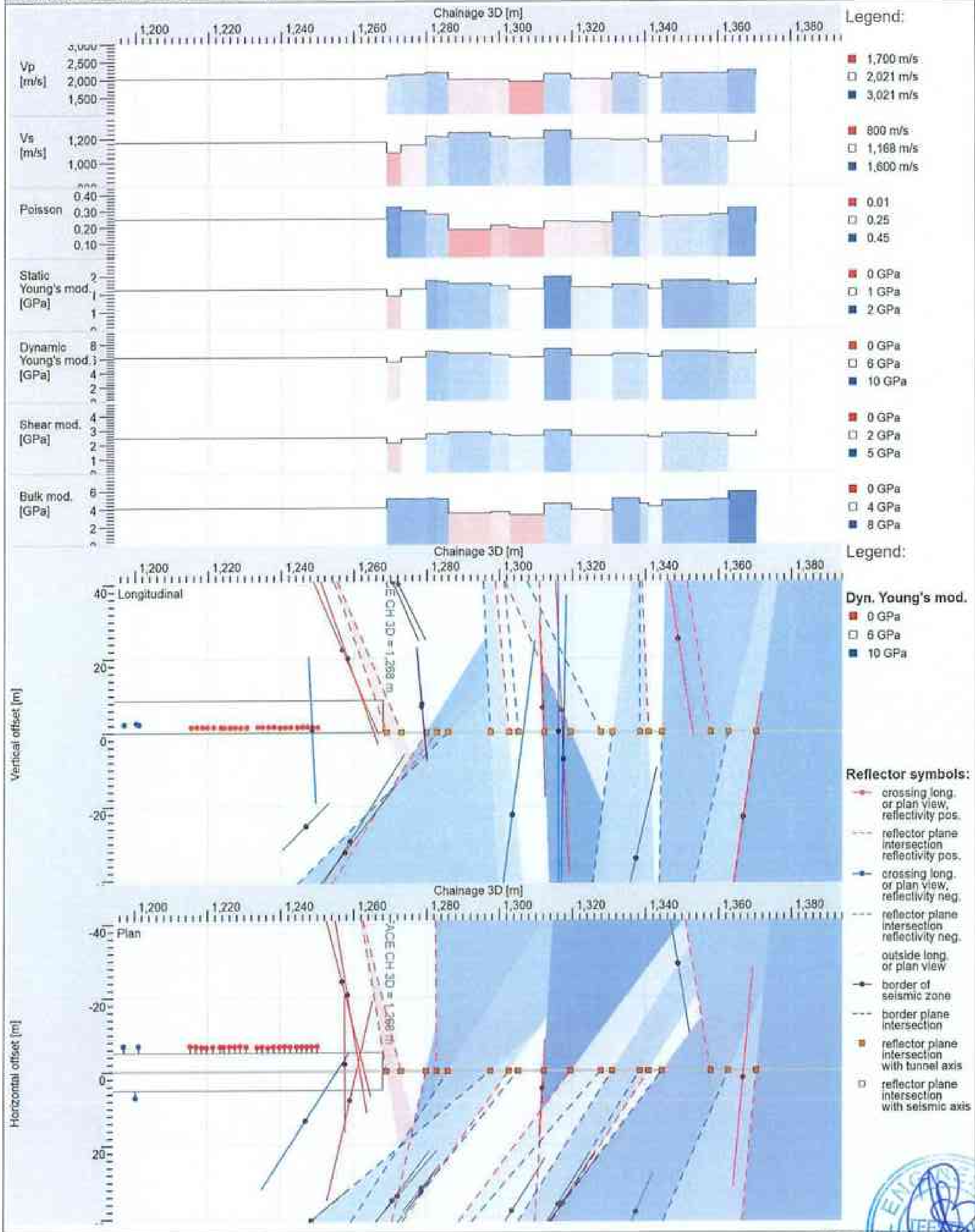
TSP - Tunnel Seismic Prediction: TEESTA-VI_PATEL

Patel Since 1949

Campaign name:	HRT1_FACE 4A_RD1268	Processing name:	#1
Campaign type:	Sporadic measurement (single face)	Evaluation set:	Set 2
Face tunnelmeter:	268m	Processing type:	Ahead
Face stationing:	268m	Construction stage date:	14-02-2020 10:31:54 UTC+05:30
Face chainage:	1,268m	Creation date:	26-02-2020
Overburden:	150m	Operator:	AMBERG

Rock properties charts / longitudinal and plan view

Scale: 1 : 1000



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AMBERG ENGINEERING

PATEL ENGINEERING LTD. TEESTA-VI HEP

Annexure-6

‘Geophysical report’

एनएचपीसी लिमिटेड
(भारत सरकार का नवरत्न उद्यम)
NHPC Limited
(A Government of India Navratna Enterprise)

तीस्ता-VI जलविद्युत परियोजना, सिक्किम के हेड रेस टनल अलाइनमेंट पर इलेक्क्ट्रिकल रेजिस्टिविटी टोमोग्राफी भूभौतिकी सर्वेक्षण की रिपोर्ट

REPORT ON
GEOPHYSICAL INVESTIGATIONS INVOLVING ELECTRIC RESISTIVITY TOMOGRAPHY (ERT) CARRIED OUT ABOVE HEAD RACE TUNNEL ALIGNMENT
TEESTA-VI HE PROJECT, SIKKIM

जून 2026
June 2026

भूभौतिकी रिपोर्ट सं./ GEOPHYSICAL REPORT No. NH/EG/GEOPHY/280

अभियांत्रिक भूविज्ञान एवं भूतकनीकी विभाग
एनएचपीसी कार्यालय परिसर, सेक्टर-33, फरीदाबाद
ENGINEERING GEOLOGY AND GEOTECHNICAL DIVISION
NHPC Office Complex, Sector-33, Faridabad

एनएचपीसी लिमिटेड

(भारत सरकार का नवरत्न उद्यम)

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ज्योतिर्मय
समूह वरिष्ठ प्रबंधक (भूभौतिकी)

Jyotirmoy
Group Senior Manager (Geophysics)

नवीन कुमार पाण्डेय
समूह वरिष्ठ प्रबंधक (भूभौतिकी)

Naveen Kumar Pandey
Group Senior Manager (Geophysics)

जून 2026
June 2026

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ENGINEERING GEOLOGY AND GEOTECHNICAL DIVISION
NHPC Office Complex, Sector-33, Faridabad

Contents of the Report

1. INTRODUCTION

Teesta Hydroelectric Project, Stage-VI is a 500MW (4 X 125 MW) run-of-the-river hydroelectric project located in South Sikkim. NHPC took over the partially constructed Teesta-VI Project in 2019 from M/s Lanco Teesta Hydro Power Limited for its completion. The project envisages the construction of a 26.5 m high barrage across the River Teesta near Sirwani village, Singtam, two Head Race Tunnels (HRTs), each of 9.8 m diameter and approximately 13.76 km in length, leading to an underground powerhouse near Tarkhola village. The twin tunnels extend from north to south along the right bank of the Teesta River. Along this investigated stretch, the tunnel alignments are overlain by a substantial super-incumbent cover varying from approximately ±180 m to ±350 m.

Approximately 85% of the tunnel excavation has been completed successfully through predominantly Class IV and Class V rock masses as classified under the Rock Mass Rating (RMR) system. However, the remaining tunnel stretch of approximately 3.6 km, located between Face 3A–4A of Head Race Tunnel-1 (HRT-1) and Face 3B–4B of Head Race Tunnel-2 (HRT-2), continues to present significant geological and geotechnical challenges. These geological conditions led to frequent overbreaks, deformation around the tunnel periphery, excessive support requirements, and repeated delays in excavation activities.

In view of the slow progress and uncertain geological conditions ahead of the tunnel face, it was considered necessary to carry out a detailed subsurface investigation to assess the rock mass condition along the remaining stretch of the tunnel.

To investigate the subsurface conditions ahead of the tunnel face, the geophysical team from the Corporate Office, Faridabad, was requested by the project vide eIOM No. NH\TEESTA-VI\Geology\2026\62 dated 15.04.2026 to carry out a detailed geophysical investigation. Accordingly, the team conducted Electrical Resistivity Tomography (ERT) survey along the tunnel alignment from 12.05.2026 to 21.05.2026 to assess the geological conditions and identify weak zones ahead of the tunnel grade.

This report presents the results of the geophysical surveys and the conclusions drawn based on the observations and interpretations of the study.

2. STUDY OBJECTIVE

The primary objectives of the investigation were:

- To delineate subsurface geological condition along HRT alignment
- To estimate the extent of water-bearing strata
- To assist the tunnelling team in planning excavation and support measures

3. SITE DESCRIPTION

As reported the HRT alignments traverse a geologically complex terrain comprising low to medium grade meta-sedimentary sequences of the Precambrian Daling Group, specifically belonging to the Gorubathan Formation. The geological setting is characterized by alternating bands of highly competent phyllitic quartzite or quartzite and comparatively weak phyllite, resulting in highly heterogeneous ground conditions.

The complexity of the rock mass is further accentuated by multiple phases of tectonic deformation associated with the Himalayan orogeny. These tectonic events have imparted intense folding, pervasive fracturing, shearing, and alteration to the rock mass, resulting in a structurally disturbed and anisotropic geological environment.

Consequently, the tunnel excavation is being carried out through rock masses exhibiting significant spatial variability in strength, deformability, discontinuity characteristics, and groundwater conditions. Such geological complexities have a direct bearing on excavation stability, support requirements, and construction progress.

4. THEORETICAL BACKGROUND

Electrical Resistivity Tomography (ERT)

Two-dimensional (2D) Electrical Resistivity Tomography or Resistivity Imaging is a useful geophysical technique to explore nature of subsurface and delineate the water bearing formations. It is carried out utilizing large numbers of electrodes connected to the instrument through multi-core cables. Data is collected by the instrument automatically for several datum points through a computerized switching system as per the selected electrode configurations.

All resistivity methods employ an artificial source of current injected into the subsurface through point electrodes and the resulting potential difference is measured at other electrodes positions in the neighbourhood of the current flow.

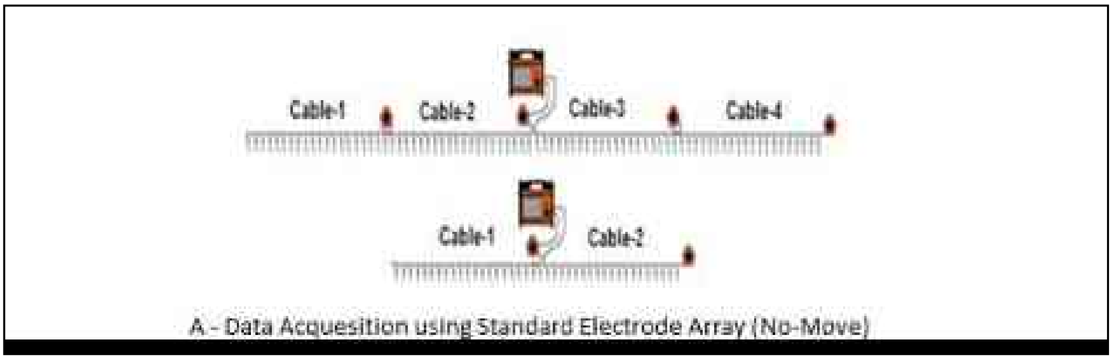


Fig. 1: Schematic diagram showing cables and instrument arrangement during Standard Electrode Array.

Terrameter LS-2 (Guideline Geo, Sweden)

The latest ABEM Terrameter LS-2, 12-Channel (Guideline Geo, Sweden) was utilized for data collection. This instrument has inbuilt switching system and different electrode configurations. Data can be collected by selecting the appropriate protocol. This Imaging System is powered by external 12V battery. For field operations a good, adequate capacity and charged battery is vital for the best performance. In instance case, 12V, 80 Ah batteries was utilized during the entire survey works. RES2DINV (Aarhus GeoSoftware, Denmark) computer software has been utilized for data processing for determination of two dimensional resistivity structure of subsurface below the profiles. It is a robust program and supports both finite-difference & finite element modelling techniques.

5. METHODOLOGY

Electrical Resistivity Tomography (ERT) Profiles

ERT surveys were conducted along selected profiles oriented in the tunnel alignment between both the HRTs, HRT-1 and HRT-2. Dipole-Dipole protocol was adopted to achieve optimal resolution for both lateral and vertical variations. Electrode spacing of 10m was kept for both the ERT profiles ERT-1 and ERT-2. A total of 81 Nos. Steel electrodes of 50 cm length and 16mm diameter were utilized for injection of current into the ground. Further, to increase the contact of ground with surface area of electrodes, these were driven with hammer in a small pit filled with salt water mixture. Apparent resistivity data were acquired using ABEM Terrameter LS-2 system and processed through two-dimensional inversion software RES2DINV to obtain resistivity sections representing subsurface conditions.

ERT instrument under operation

6. STUDY DETAILS

Data acquisition for the geophysical exploration was carried out comprising of 02 Nos. Electrical Resistivity Tomography (ERT) profiles of a cumulative profile length of 1400m. The locations of the executed ERT profiles laid in the area are shown in the layout Plan-1. Details of ERT profiles are given in Table-1.

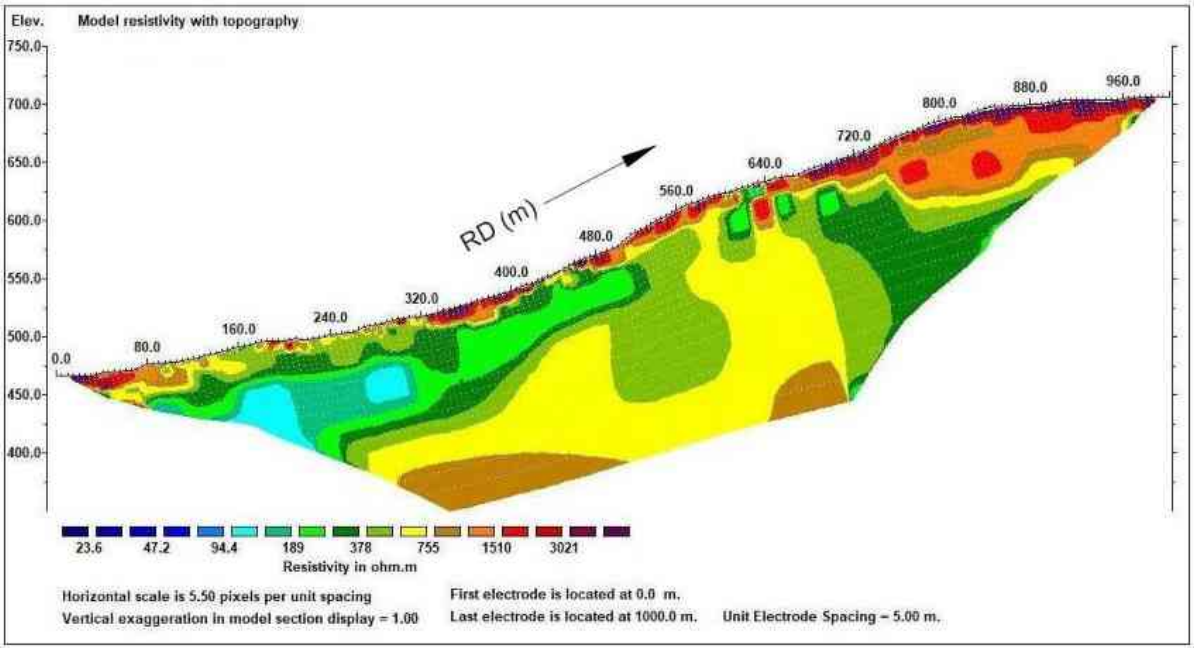
Table-1: Details of ERT Profiles (in UTM)

Location	Profile No.	Start (Easting, Northing & Elevation)	End (Easting, Northing & Elevation)	Profile Length	Electrode Spacing
Along Head Race Tunnel Alignment (From 4A-4B side)	ERT-1	E93960.876 N46217.72 EL467.34M	E93272.015 N46821.854 EL707.37M	1000m	10m
Along Head Race Tunnel Alignment (From 3A-3B side)	ERT-2	E92995.011 N47199.597 EL 530.89M	E92770.18 N47481.69 EL 598.23M	400m	10m
			Total Length	1400 m	

7. OBSERVATIONS AND RESULTS

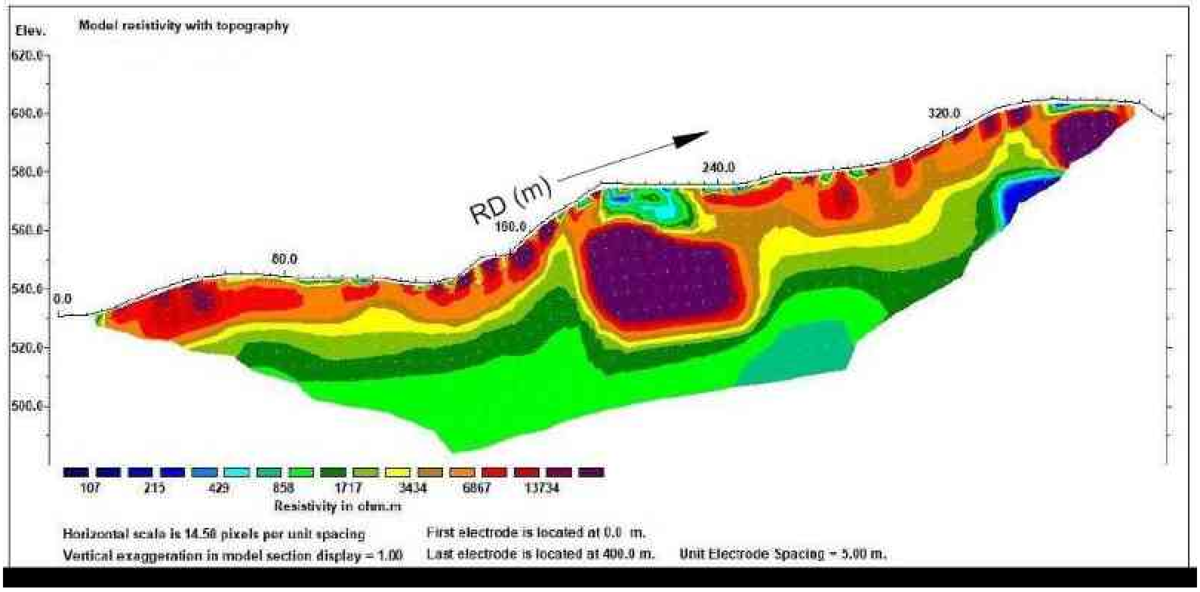
The observations and interpretations of the Electrical Resistivity Tomography (ERT) is presented in the form of resistivity sections. The profile locations are shown in **Plan–1**, and the interpreted resistivity sections are provided as **Plates-1 to 2**. The results of the individual profiles are described below. The ERT sections are also projected on longitudinal HRT-1 section and presented as **Plate-3.**

ERT-1 (Refer Plan-1 and Plate-1):



- This 1000m long ERT profile ERT-1 was undertaken in a roll along manner on the tunnel alignment from RD 0m to RD 1000m starting from 4A-4B side. The topography of the profile varied between EL467.22m to EL707.37m. The maximum depth of penetration of about 200m has been achieved at the centre portion of profile.
- The near-surface zone along most of the profile is characterized by moderate to high resistivity values (~1500 Ω-m to 5000 Ω-m). These high-resistivity zones are interpreted as overburden from RD±0m to RD±640m and rock masses with low moisture content and limited fracturing from RD±640m to RD±1000m.
- Several localized low-resistivity anomalies (~100–200 Ω-m) occur predominantly between RDs ±80m and ±480m and between RDs ±600m and ±720m. These low-resistivity pockets may indicate highly fractured and altered rockmass, zones of enhanced groundwater saturation, or localized shear zones.
- The deeper central portion of the profile, extending approximately from RDs ±240m to ±660m, is dominated by moderate resistivity values ranging from 200 Ω-m to 1000 Ω-m. This resistivity range is indicative of moderately altered and fractured rock masses with variable moisture conditions. Increase in resistivity values at deeper levels between RD±340m to RD±720m may primarily due to relatively dry rockmass condition. The gradual transition from low to moderate resistivity suggests a heterogeneous rock mass with varying degrees of fracturing and alteration.

ERT-2 (Refer Plan-1 and Plate-2):



- The 400m long ERT profile (ERT-2) was carried out along the tunnel alignment starting from 3A-3B side. The ground elevation along the profile varies from EL530.89m to EL605.39m. A maximum depth of investigation of approximately 80m was achieved at the central portion of the profile.
- The top layer of profile is predominantly characterized by moderate to high resistivity values (>2000 Ω-m). Such high resistivity values are indicative of overburden/ boulders/rock masses with low moisture content and limited fracturing. These zones are interpreted to represent quartzitic phyllite formations.
- Localized low-resistivity anomalies (100–400 Ω-m) are observed near the surface between RDs ±200m and ±230m and towards the end of the profile between RDs ±330m and ±380m. These anomalies may be associated with fractured rock, moisture accumulation, or minor shear zones.
- In the deeper portion of the subsurface profile, resistivity decreases significantly with increasing depth, ranging from approximately 1800 Ω-m to 700 Ω-m. Such resistivity characteristics are indicative of altered and possibly fractured rock masses with relatively higher moisture retention.

8. CONCLUSIONS:

The Electrical Resistivity Tomography (ERT) investigations carried out along the tunnel alignment have provided valuable information regarding the subsurface geological and geotechnical conditions in the remaining stretch of the Head Race Tunnels (HRTs) of the Teesta Hydroelectric Project Stage-VI.

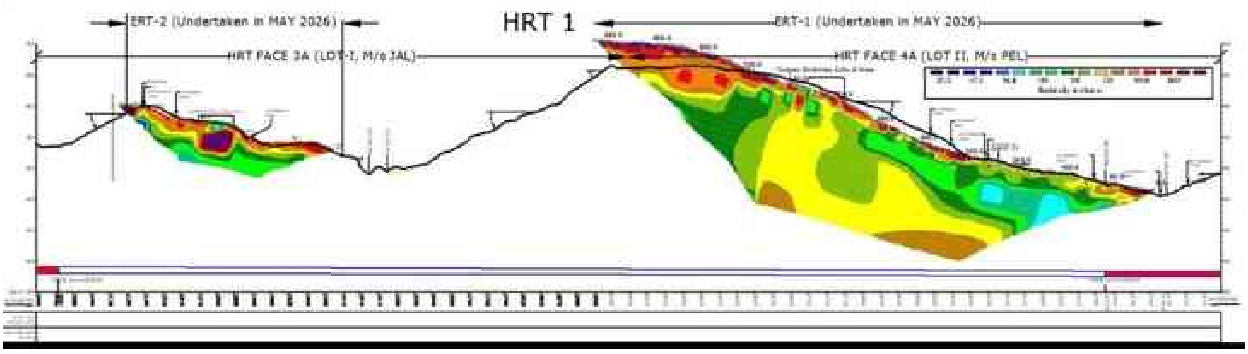
The ERT results indicate that the subsurface is characterized by significant lateral and vertical variations in resistivity, reflecting heterogeneous rock mass conditions associated with the complex geological setting. High-resistivity zones >1500 Ω-m identified in both profiles are interpreted as overburden with boulders/ relatively moderately weathered/altered quartzitic phyllite formations with low moisture content and limited fracturing.

However, several localized low-resistivity anomalies ranging from approximately 100 Ω-m to 400 Ω-m have been delineated along the investigated profiles. These anomalous zones are interpreted as fractured and altered rock masses, groundwater-saturated zones, and/or localized shear zones. Such features are indicative of comparatively poor rock mass quality and may adversely affect tunnel excavation. The presence of these zones suggests a higher likelihood of localized weak zones, deformation around the excavation boundary, groundwater ingress, and increased support requirements during excavation.

The central and deeper portions of the profiles are generally characterized by moderate resistivity values ranging from approximately 200 Ω-m to 1000 Ω-m. These resistivity characteristics indicate moderately altered and fractured rock masses with variable moisture content.

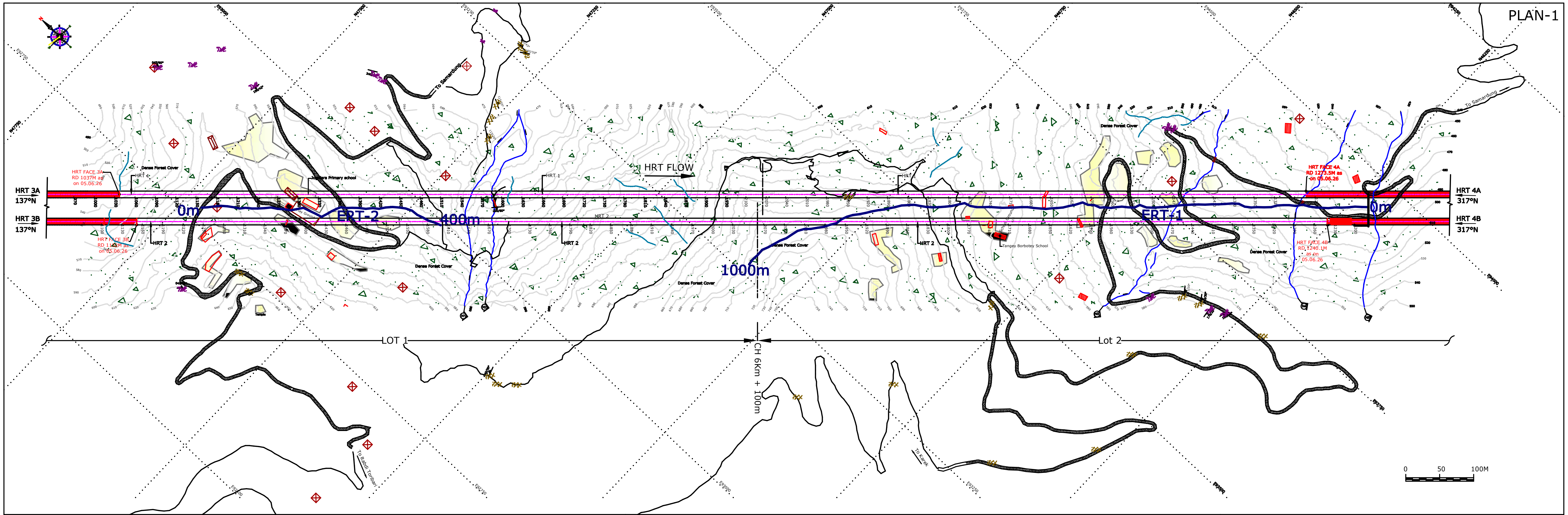
The gradual reduction in resistivity with depth, suggests increasing fracturing, and moisture retention within the rock mass. Low-resistivity zones are interpreted as weak, fractured/weathered, and/or water-bearing zones that may adversely affect excavation stability. Such conditions are consistent with structurally disturbed rock masses and may result in reduced stand-up time and increased excavation support requirements.

For a better understanding of rock prognosis along the tunnel alignment, the resistivity sections ERT-1 and ERT-2 have been projected on the Longitudinal Section along HRT-1 (from Face-3A, RD 1000.00 towards HRT Face-4A) presented in Plate-3. This section also prognosticates fractured/weathered/altered weak rock mass under varying water-saturation condition in remaining part of tunnel.



The results of the present investigation provide a useful basis for anticipating subsurface conditions ahead of the tunnel face and will assist the construction team in optimizing excavation strategies, risk mitigation measures, and support system design for the safe and efficient completion of the remaining tunnel works.

TSP tests have already been carried out from both the faces of the tunnel indicating similar results. TSP tests may further be continued for correlation and better assessment during excavation.



Legends

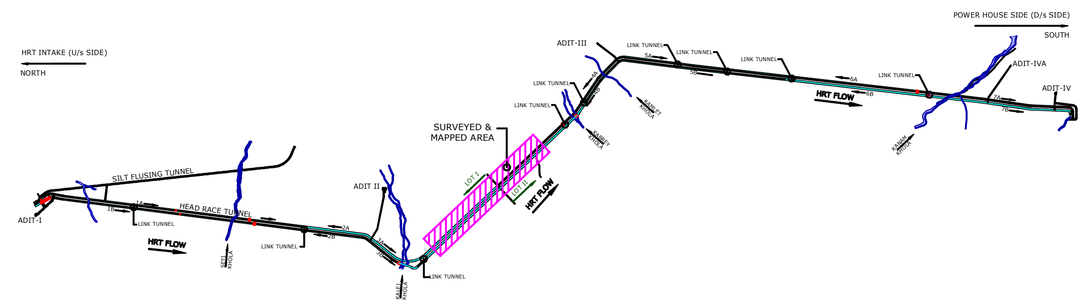
- State Road Networks (Unmettaled)
- Perennial Nala / Khola
- Seasonal Nala
- Culvert
- House / Pvt. Buildings
- Human habitations / cultivation
- High Power Transmission Towers
- Slope Wash Materials
- Rock Expoures: Phyllitic Quatzite
- Rock Exposures: Phyllite
- Foliation Joints
- Prominent Joints
- Shear Seams / Fractured Zones
- Geological Traverses Taken
- Heading Excavation Completed in HRT
- Incidence of Methane Gas Release at Tunnel Grade
- Incidence of Seepage at tunnel Grade (> 50LPM)
- HRT Face RD
- Electrical Resistivity Survey (May 2026)

1000m 0m Electrical Resistivity Tomography (ERT) Profile Location

ERT profile locations are marked in the drawing no. NH/T-VI/Geo/Plan/2026, dated 21.05.2026 prepared and submitted by Project (sheet 1 of 3)

NOTE

1. This contour plan has been developed to address the limitations of the contour data inherited from the previous developer which lacked critical details on current surface developments.Subsequently, PID, CO conducted a high-precision topographical survey using a long-range scanner in February 2026 on the request of project. This effort was performed concurrently with detailed geological mapping by the Project Geology Division to ensure a complete and accurate surface features along the alignment of HRT particulary between the critical HRT Faces 3A-4A & 3B-4B.



KEY PLAN OF HRT ALIGNMENT

NHPC Limited
एनएचपीसी लिमिटेड

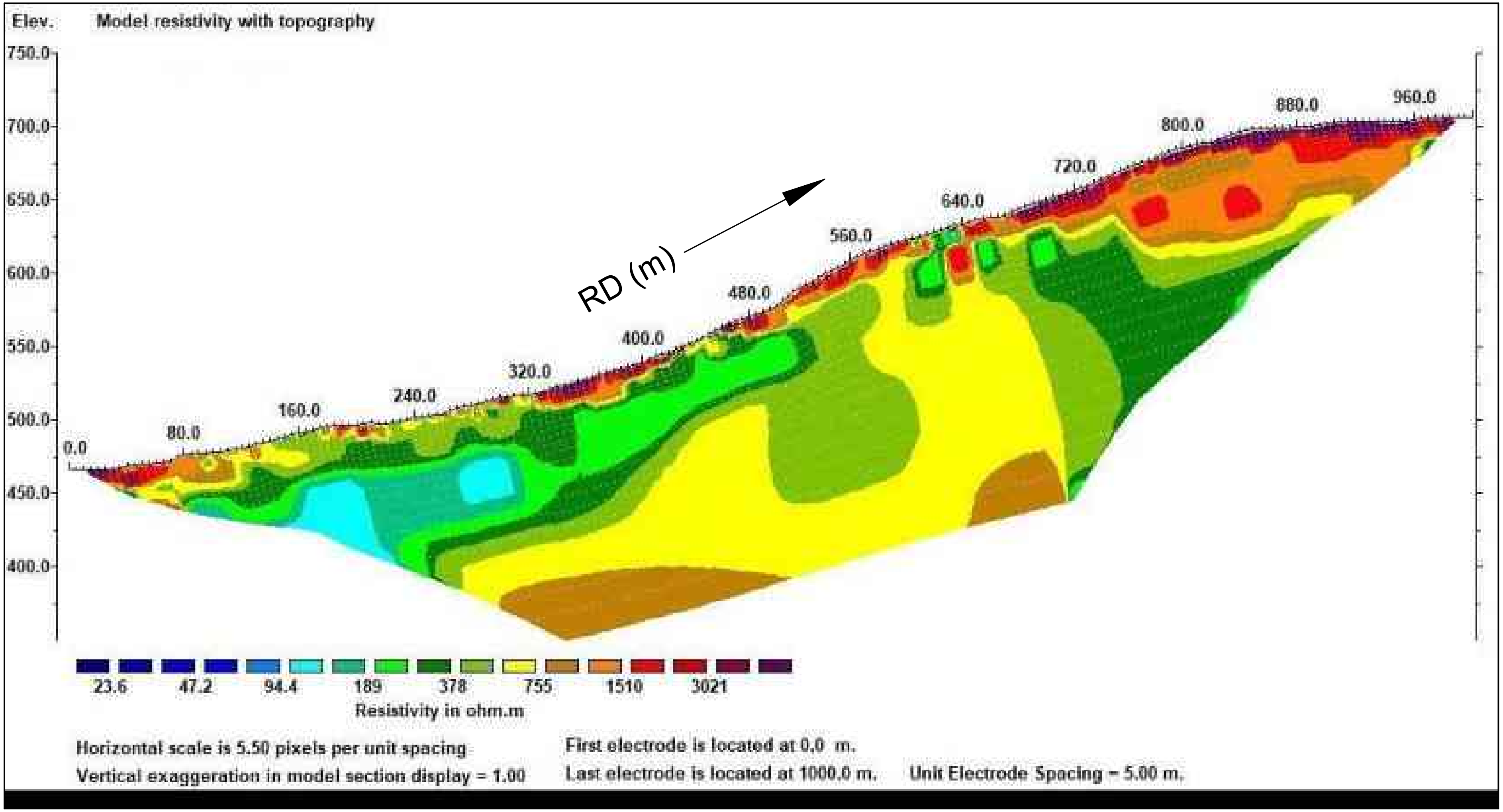
Teesta-VI Hydroelectric Project
तीस्ता-VI जलविद्युत परियोजना

Plan shwoing location of ERT Profiles

DRG No. NH/EG/GEOPHY/280 June 2026

PLATE-1

HRT (Face-4A): RESISTIVITY SECTION ALONG PROFILE ERT-1



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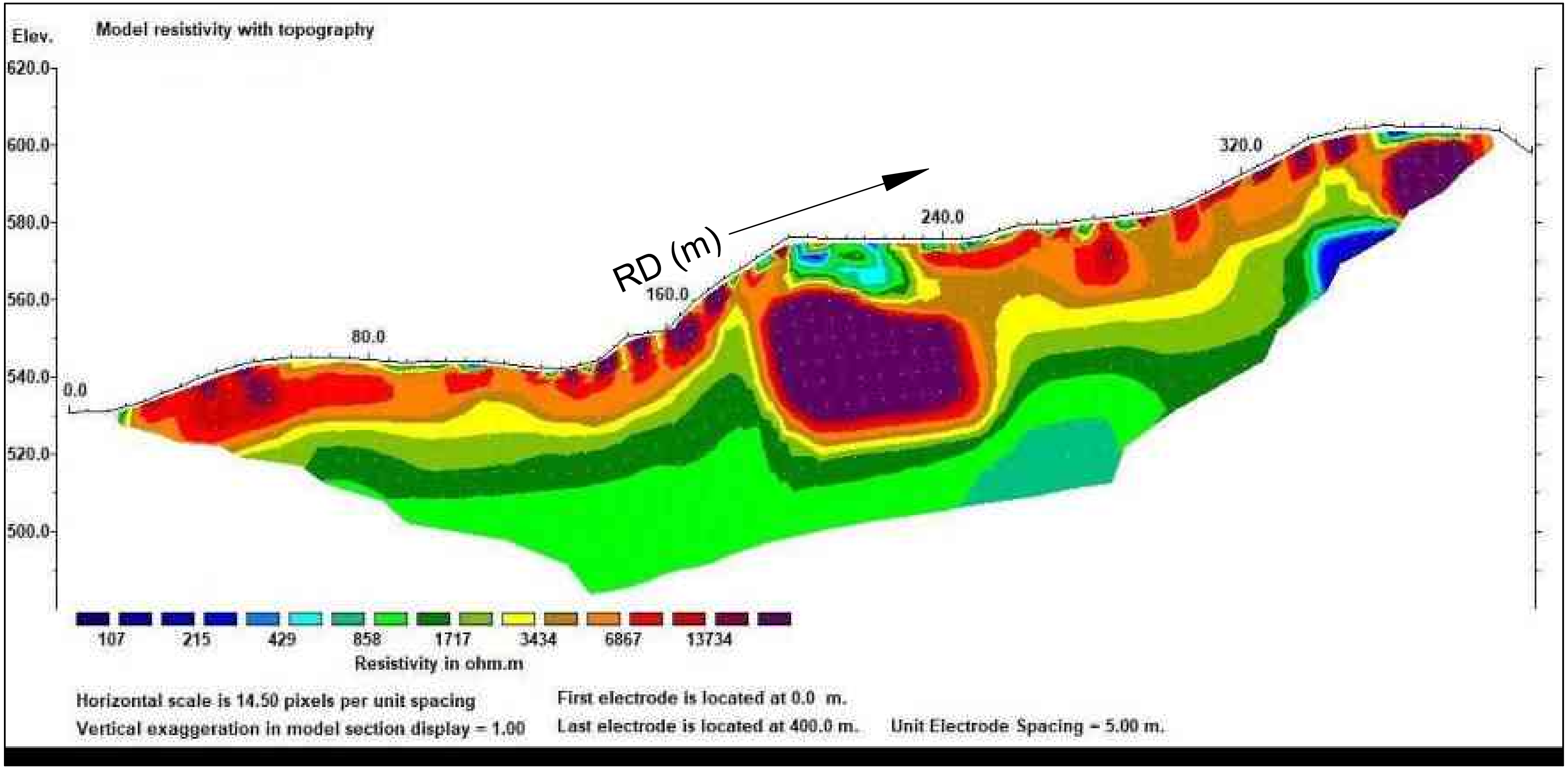
Teesta-VI Hydroelectric Project
तीस्ता-VI जलविद्युत परियोजना

Resistivity Section along Profile ERT-1, HRT, Face-4A

DRG No. NH/EG/GEOPHY/280A June 2026

PLATE-2

HRT (Face-3A): RESISTIVITY SECTION ALONG PROFILE ERT-2



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Teesta-VI Hydroelectric Project
तीस्ता-VI जलविद्युत परियोजना

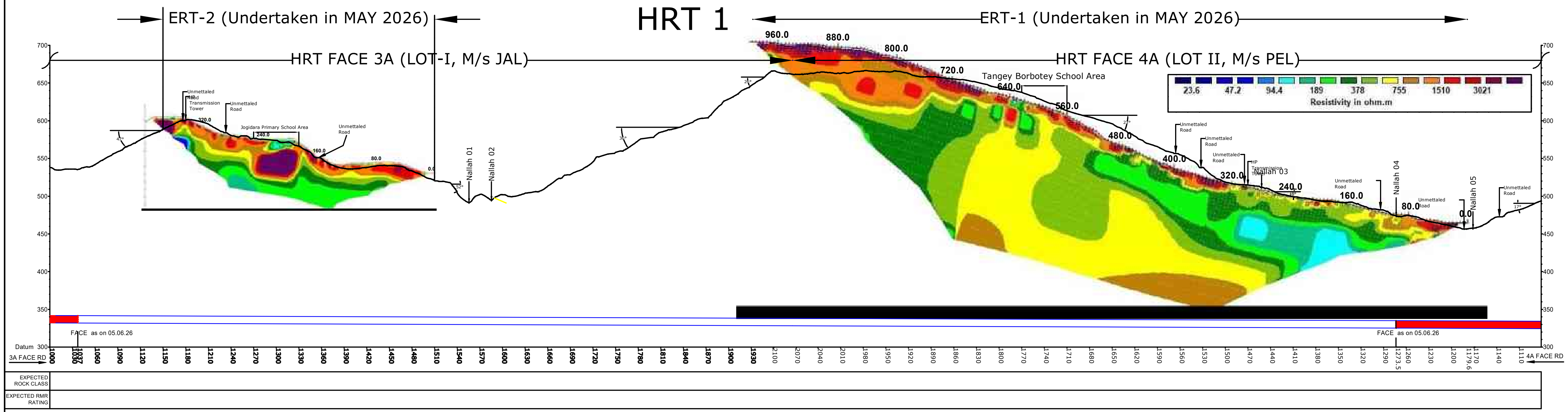
Resistivity Section along Profile ERT-2, HRT, Face-3A

DRG No. NH/EG/GEOPHY/280B June 2026

Plate-3

Projection of ERT-1 on a section along HRT-1

(Longitudinal Section Along HRT 01 (from Face 3A RD 1000.00 towards HRT Face 4A)



<u>Expected Rockmass Condition</u>

The remaining tunnel section will traverse poor-quality bedrock (Class IV to V, RMR 10–25) dominated by soft, intensely jointed, and thinly foliated phyllite that is prone to crumbling and volume loss upon saturation. Intermittent bands of moderately strong phyllitic quartzite are expected to facilitate groundwater seepage ranging from dripping to flowing conditions. No high-quality rock (Classes I to III) is anticipated for this stretch.

NOTE:-

1. This section has been developed from contour Plan surveyed and prepared by Project Investigation Division, CO using a long-range scanner in February 2026 on the request of project.
2. Reference Plan: Drg. No.:NH/ T-VI/ GEO/ PLAN/2026. (Sheet 1 OF 3)

0 50 100M

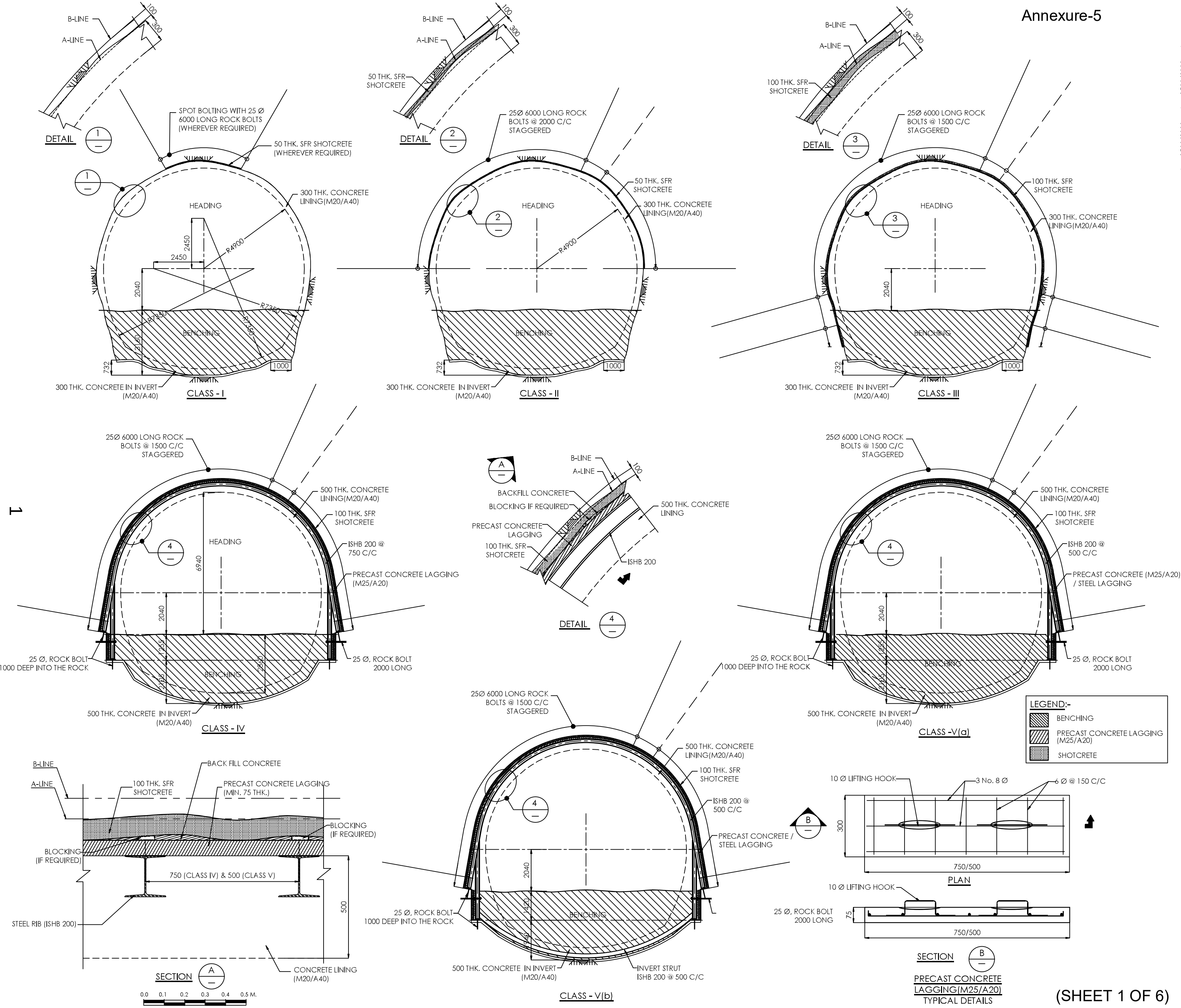
Note: 1. The location of ERT-1 and ERT-2 is between the HRT-1 & HRT-2 alignment.
2. Refer Plan-1 for Section location

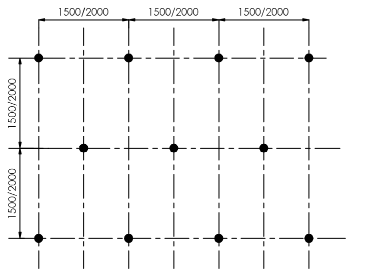
NHPC Limited
एनएचपीसी लिमिटेड
Teesta-VI Hydroelectric Project
तीस्ता-VI जलविद्युत परियोजना
HRT-1(FACE 3A-4A) Section showing projected ERT section
DRG No. NH/EG/GEOPHY/280C June 2026

Annexure-7

‘Relevant Drawings’

Annexure-5





TYPICAL ROCK BOLT PATTERN
(NOT TO SCALE)

NOTES:-

1. ALL DIMENSIONS ARE IN MILLIMETER AND LEVELS IN METER.
2. THE DEFINITION OF 'A' & 'B' LINE AND VARIOUS CLASSES OF EXCAVATION SHOWN SHALL BE AS PER SECTION B.3 OF TECHNICAL SPECIFICATION.
3. ROCK BOLT SHOWN IN THE DRAWING SHALL BE CONFORMING TO SECTION B.4 OF TECHNICAL SPECIFICATION. THE ROCK BOLT SHOULD BE RESIN END ANCHORED, FULLY CEMENT GROUTED.
4. ROCK BOLT TO BE INSTALLED IN CLASS IV & CLASS V REACHES SHALL BE TENSIONED UPTO 10 % OF THE ROCK BOLT CAPACITY AS SPECIFIED IN SECTION B.3.7 OF TECHNICAL SPECIFICATION.
5. 25MM Ø ROCK BOLT TO BE INSTALLED IN CLASS I & CLASS II REACHES SHALL BE TENSIONED TO 15 TON, CLASS III SHALL BE TENSIONED BETWEEN 7.5 TON TO 15 TON AND CLASS IV & CLASS V SHALL BE TENSIONED UPTO 2.45 TON.
6. MINOR MODIFICATION IN THE LENGTH, ORIENTATION, PATTERN AND LOCATION OF ROCK BOLTS MAY BE DONE TO SUIT THE SITE CONDITIONS WITH THE APPROVAL OF ENGINEER-IN-CHARGE.
7. STEEL RIBS SHOWN IN THE DRAWING SHALL BE CONFORMING TO SECTION B.4 OF TECHNICAL SPECIFICATIONS. SPACING OF RIBS SHOWN MAY BE MODIFIED TO SUIT THE SITE CONDITIONS WITH THE APPROVAL OF ENGINEER-IN-CHARGE.
8. SHOTCRETE SHOWN ON DRAWING SHALL BE APPLIED AS SPECIFIED IN SECTION B.5 OF TECHNICAL SPECIFICATION.
9. IN SOME CASES OF CLASS III, IV AND V WIREMESH REINFORCEMENT MAY BE REQUIRED IN ADDITION TO SFR SHOTCRETE AS DIRECTED BY ENGINEER-IN-CHARGE.
10. CONCRETE SHALL BE OF GRADE M20/A40 FOR LINING, M25/A40 FOR RCC LINING AND M15/A40 FOR BACKFILL CONFORMING TO SECTION B.9 OF TECHNICAL SPECIFICATION.
11. STEEL LAGGING OR PRECAST CONCRETE LAGGING AS SPECIFIED IN SECTION B.4 OF TECHNICAL SPECIFICATIONS SHALL BE USED IN CLASS IV & V WITH THE APPROVAL OF ENGINEER-IN-CHARGE.
12. UNDERGROUND EXCAVATION INCLUDING PROTECTION OF TUNNEL INVERT SHALL BE CONFORMING TO SECTION B.3 OF TECHNICAL SPECIFICATION.
13. FOR ADDITIONAL ROCK SUPPORT MEASURES IN POOR ROCK/REACHES REFER SEPARATE DRAWING.
14. THE LINING SHALL BE REQUIRED TO BE REINFORCED IN LOW COVER ZONE AND IN WEAK ROCK SUBJECT TO IN-SITU TEST DURING EXECUTION. FOR DETAILS REFER SEPARATE DRAWING.

SCALE:-
0 1 2 3 4 5 M.
0.0 0.25 0.50 0.75 1.00 1.25 M (FOR DETAILS ONLY)

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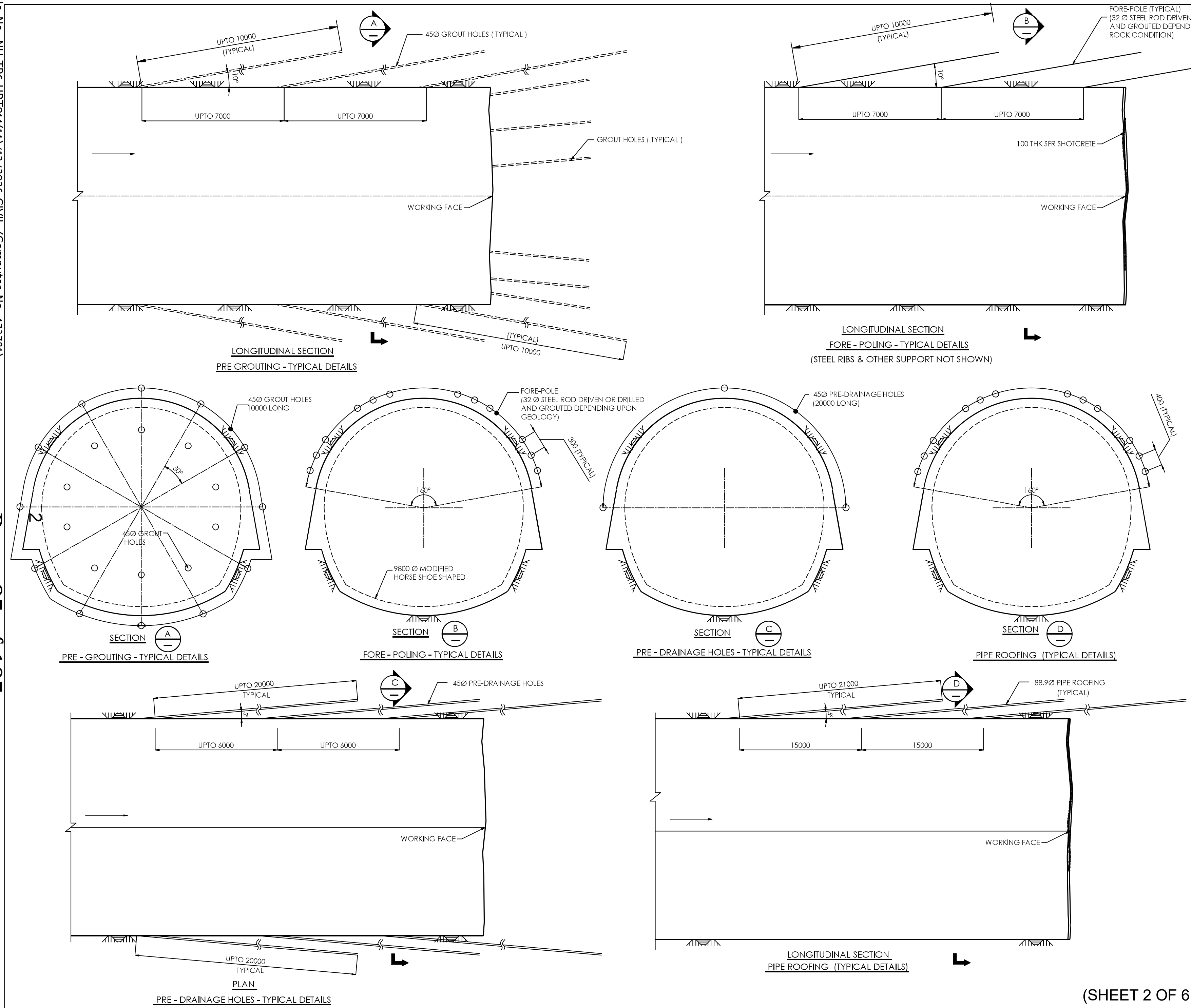
NHPC Limited
(A GOVT. OF INDIA ENTERPRISE)
तीस्ता (चरण– VI) जलविद्युत परियोजना
TEESTA (STAGE-VI) H.E. PROJECT

HEAD RACE TUNNEL
ROCK SUPPORT DETAILS

(SHEET 1 OF 6)

1



NOTES:-

1. ALL DIMENSIONS ARE IN MILLIMETERS AND LEVELS IN METRE.
2. PROBE HOLES (UPTO 20 m. LONG) SHALL BE CONDUCTED TO EXPLORE THE STRATA AHEAD OF EXCAVATION PRIOR TO EMPLOYING FORE-POLING OR PIPE ROOFING TECHNIQUE IN GEOLOGICAL POOR REACHES.
3. FORE-POLING ALONG WITH PRE-GROUTING SHALL BE ADOPTED TO SUPPORT THE POOR ROCK AS DIRECTED BY ENGINEER-IN-CHARGE.
4. THE LENGTH OF FORE POLES AND PRE GROUT HOLES AS WELL AS SPACING OF THESE HOLES SHALL CONFORM TO SECTION B.4 OF TECHNICAL SPECIFICATION AND WILL DEPEND UPON GEOLOGICAL CONDITIONS AT SITE AND MAY BE MODIFIED WITH THE APPROVAL OF ENGINEER-IN-CHARGE.
5. WHEN GROUND CONDITION IN TUNNELING ARE SUCH THAT FACE CANNOT BE SUPPORTED BY FORE POLING, THE SPECIAL TECHNIQUE OF PIPE ROOFING SHALL BE REQUIRED TO BE IMPLEMENTED. THE PIPE ROOFING SHALL BE CARRIED OUT BY A SPECIALISED AGENCY ONLY, CONFORMING TO SECTION B.4 OF TECHNICAL SPECIFICATION.
6. PRE-DRAINAGE HOLES (UPTO 20 M. LENGTH) MAY BE REQUIRED IF INGRESS OF WATER IS SIGNIFICANT WITH THE APPROVAL OF ENGINEER-IN-CHARGE.
7. WATER PRESSURE TESTING SHOULD BE DONE PRIOR TO GROUTING FOR PERMEABILITY OF ROCK MASS AND SELECTION OF GROUT MIX.
8. PRE-GROUTING SHALL BE CONDUCTED TO STRENGTHEN THE PERIPHERY OF FACE AHEAD OF EXCAVATION TO REDUCE WATER INFLOW DURING EXCAVATION AS DIRECTED BY ENGINNER-IN-CHARGE.
9. PIPE ROOFING SHALL BE DONE IN SUCH A WAY THAT BETWEEN CONSECUTIVE PIPE ROOFING ATLEAST 6 M LENGTH OF PIPE ROOFING IS OVERLAPPED .
10. PRE-GROUTING SHALL BE DONE IN SUCH A WAY THAT BETWEEN CONSECUTIVE PRE-GROUTING ATLEAST 3 M LENGTH OF PRE-GROUTING IS OVERLAPPED .
11. FORE POLING SHALL BE CARRIED OUT IN SUCH A WAY THAT ATLEAST 3 M LENGTH OF FORE POLE IS OVERLAPPED.
12. MICROFINE CEMENT GROUTING IN ADDITION TO NORMAL CEMENT GROUTING MAY BE REQUIRED DURING PRE-GROUTING / CONSOLIDATION GROUTING AS PER SITE CONDITIONS.

SCALE:-
0 1.0 2.0 3.0 4.0 5.0 M

(SHEET 2 OF 6)

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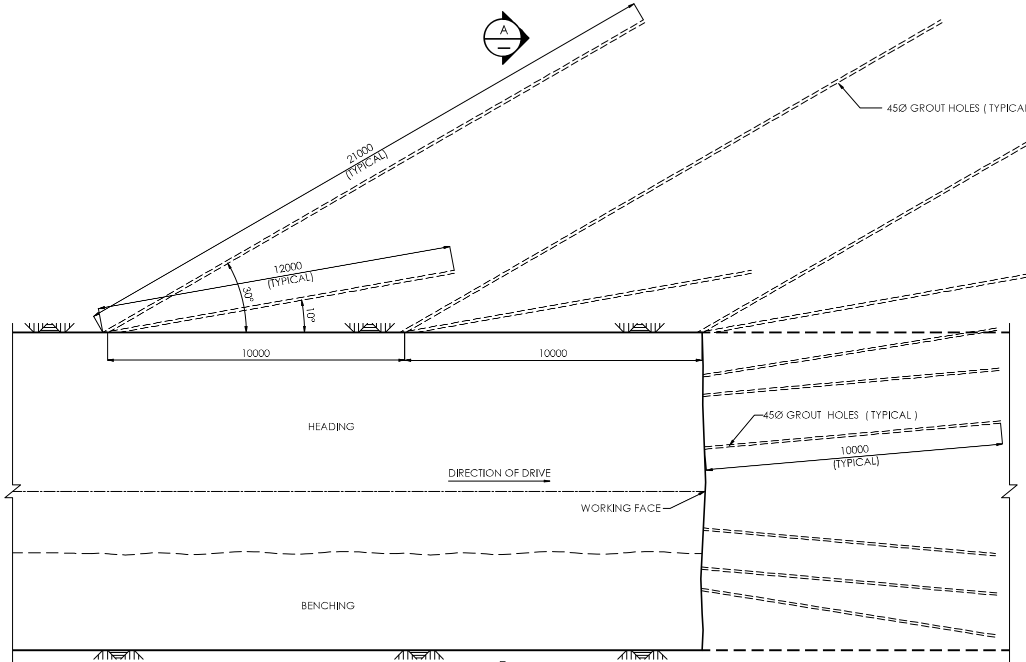
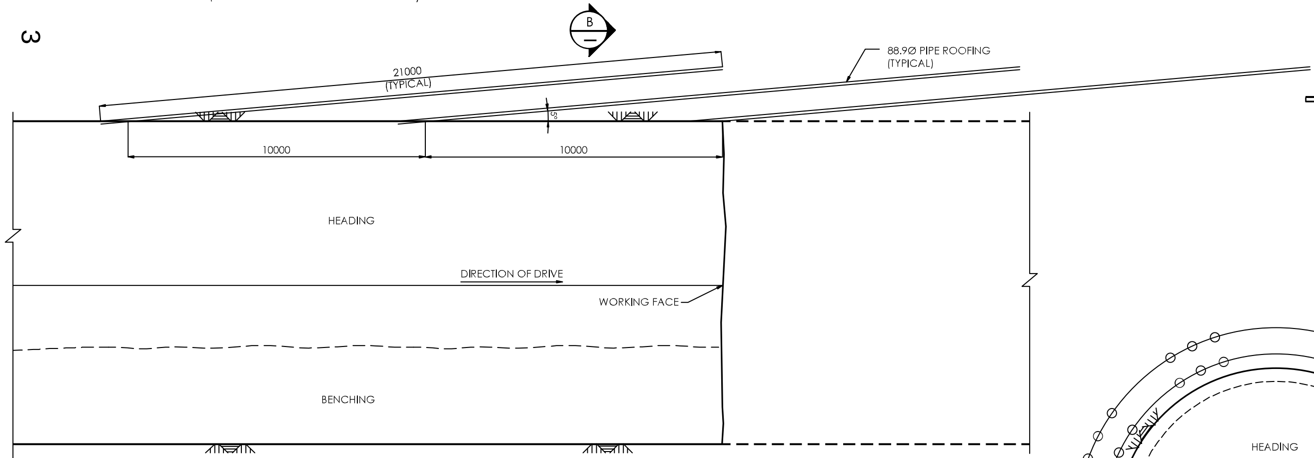
TEESTA (STAGE-VI) H.E. PROJECT

HEAD RACE TUNNEL
ADDITIONAL MEASURES FOR
TUNNELING IN POOR REACHES

2

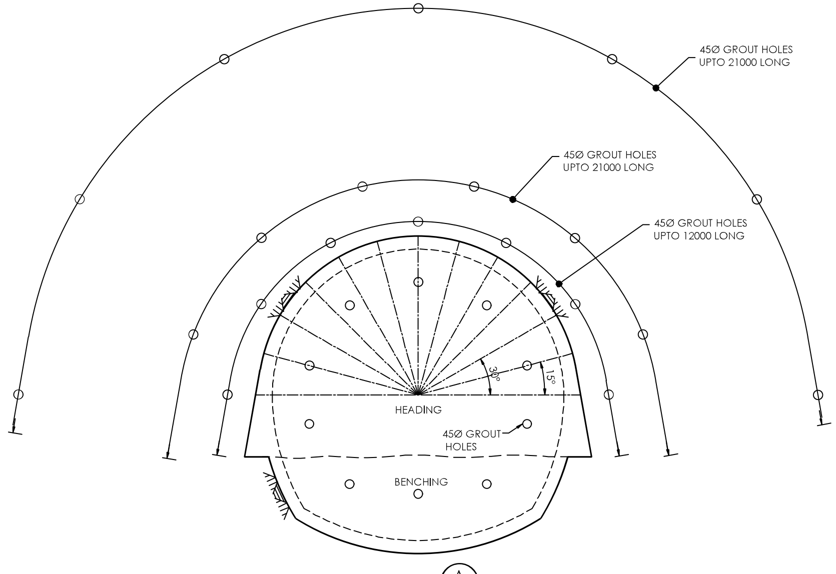


LONGITUDINAL SECTION
PRE-GROUTING -(TYPICAL DETAILS)
(PIPE ROOFING NOT SHOWN FOR CLARITY)

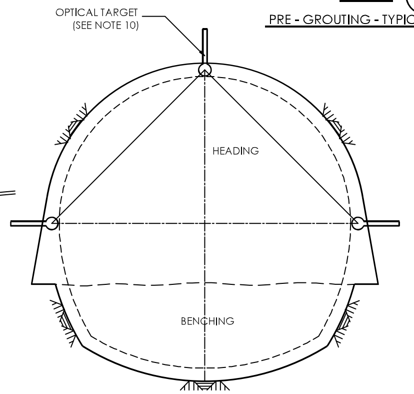


LONGITUDINAL SECTION
PIPE ROOFING (TYPICAL DETAILS)
(PRE-GROUTING NOT SHOWN FOR CLARITY)

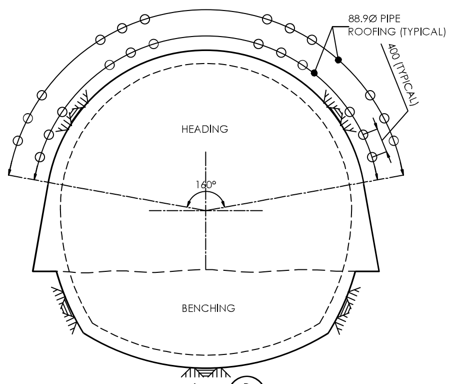
3



SECTION A
PRE - GROUTING - TYPICAL DETAILS



SECTION SHOWING OPTICAL TARGET POINT



SECTION B
PIPE ROOFING (TYPICAL DETAILS)

NOTES:-
1. ALL DIMENSIONS ARE IN MILLIMETERS AND LEVELS IN METER.
2. THE ROCK SUPPORT NEAR THE FACE SHALL BE RESTORED AS THAT OF CLASS V(B) AS PER DRAWING NO NHTS-VI-3CC1-41-DD-104.
3. THE DRILLING SPEED AT THE FACE SHALL BE OBSERVED/RECORDED TO UNDERSTAND THE ROCK MASS AHEAD OF EXCAVATION.
4. WATER PRESSURE TESTING SHALL BE PERFORMED PRIOR AND AFTER TO GROUTING OPERATIONS AS PER THE SECTION B.7 OF TECHNICAL SPECIFICATION.
5. INITIALLY PRE-GROUTING SHALL BE CARRIED OUT BY USING OPC/PPC ONLY. IF THE ROCK MASS IS NOT ABLE TO BE GROUTED BY OPC/PPC BECAUSE OF LOW PERMEABILITY THEN ONLY MICROFINE CEMENT CAN BE USED FOR PRE GROUTING PURPOSE.
6. PRE-GROUTING SHALL BE CARRIED OUT TO STRENGTHEN THE PERIPHERY OF THE ROCK MASS FACE AND TO ARREST SEEPAGE DEPENDING UPON THE GEOLOGICAL CONDITION / SITE REQUIREMENT OR AS PER THE DIRECTION OF ENGINEER IN CHARGE.
7. IN CASE OF VERY POOR GEOLOGICAL CONDITIONS AND HEAVY INGRESS OF WATER, PRE-GROUTING WITH COLLOIDAL SILICA SHALL BE CARRIED OUT CONFORMING TO CLAUSE NO 4.8.1 OF SECTION B.4 OF TECHNICAL SPECIFICATION AS DIRECTED BY ENGINEER-IN-CHARGE.
8. THE PIPE ROOFING SHALL BE CARRIED OUT BY A SPECIALIZED AGENCY ONLY, CONFORMING TO SECTION B.4 OF TECHNICAL SPECIFICATION.
9. HRT-B SHALL BE UTILIZED FOR GROUTING THE ROCK PILLAR BETWEEN THE TWO TUNNELS TO IMPROVE THE ROCK PROPERTIES AND MATRIX PRESENT IN THIS ZONE.
10. OPTICAL TARGET SHALL BE INSTALLED AT 10 M INTERVAL TO MONITOR THE MOVEMENT IN TUNNEL DURING CONSTRUCTION, AS PER THE DIRECTION OF ENGINEER IN CHARGE.
11. PROBE HOLES (UP TO 20M LONG) SHALL BE CONDUCTED TO EXPLORE THE STRATA AHEAD OF EXCAVATION PRIOR TO EMPLOYING PIPE ROOFING TECHNIQUE IN GEOLOGICAL POOR REACHES.
12. 3D TSP SHALL BE USED AS PER THE SITE REQUIREMENT CONFORMING TO SECTION B.18 OF THE TECHNICAL SPECIFICATION.
13. SELF DRILLING FIBRE GLASS BOLTS (25MM Ø) OF SUITABLE LENGTH MAY BE USED AS PER SITE CONDITION FOR FACE STABILIZATION.

SCALE:-
0 1.0 2.0 3.0 4.0 5.0 M

(SHEET 3 OF 6)

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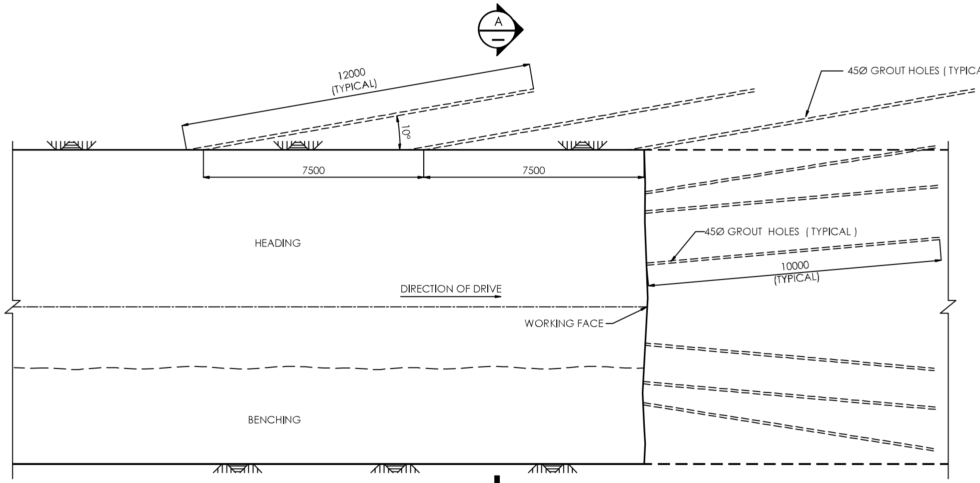
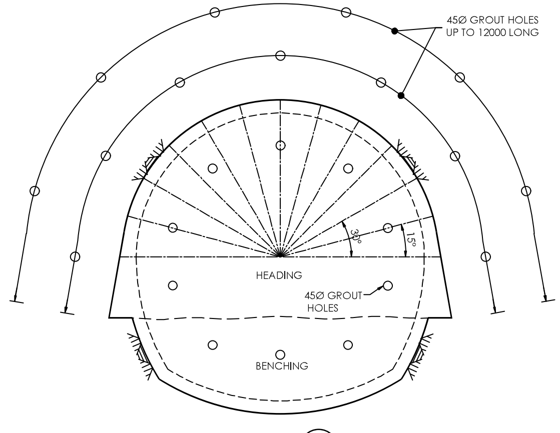
तीस्ता (चरण–VI)जलविद्युत परियोजना
TEESTA (STAGE-VI) H.E. PROJECT

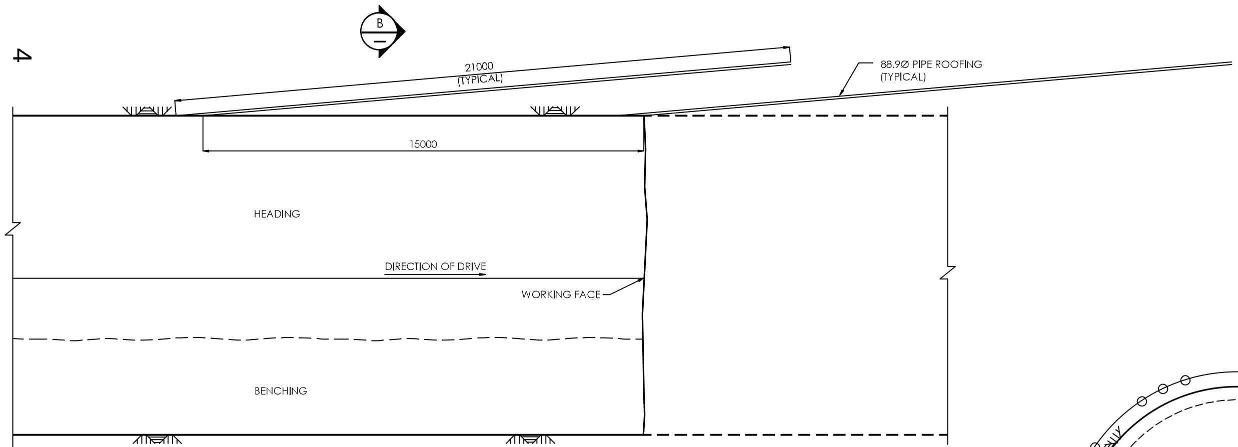
HEAD RACE TUNNEL
SUPPORT MEASURES IN VICINITY OF KALEJ
KHOLA CAVITY
(FROM 25M U/S TO 25M D/S OF CAVITY)



LONGITUDINAL SECTION
PRE-GROUTING -(TYPICAL DETAILS)
(PIPE ROOFING NOT SHOWN FOR CLARITY)

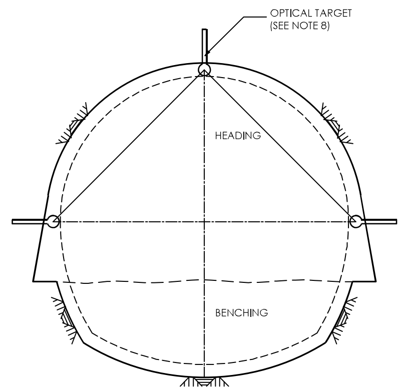


SECTION A
PRE - GROUTING - TYPICAL DETAILS

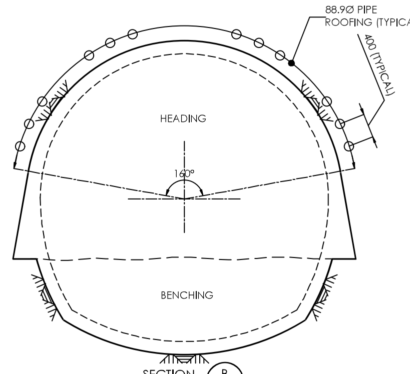


LONGITUDINAL SECTION
PIPE ROOFING (TYPICAL DETAILS)
(PRE-GROUTING NOT SHOWN FOR CLARITY)

4



SECTION SHOWING OPTICAL TARGET POINT



SECTION B
PIPE ROOFING (TYPICAL DETAILS)

NOTES:-

1. ALL DIMENSIONS ARE IN MILLIMETERS AND LEVELS IN METER.
2. THE DRILLING SPEED AT THE FACE SHALL BE OBSERVED/RECORDED TO UNDERSTAND THE ROCK MASS AHEAD OF EXCAVATION.
3. WATER PRESSURE TESTING SHALL BE PERFORMED PRIOR AND AFTER TO GROUTING OPERATIONS AS PER THE SECTION B.7 OF TECHNICAL SPECIFICATION.
4. INITIALLY PRE-GROUTING SHALL BE CARRIED OUT BY USING OPC/PPC ONLY. IF THE ROCK MASS IS NOT ABLE TO BE GROUTED BY OPC/PPC BECAUSE OF LOW PERMEABILITY THEN ONLY MICROFINE CEMENT CAN BE USED FOR PRE GROUTING PURPOSE.
5. PRE-GROUTING SHALL BE CARRIED OUT TO STRENGTHEN THE PERIPHERY OF THE ROCK MASS FACE AND TO ARREST SEEPAGE DEPENDING UPON THE GEOLOGICAL CONDITION / SITE REQUIREMENT OR AS PER THE DIRECTION OF ENGINEER IN CHARGE.
6. IN CASE OF VERY POOR GEOLOGICAL CONDITIONS AND HEAVY INGRESS OF WATER, PRE-GROUTING WITH COLLOIDAL SILICA SHALL BE CARRIED OUT CONFORMING TO CLAUSE NO 4.8.1 OF SECTION B.4 OF TECHNICAL SPECIFICATION AS DIRECTED BY ENGINEER-IN-CHARGE.
7. THE PIPE ROOFING SHALL BE CARRIED OUT BY A SPECIALIZED AGENCY ONLY, CONFORMING TO SECTION B.4 OF TECHNICAL SPECIFICATION.THE SPACING OF PIPE ROOFING CAN BE REDUCED UPTO 10M AS PER SITE CONDITION OR AS PER THE DIRECTION OF ENGINEER IN CHARGE.
8. OPTICAL TARGET SHALL BE INSTALLED AT 10 M INTERVAL TO MONITOR THE MOVEMENT IN TUNNEL DURING CONSTRUCTION. THE SPACING OF OPTICAL TARGET MAY BE MODIFIED AS PER SITE CONDITION OR AS PER THE DIRECTION OF ENGINEER IN CHARGE.
9. PROBE HOLES (UP TO 20M LONG) SHALL BE CONDUCTED TO EXPLORE THE STRATA AHEAD OF EXCAVATION PRIOR TO EMPLOYING PIPE ROOFING TECHNIQUE IN GEOLOGICAL POOR REACHES.
10. 3D TSP SHALL BE USED AS PER THE SITE REQUIREMENT CONFORMING TO SECTION B.18 OF THE TECHNICAL SPECIFICATION.

SCALE:-
0 1.0 2.0 3.0 4.0 5.0 M

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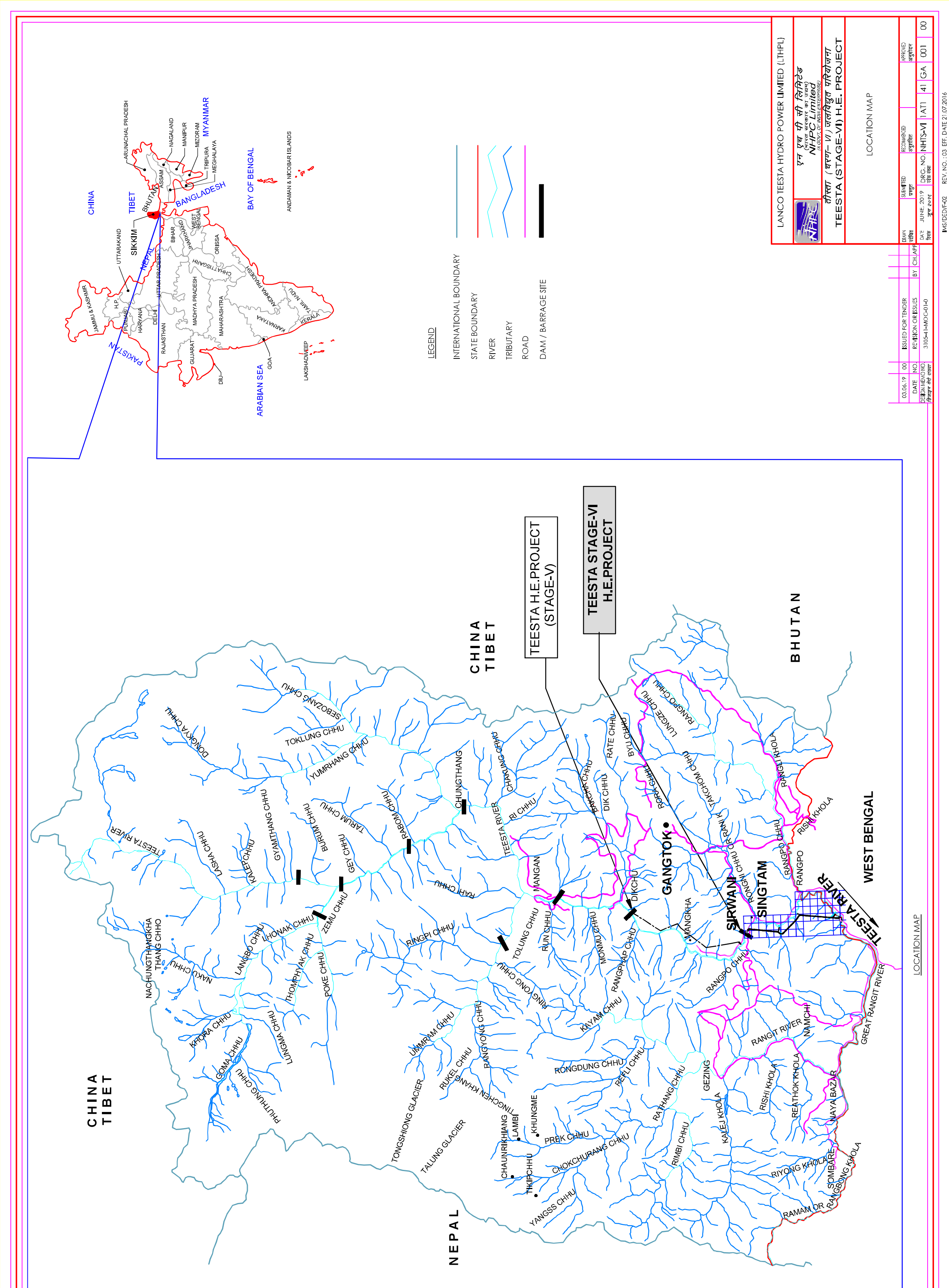
तीस्ता (चरण–VI)जलविद्युत परियोजना
TEESTA (STAGE-VI) H.E. PROJECT

HEAD RACE TUNNEL
SUPPORT MEASURES NEAR KALEJ
KHOLA ZONE
(FACE 3A & FACE 3B UP TO RD 900)

(SHEET 4 OF 6)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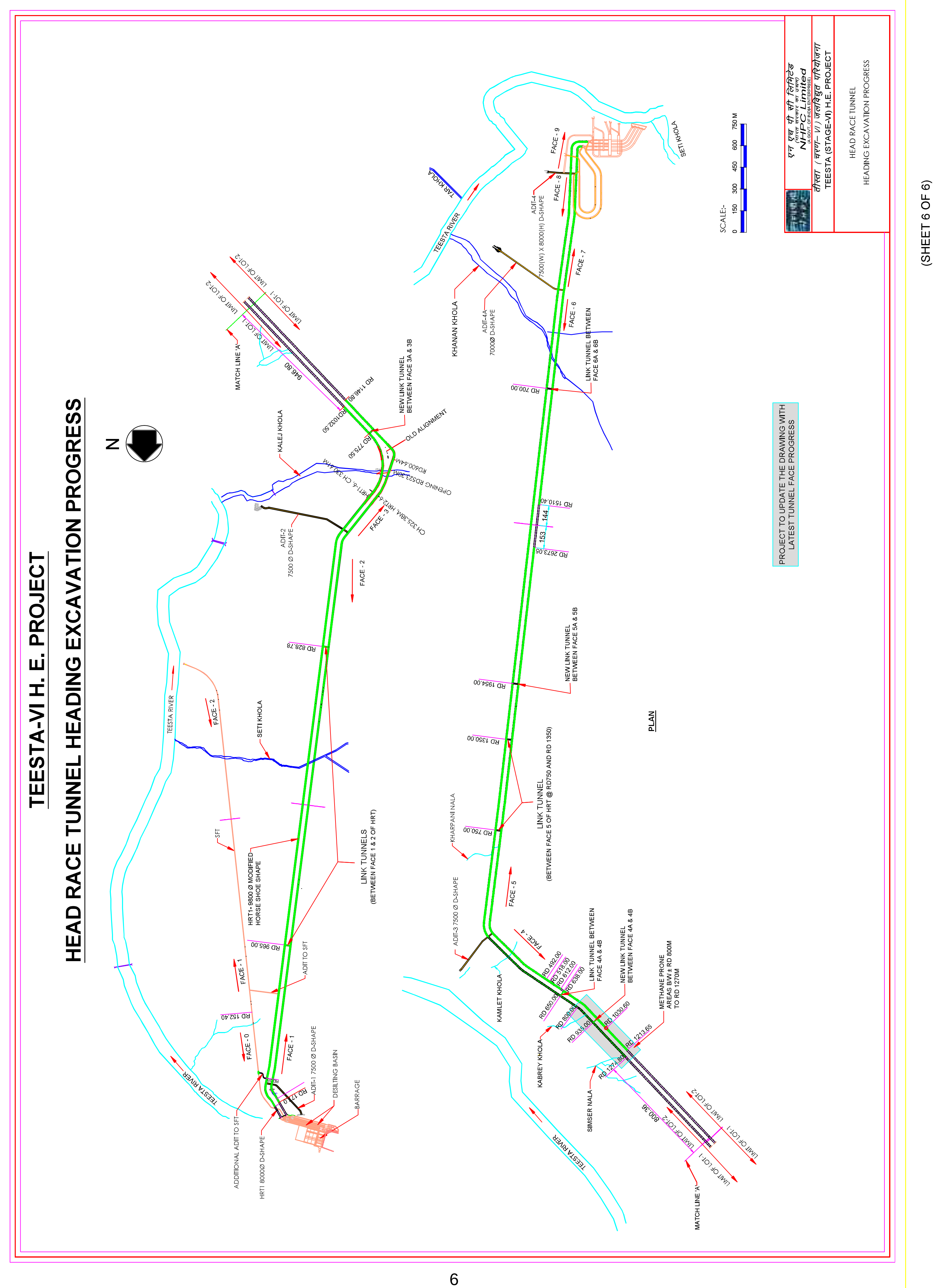
NHPC Limited
तीस्ता (चरण- VI) जलविद्युत परियोजना
TEESTA (STAGE-VI) H.E. PROJECT
LOCATION MAP
LEGEND
INTERNATIONAL BOUNDARY
STATE BOUNDARY
RIVER
TRIBUTARY
ROAD
DAM / BARRAGE SITE
CHINA
TIBET
SIKKIM
NEPAL
BHUTAN
BANGLADESH
MYANMAR
PAKISTAN
BAY OF BENGAL
ARABIAN SEA
TEESTA H.E.PROJECT (STAGE-V)
TEESTA STAGE-VI H.E.PROJECT
CHINA TIBET
BHUTAN
WEST BENGAL
NEPAL
GANGTOK
SINGTAM
SIRWANI
RANGPO
MANGAN
TEESTA RIVER
LOCATION MAP
DRG. NO. 1AT1-001

(SHEET 5 OF 6)


TEESTA-VI H. E. PROJECT
HEAD RACE TUNNEL HEADING EXCAVATION PROGRESS
N
PLAN
SCALE:-
0 150 300 450 600 750 M
NHPC Limited
तीस्ता (चरण- VI) जलविद्युत परियोजना
TEESTA (STAGE-VI) H.E. PROJECT
HEAD RACE TUNNEL
HEADING EXCAVATION PROGRESS
PROJECT TO UPDATE THE DRAWING WITH LATEST TUNNEL FACE PROGRESS
TEESTA RIVER
SETI KHOLA
KALEJ KHOLA
KHANAN KHOLA
TAR KHOLA
KHARPANI NALA
KAMLET KHOLA
KABREY KHOLA
SIMSER NALA
BARRAGE
DESILTING BASIN
SFT
ADIT TO SFT
ADDITIONAL ADIT TO SFT
HRT1 8000Ø D-SHAPE
ADIT-1 7500 Ø D-SHAPE
ADIT-2 7500 Ø D-SHAPE
ADIT-3 7500 Ø D-SHAPE
ADIT-4 7500(W) X 8000(H) D-SHAPE
ADIT-4A 7000Ø D-SHAPE
HRT1- 9800 Ø MODIFIED HORSE SHOE SHAPE
LINK TUNNELS (BETWEEN FACE 1 & 2 OF HRT)
LINK TUNNEL (BETWEEN FACE 5 OF HRT @ RD750 AND RD 1350)
NEW LINK TUNNEL BETWEEN FACE 3A & 3B
NEW LINK TUNNEL BETWEEN FACE 5A & 5B
LINK TUNNEL BETWEEN FACE 6A & 6B
LINK TUNNEL BETWEEN FACE 4A & 4B
NEW LINK TUNNEL BETWEEN FACE 4A & 4B
METHANE PRONE AREAS B/W ± RD 800M TO RD 1270M
OLD ALIGNMENT
FACE - 0
FACE - 1
FACE - 2
FACE - 3
FACE - 4
FACE - 5
FACE - 6
FACE - 7
FACE - 8
FACE - 9
RD 152.40
RD 965.00
RD 828.78
RD 775.50
RD 1032.50
RD 1146.80
946.80
RD 700.00
RD 1510.40
RD 2673.05
144
153
RD 1954.00
RD 1350.00
RD 750.00
RD 492.00
RD 518.00
RD 612.00
RD 636.00
RD 650.00
RD 800.00
RD 935.00
RD 1030.60
RD 1213.65
RD 1274.80
800.36
LIMIT OF LOT-1
LIMIT OF LOT-2
MATCH LINE 'A'
(SHEET 6 OF 6)

Annexure-8

‘The average cycle time’

Time cycle for Heading Excavtion with pipe roofing (15m cycle) and segmental grouting

Geological condition: Very poor with seepage

Pre-grouting : 28 Hole 10m long

Pipe roofing : 89mm dia 21 m long @ 300-400mm C/C

Segmental Excavation - 4 to 8 segments as per standing time

Steel ribs ISHB 200@ 500mm C/C

Description	Unit	Time (15 m cycle)	Time (01 m)
Survey and profile marking	Hr.	15	1
Pre-grouting/ grouting	Hr.	85	5.67
Pipe roofing (Hr)	Hr.	47	3.13
Grouting Pipe roofing	Hr.	39	2.6
Excavation	Hr.	42	2.8
Removal of muck	Hr.	65	4.33
Shotcrete	Hr.	47	3.13
Rock bolt	Hr.	32	2.13
Erection ribs	Hr.	86	5.73
Erection of steel lagging	Hr.	73	4.87
Backfill Concrete	Hr.	45	3
Misc. Works (Hr)	Hr.	10	0.67
		586	**39.06**

Working days	**28**	**Days**
Working Hr.	**21**	**Hrs**
Montly progress	**15.05**	**M per month**
Say	**15**	**m/Month**

Time cycle for Heading Excavation with pipe roofing (15m cycle) and complete Heading Excavation

Geological condition: Very poor

Pre-grouting

Pipe roofing : 89mm dia 21 m long @ 300-400mm C/C

Segmental Excavation - 4 to 8 sements as per standing time

Steel ribs ISHB 200@ 500mm C/C

Description	**Unit**	**Time (15 m cycle)**	**Time (01 m)**
Survey and profile marking	Hr.	7.5	0.5
Pre-grouting	Hr.	35	2.33
Pipe roffing (Hr)	Hr.	47	3.13
Grouting Pipe roofing	Hr.	39	2.6
Excavation	Hr.	25	1.67
Removal of muck	Hr.	58	3.87
Shotcrete	Hr.	19	1.27
Rock bolt	Hr.	30	2
Erection ribs	Hr.	70	4.67
Erection of steel lagging	Hr.	71	4.73
Backfill Concrete	Hr.	35	2.33
Misc. Works (Hr)	Hr.	10	0.67
		446.5	**29.77**

Working days	**28**	**Days**
Working Hr.	**21**	**Hrs**
Montly progress	**19.75**	**M per month**
Say	**20**	**m/Month**

Annexure- 9

Relevant Photographs of tunnel faces

Expression of Interest (EOI) for Selection of Firms /Experts to accelerate the progress of Heading excavation at four critical faces in the Head Race tunnels (HRTs) of Teesta-VI HE Project, Gangtok, Sikkim

(Photographs)

Face 4A RD: 1150

Face 4B RD: 967m

(Photographs)

Face 4A RD: 1268m

Face 4B RD: 1238m

(Photographs)

Face 3A RD: 1048m

Face 3B RD: 1153.5m