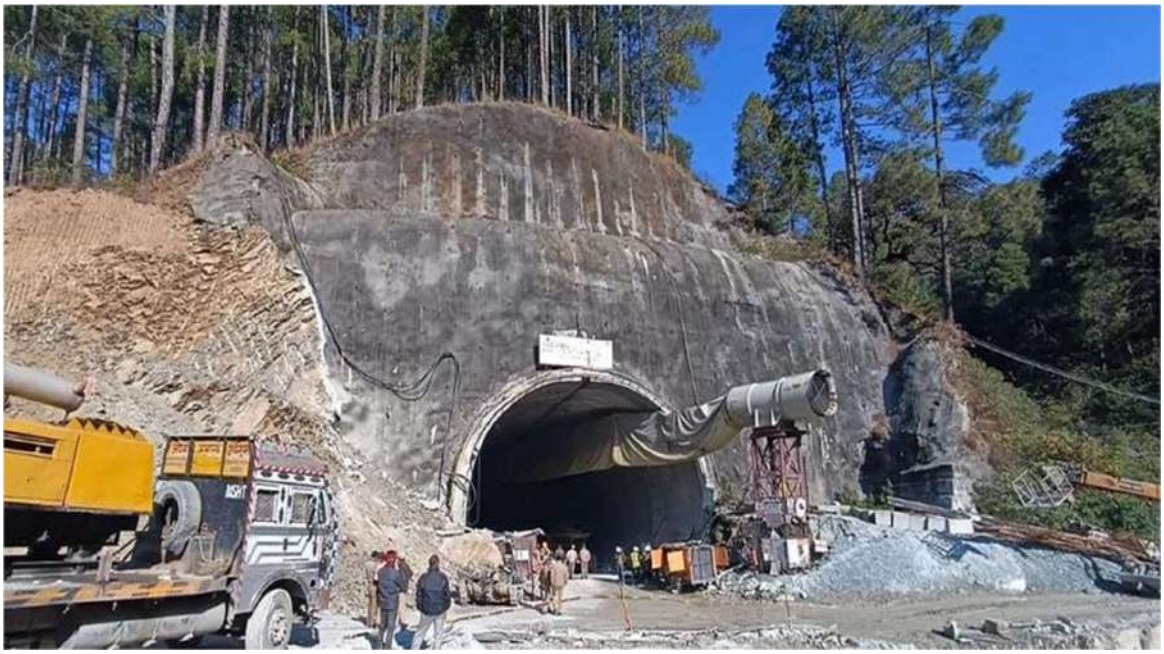
A

Report on

Silkyara-Barkot Tunnel (Uttarkashi) Collapsed Disaster



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1. Introduction

Under the prestigious Chardham Project of the Government of India to join the pilgrims Gangotri and Yamunotri under the Radi pass area, the Silkyara Tunnel for a length of 4531 meters is under construction by NHIDCL through M/S Navayuga Engineering Company Ltd. for a total cost of Rs. 853.76 crore. The tunnel construction shall immensely benefit the pilgrims and local peoples as it will provide all-weather connectivity and shorten the distance by 26 km and 01 hours of travel time through steep, mountainous, narrow roads prone to accidents and landslides.

2. Incident detail

On November 12, 2023, the construction faced a setback. The excavation work, initiated between Chainage (Ch) 260m and Ch 263m, encountered an unexpected incident around 5:30 AM. A tunnel roof collapse transpired between Ch 205m and 260m, specifically in the area where re-profiling of the right-hand side of the tunnel cross-section was underway. 41 workers were trapped inside the Tunnel.

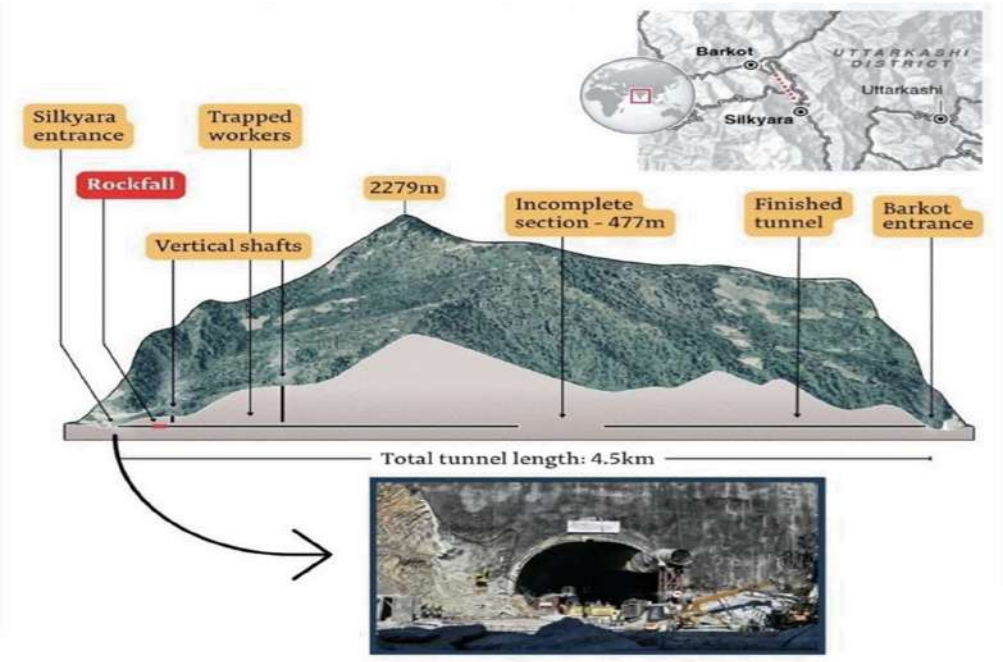


Figure 1: Schematic 3D view of Sikyara Tunnel

3. Profile and Geology

The tunnel alignment lies in Survey of India Toposheet no. 53J/5 in SW corner and 53J/1 SE corner between Silkyara bend and Barkot bend passes through Radi Top and is located 51 km south of Uttarkashi town (Fig. 2). The slopes have a considerable overburden that supports a thick forest of Oak, Rhododendron, Deodar and Pine. The azimuth of the tunnel alignment is 333oN. The foliation of the rock has a 43° dip with direction N240°. The alignment of the Tunnel makes a 0° angle with the foliation of the rock, which is parallel (data available from the geological record). The shear zones follow the trend of the foliation plane and run for a considerable distance along the tunnel alignment.

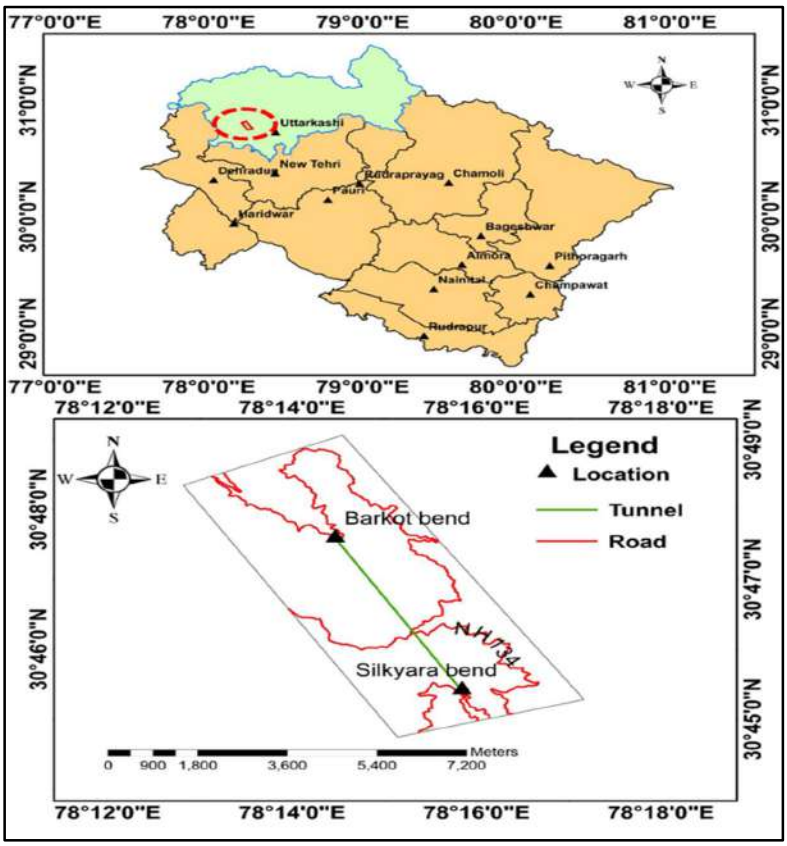
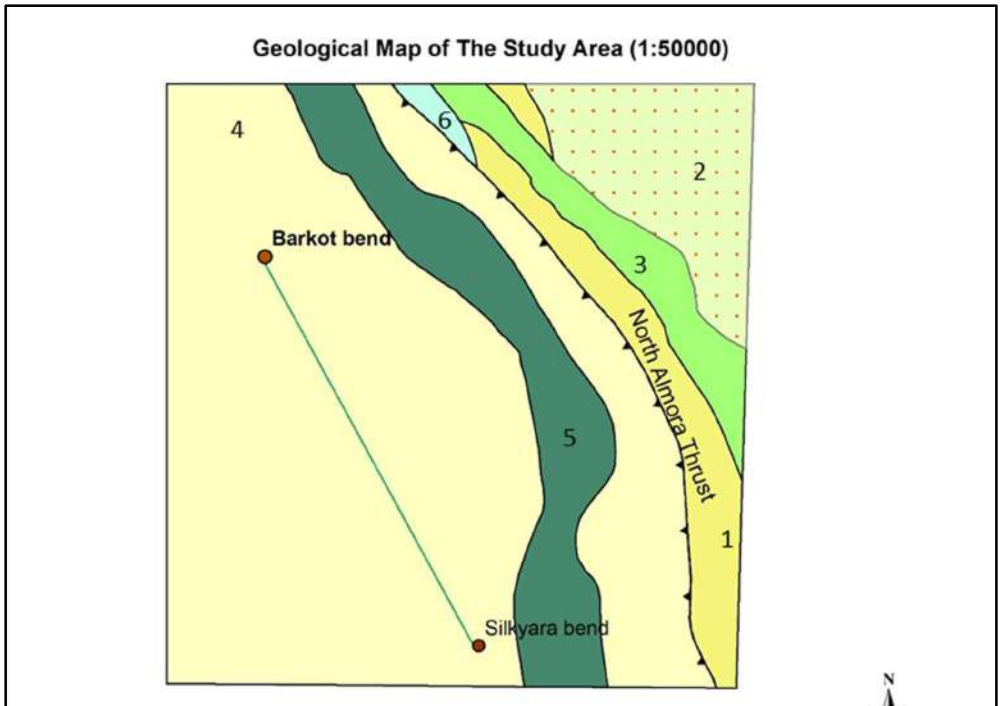


Figure 2: Location map of the Tunnel

The tunnel alignment falls in the inner part of the Lesser Himalaya in Uttarkashi District of Uttarakhand. Geologically, the area is occupied by the rocks belonging to the Garhwal groups of Meso-Proterozoic age and Jaunsar Group and Morar-Chakrata Formation of Neo- -Neo-Proterozoic age and undifferentiated Quaternary deposits of Pleistocene to Holocene age. Morar-Chakrata Formation has a tectonic contact North Almora thrust (NAT) with the rocks of

Garhwal Group, and the rocks of Garhwal Group are folded along the NE-SW axis. The geology of the study area belongs to the morar Chakrata -Chandpur formation of the Jaunsar group of rock represented by slate, phyllite, quartzite, dolomite, and basic intrusive (Fig. 3).



Legend

	Lithology	Formation	Group
6	Gravel, pebble, sand, silt and clay		
5	Basic Rock(Epidiorite)	Morar Chakrata	Jaunsar Group
4	Slate,phyllite, quartzite, dolomite, with basic intrusives		
3	Metavolcanics	Nagnithank	Garhwal Group
2	Quartzite and slate with basic metavlcanics		
1	Quartzite, slate, lensoidal limestone and tuff	Uttarkashi	

Figure 3: Geological Map of the study area (GSI compilation, 2019)

A collapse zone has been identified approximately 200 meters from the tunnel portal. The rock in this area exhibits characteristics of a shear zone, as illustrated in Figure 4. The rock is fine-grained, dark grey, and has alternating bands of chloritic phyllite and siltstone, predominantly dominated by siltstone and thin to moderately foliated. The subsidence is occurring in the hanging wall of the shear zone, indicating a vulnerability in this specific geological formation.

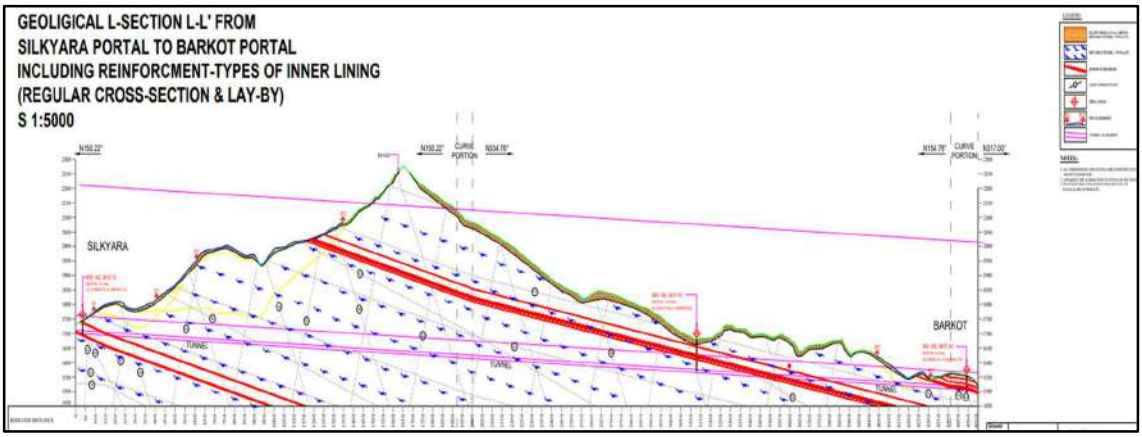
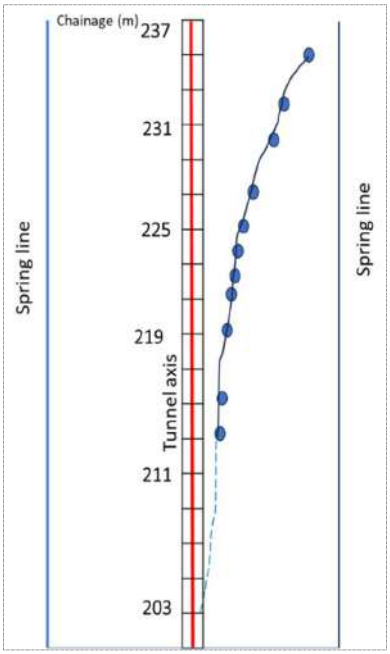


Figure 4: Geological section along the tunnel length

Notably, two distinct shear zones are evident as we move toward the tunnel portal. The first shear zone is marked at 1700 meters from the portal, and the second is identified at 1748 meters, approximately 150 meters from the portal. Both shear zones align parallel to the foliation planes of the rock, emphasizing the significance of geological considerations in understanding and mitigating the risks associated with subsidence and collapse in the tunnel construction project. From the available face logs, the 3D geological log is prepared for the shear zone in this reach to get a first-hand assessment. The shear zone thickness is 100cm at some places containing pulverized and crushed rock mass.



As per available face logs, this shear zone appeared from Ch 213m and continued along the foliation trend along the right side of the tunnel arch till Ch 237m. The tunnel records reported over-breaks and cavity formation between Ch 203m and 237m. The condition of rock mass based on the face logs is folded strata, indicating deformation suffered by the rock. An attempt has been made to plot the shear zone tentatively from the available face logs with tunnel axis, as shown in Fig. 5

Figure 5: shear zone represented from available face logs with tunnel axis

4. Design of Tunnel

The construction of this Tunnel serves a strategic purpose by significantly reducing the distance between Silkyara Bend (CH. 25.400) and Barkot (CH. 51.000) on NH-94. The Tunnel's alignment aims to transform a distance of 25.6 km into less than 5.0 km. The proposed alignment spans a straight distance of 4.531 km with a vertical gradient of 4.4%. Notably, the Tunnel boasts a minimum rock cover of approximately 40m, exceeding three times the tunnel diameter. The proposed road tunnel has the following dimensions: 14.075m (W) x 9.9.00m (H) (excavated size). The specific dimensions and shape of the proposed Tunnel are integral to the overall design. The D-shaped configuration aligns with the project requirements and geological considerations.

The geological composition of the region presents a unique challenge and opportunity for construction. The Tunnel will traverse extensive successions of fine-grained sandstone, siltstone, slates, and shales, occasionally displaying phyllitic characteristics. Intricately woven into this geological tapestry are thick Amphibolite and Epidiorite dykes and sills, constituting over 40% of the rock formation in the present section.

The dimensions and profile of the Tunnel are meticulously designed to accommodate the project's specific needs. Unlike tunnels driven by Tunnel Boring Machines (TBMs) that produce circular profiles, this Tunnel adopts a D-shape. The chosen profile is well-suited for conventional tunneling methods. It aligns with the project's requirements, providing a 7.0 m carriageway width, a 3.5m escape carriageway, 0.75m wide sidewalks, a minimum of 5.5 m clear headroom, and dedicated space for ventilation channels, ensuring a fully transversal ventilation system.

4.1 Philosophy of Tunnel Design

Designing tunnels involves meticulously considering various factors to ensure the structural integrity and safety of the construction. The location of tunnel portals is primarily determined by the overall road alignment, tunnel gradient, geological and geotechnical parameters, and the imperative to keep all construction work outside weak zones. The design of Tunnel primary support adheres to current codes and standards, utilizing empirical methods such as the Rock

Mass Rating (RMR) and the Q-system chart developed by Barton to derive the tunnel support needs.

As a discipline, tunneling inherently carries a high level of risk due to the myriad uncertainties entwined throughout all stages of the work. To mitigate the risks effectively, a comprehensive strategy is imperative. This strategy involves thorough investigations to gather accurate data, designing based on the results of these investigations, and adopting construction practices specifically tailored to address any residual risks that may persist. By recognizing and systematically addressing the uncertainties inherent in tunneling projects, engineers can enhance the resilience and safety of underground structures. This approach ensures that the infrastructure meets engineering standards and supports the unpredictable nature of the geological and construction challenges associated with tunneling. The silent design considerations for tunnel construction are as follows:

(a) In the context of ground interpretation, the rock mass along the tunnel alignment is categorized based on the geological and geotechnical data. Factors such as weathering, jointing, local hydrogeology, and in-situ stress influence the rock mass condition and parameter allocation.

(b) A comprehensive site investigation aims to characterize geological units and evaluate their geo-mechanical properties to anticipate behavior during excavation.

(c) Tectonic stresses can lead to locked-in stresses within the rock mass, influencing the stability of the tunnel opening will be assessed carefully. In case of limited information on the site, in-situ testing and sensitivity analysis shall be done.

(d) Various aspects of tunnel design, including geological conditions, material behavior of sprayed concrete, waterproofing, durability, stand-up time, and face stability, are integral parts of DPR.

(e) The tunnel design includes the ground-structure interaction, consideration of the load carried by the composite structure of the ground and lining, and the inevitability of ground deformation.

(f) The engineering of underground structures necessitates a pragmatic approach, and any uncertainties that can affect the design should be incorporated.

(g) Geological and geotechnical aspects to the interpretation of ground behavior, the assessment of tunnel structure interaction with the surrounding environment, construction variables, market factors, and the opinions and responses of the final infrastructure users, the variables at play are fraught with uncertainty.

4.2 Methodology of Tunnel Design

The design methodology encompasses primary support, permanent support, seismic design, and various support elements. Shotcrete, rock bolts, and steel ribs constitute the primary support, while concrete lining is the permanent support. The general steps followed in the design of the Tunnel are as follows:

(a) Rock Mass (Ground) Characterization and Determination of Excavation & Support: Site investigations and expert onsite evaluations are crucial for characterizing the rock mass. This information informs decisions regarding excavation methods and the type of support required.

(b) Structural Analysis of Tunnel Supports: Structural analysis, employing wedge analysis for discontinuous rock, is utilized to model rock block behavior. This analysis helps determine whether the support measures can prevent local block failure.

(c) Modeling of Passive Initial Support Arrangements: Full-bodied passive support is necessary for areas with a low cover or highly fractured rock masses. This typically involves steel ribs or lattice girders embedded in shotcrete to stabilize tunnel sections effectively.

(d) Seismic Design: Tunnel structures must be designed to withstand seismic ground acceleration, focusing on ground deformations induced by seismic waves. This design approach ensures the structural integrity of the Tunnel during seismic events.

(e) Final Lining Design: The final lining design accounts for external strata loads, self-load of lining, external surcharge, and seismic loading. It aims to provide the Tunnel with a structurally sound and aesthetically pleasing finish.

(f) Extreme Tunnelling Conditions: In challenging conditions like the Himalayas, high in-situ stress, and poor quality, weathered rock mass necessitates careful excavation planning. Potential issues such as squeezing and rock-bursting phenomena must be considered and mitigated.

(g) Tunnel Instrumentation: Instrumentation, including deformation and stress measurements, is crucial for real-time monitoring. Deformation instruments along the tunnel walls and roof track vertical, horizontal, and longitudinal components. Stress measurements provide critical information about the forces acting on the tunnel structure.

4.3 Construction Methodology for Tunnel

(a) The expected work cycle for tunnel excavation and support installation involves critical steps such as excavation, spoil removal, steel ribs, lattice girder, meshes, shotcreting, and installation of rock bolts. This systematic approach ensures the efficiency and safety of the construction process. Following are the general steps in the construction of a tunnel:

(b) Construction Management: Effective construction management is crucial for successfully executing tunneling projects. This involves meticulous planning, resource allocation, and coordination to ensure the construction process aligns with project goals and timelines.

(c) Construction Sequencing: The order and timing of construction activities play a pivotal role in the efficiency and safety of tunnel construction. Proper sequencing ensures that each step is executed logically and systematically, minimizing risks and optimizing progress.

(d) Monitoring: Installing instrumentation for continuous monitoring is imperative to track the behavior of the excavated Tunnel and the surrounding rock mass. Monitoring aids in determining and optimizing the required support, contributing to the overall safety and stability of the construction site.

(e) Health and Safety: Prioritizing health and safety measures is paramount in tunnel construction. Comprehensive protocols and practices must be in place to safeguard the well-being of the personnel involved and mitigate potential risks associated with the challenging tunneling environment.

5. Observations on Silkyara Tunnel DPR

The general design methodology for the rock support system followed in the Silkyara tunnel is as follows:

Step-1: Evaluation of the rock mass quality (Q) post-excavation;

Step 2: Estimate the parameters like the length of rock bolts and their spacing by different empirical relations as per the IS Code method for different rock classes;

Step 3: Calculate roof and wall support pressures as per IS Code;

Step-4: Perform detailed calculation and find suitable shotcrete thickness and spacing of rock bolt;

Step 5: Adopt the rock support measures.

Stress Deformation analysis was carried out for all classes of rock mass. The maximum predicted displacement of the Tunnel (in Class E type rock) was 128 mm. Tunnel closure is in the range of 256 mm in the present analysis, which is less than 2% of the excavated span, and it falls under the customarily accepted limit for rigid support systems as per IS Code. However, Class A, B, C, C, and D tunnel closures in rock mass are 16mm, 28mm, 102mm, and 160mm, respectively, which is well within the allowable limit. It is also observed that the material behavior improves with increasing RMR values. The yielded rock mass zone remained within the rock bolt lengths. Hence, based on the analysis, different support measures were prescribed for different rock mass classes. This includes shotcrete, rock bolts, lattice girders, and pipe roofing. The DPR tunnel rock support design for all five rock mass classes has been given in detail.

The geotechnical design parameters have been recorded from the available DPR. These parameters are used for the analysis and design of rock support structures. It is noted from drill holes' information at both the portals that the UCS values of intact rock were in the range of 80 to 40 MPa, whereas the modulus of elasticity of the same is 25 to 20 GPa. Moreover, the following observations are also recorded in the DPR:

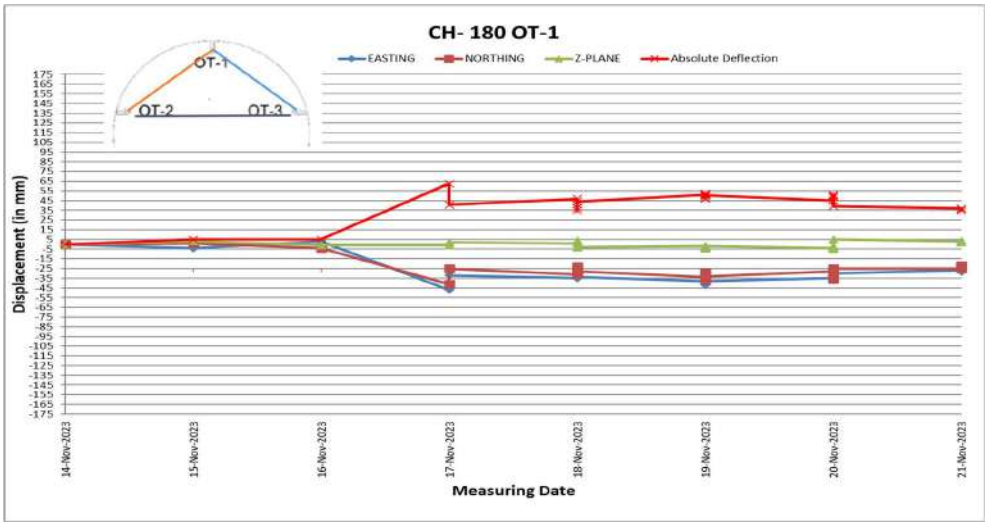
- **Discontinuities & Rock Mass Parameters:** An understanding of discontinuities and rock mass parameters is essential for assessing the stability of the Tunnel. It involves a comprehensive analysis of the structural characteristics and behavior of the rock mass surrounding the Tunnel. For the present Tunnel, three major discontinuities encountered along the tunnel portal area are taken as references for discontinuities along tunnel alignment for doing UnWedge analysis. The direction of tunnel alignment is $N175^0$. The possibility for wedge formations due to the intersection of the joints defined above is also checked with UnWedge software. The formation of wedges due to three joint sets without any support system and with a support system has been analyzed. All these rock mass parameters for all the five classes, A, B, C, D, and E, were determined/estimated. The necessary parameters for concrete lining, rock bolt, shotcrete, and steel ribs have been determined and mentioned in the DPR.
- ***Wedge Stability Analysis*:** Wedge stability analysis is employed to evaluate the stability of rock wedges within the Tunnel. This method helps identify potential failure mechanisms and informs the design of support systems to mitigate instability risks.

- ***Design of Rock Support*:** As per the geological report, the general rock mass rating for the Tunnel was estimated. The values of different geo-mechanical parameters for different classes of rock were adopted for the design of rock support. Support pressures were estimated to assess the ultimate rock support pressures on the roof and wall for squeezing and non-squeezing ground, involving ultimate roof support pressure and ultimate wall support pressure.
- ***Concrete Lining*:** Concrete lining is critical in providing permanent support to the tunnel structure. The design and implementation of the concrete lining are essential for ensuring the long-term stability and durability of the Tunnel.
- ***Shotcrete*:** Shotcrete serves as a primary support measure for tunnel excavation. Its application involves spraying concrete onto the exposed rock surfaces, enhancing the immediate stability of the Tunnel during construction.
- ***Rock Bolting*:** Rock bolting reinforces and stabilizes the rock mass. It involves the installation of steel bolts into the rock, providing additional support to prevent collapses and enhance overall tunnel stability.
- ***Steel Rib*:** Using steel ribs contributes to the support system within the Tunnel. Embedded in shotcrete, steel ribs provide structural reinforcement, particularly in areas with low cover or highly fractured rock masses.
- **Empirical Design of Rock Support:** An empirical rock support design is undertaken based on the geological report. This involves an assessment of the general rating of the rock mass, informing the selection and implementation of appropriate support measures.
- ***Estimation of Support Pressures*:** The estimation of support pressures follows the guidelines outlined in Section 3.5 of IS 13365 (Part-2):1992, providing a standardized approach to determining the support requirements for the Tunnel.
- ***Ultimate Roof Support Pressure (for Crown)*:** This parameter addresses the ultimate support pressure required for the Crown of the Tunnel, ensuring that the roof remains stable under various conditions.
- ***Ultimate Wall Support Pressure*:** Similar to the roof, the ultimate wall support pressure is calculated to determine the necessary support measures for the Tunnel's sidewalls.
- ***Roof Pressure for Different Classes of Rocks*:** Considering variations in rock classes, the roof pressure is assessed differently for each class, ensuring that support systems are tailored to the specific geological conditions encountered.

- ***Stress-Deformation Analysis for Tunnel*:** A stress-deformation analysis is conducted to evaluate how the tunnel structure responds to the applied stresses during excavation. This analysis aids in predicting potential deformations and optimizing support measures.
- ***Support System for Different Rock Mass Classes*:** Different rock mass classes may require distinct support systems. Tailoring the support approach to the specific characteristics of each rock mass class is essential for ensuring effective stabilization.
- ***Wall Support Pressure – Shotcrete and Bolt*:** The assessment of wall support pressure involves the combined use of shotcrete and bolts to reinforce and stabilize the tunnel sidewalls, ensuring the overall stability and safety of the structure.

6. Monitoring of Tunnel by Instrumentation

Instrumentation has to be installed to monitor the behavior of the excavated Tunnel and the rock mass around the Tunnel. Monitoring assists in determining and optimizing the required support and also helps in making decisions regarding safety measures. NHIDCL monitors the movement in different sections of the Tunnel by collecting periodic data through the total Station. NHIDCL mentioned that they do the monitoring survey and collect data every week. NHIDCL provided displacement data of some sections after the collapse from 14 to November 21, 2023. The displacement monitoring data of Tunnel left, right side, and crest for chainage 180 and 190 are shown below (Figures 6 to 11). The absolute deflection has been seen in the provided sections. The past monitoring data of the Tunnel and other engineering data from Chainage 190 to 270 are required to ascertain the actual cause of the tunnel collapse. Proper investigation reports from expert agencies (GSI, IITs, CBRI, Wadia, etc.) shall be asked for future action and safety measures.



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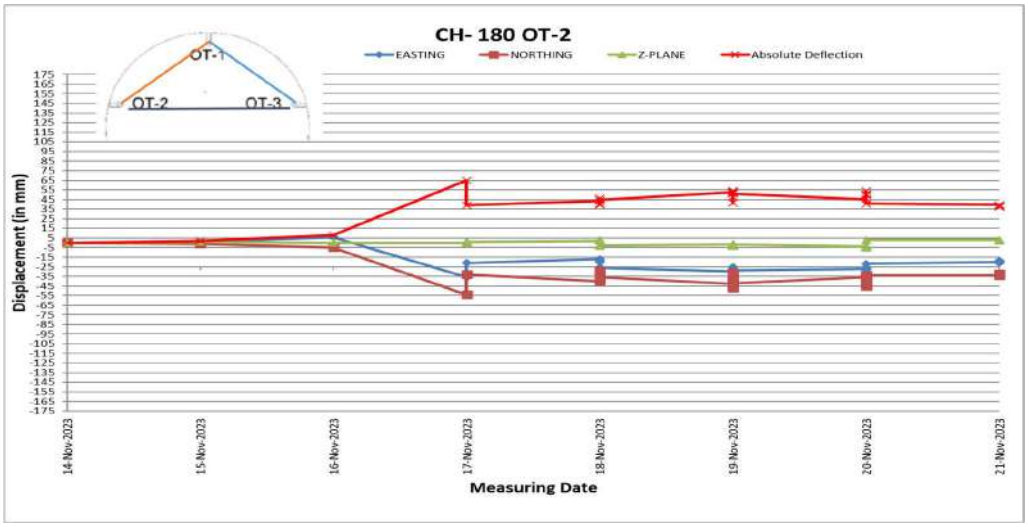

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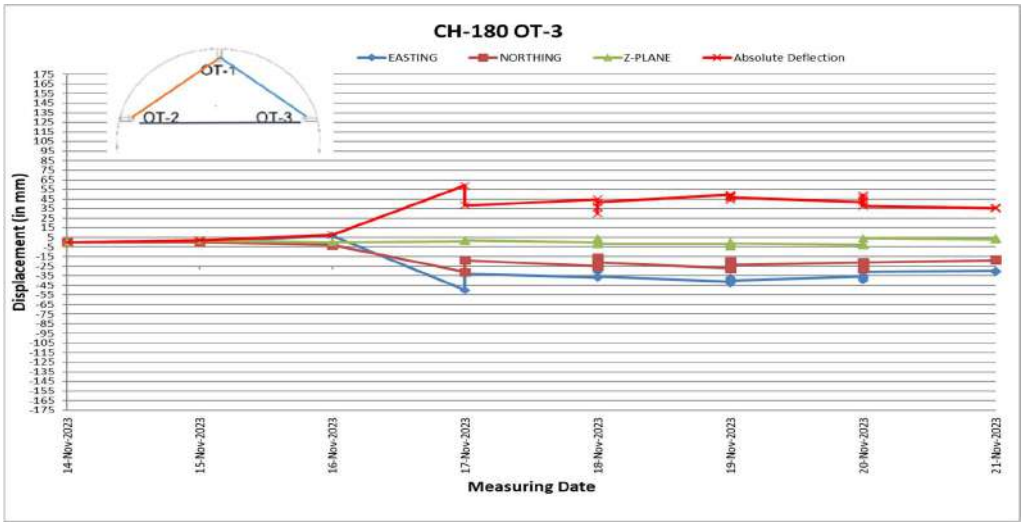

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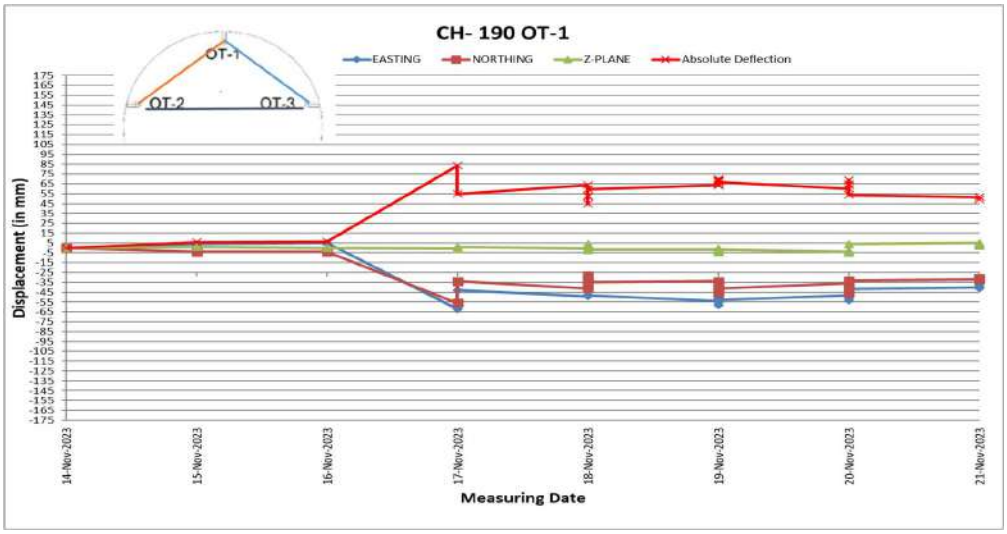

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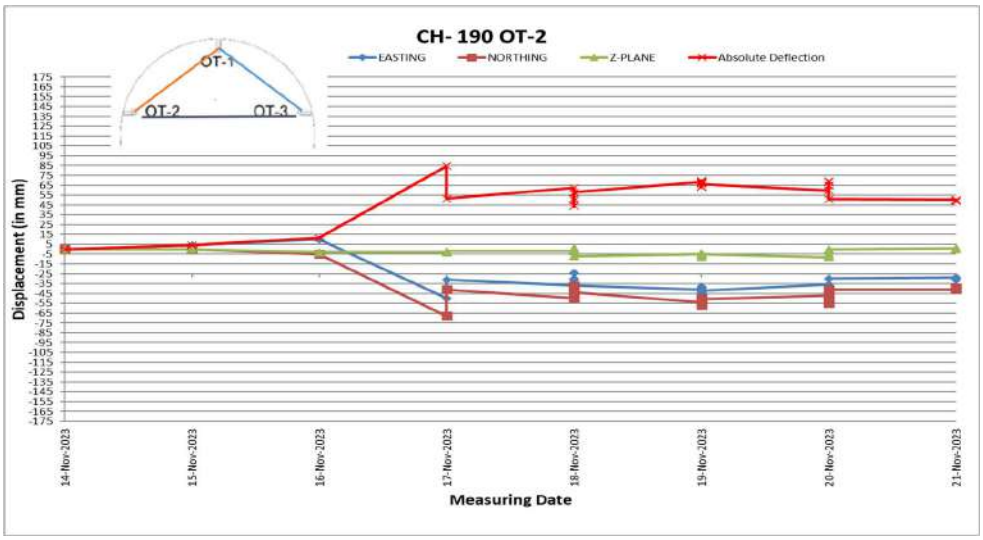

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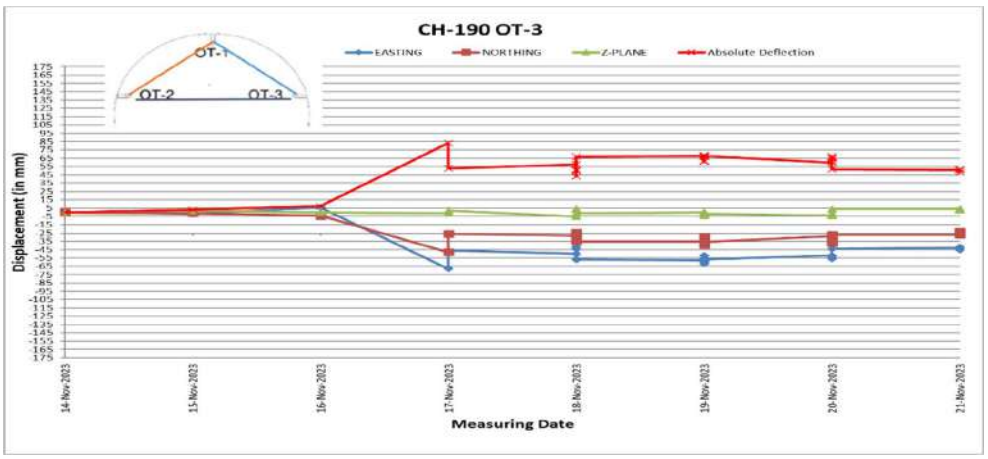

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7. Search and Rescue Operation for Collapsed Silkyara Tunnel

In the aftermath of the tunnel collapse incident, a series of urgent and coordinated rescue activities have been initiated to address the situation and ensure the safety of the trapped workers. The combination of these rescue measures demonstrates a comprehensive and strategic approach to address the challenges posed by the tunnel collapse. The collaborative efforts of experts and the deployment of specialized equipment underscore the commitment to ensure the safety and well-being of the individuals affected by the incident. Through a "Whole of Government" approach, the rescue of all trapped workers was successfully carried out. Many state and central government agencies deployed resources and expertise in a cohesive team spirit. The successful conduct of such a complex rescue operation provides a great learning experience for all the different domain agencies that worked during the operation. The following central, state, and private agencies are deployed in this operation:

1. Ministry of Road Transport and Highway (MoRTH), Govt of India
2. Government of Uttarakhand (All Concerned departments like Disaster Management, District Administration, Police, SDRF, PWD, Health, Water Supply, Civil Aviation, Geology and Mining etc.)
3. NDRF
4. Indian Army
5. Geological Survey of India (GSI)
6. Coal India Ltd.
7. NHIDCL
8. ONGC
9. SJVNL
10. RVNL
11. THDC
12. DRDO
13. BSNL
14. Navyuga Construction
15. Private agencies and skilled worker

8. Approaches for Rescue Operation

8.1 Life Support to the Trapped Workers

Immediately after the Tunnel collapsed, the main focus was to provide a life support system to the stranded workers. Two horizontal directional drilling (HDD) machines were mobilized to create a pilot tunnel through the debris for the insertion of 100mm/150mm/200mm MS pipe to ensure the following:

- Supply fresh air continuously
- Supply of drinking water
- Establish communication with personnel inside the Tunnel

After successfully inserting one 4-inch/100 mm pipe, water, food, and oxygen were pumped inside the pipe with compressed air. The life support essential requirement has been successfully received by the stranded workers. All the stranded workers are safe, as they communicated.

Realizing the extended period of the rescue operation and anticipated future challenges, on November 18, 2023, construction of an additional pipeline (6 inch/150 mm) for life support at the right side of the Silkyara end of the Tunnel was started. After the 3rd attempt, another 150 mm diameter steel pipe lifeline service was pushed through the debris on November 21, 2023. Over this life support line, the stranded workforce established the video connection. Also, proper food packets of Dal, Rice, Roti, Sabji, dry fruits, and medicines were sent regularly through this pipe. The timeline of complete rescue operation is also annexed with this report to capture the complete story *(Annexure B)*.

8.2 Excavation and Shortcreting of Tunnel Line

Initially, after the onset of the collapsed Tunnel, debris/muck removal from one side of the Tunnel and shotcreting of the exposed face commenced. Excavation with shortening was done for 40 meters of the collapsed Tunnel. However, after observation of cavities formed 10 meters above the Crown on both the left and right sides, mucking and shotcreting were stopped.

8.3 Rescue Plan

The most suited and early rescue option is horizontal drilling of MS steel pipe through the debris at the Silkyara end tunnel. A decision has been made to use a 900 mm/800 mm diameter

MS Steel Pipe with the assistance of a Hydraulic Jack to create a pathway for evacuating the trapped workforce. Various options for auger machines have been explored. The first auger machine was found incompatible with horizontal drilling. After that, another high-power drilling machine was airlifted from New Delhi. Fabrication of base for installation of auger machine has been done so that proper pushing of pipes can be executed with slightest vibrations.

On November 17, 2023, after 22-meter pipe pushing and during the positioning of the fifth pipe, it was reported that the auger machine could not push further as the machine was getting lifted and the bearings of the machine were damaged. Therefore, it was planned to fix the machine with anchors to avoid uplifting. After a detailed discussion, it has been decided and agreed by the expert executing agency that 900 mm diameter pipe pushing can only be feasible if the auger machine and pipe both are on the same inclination. After that, additional plates are put up below the platform to modify the machine mounting platform. During the further execution of the drilling at mid-day, the workforce agencies, security personnel, and local police heard a large-scale cracking sound, and the team working inside the Tunnel created a panic situation in the Tunnel and the team working. Consequences of the incident: The General Manager, NHDCIL, has described similar cracking sound/noise/symptoms on many previous occasions of cavity formation/collapse in the vicinity from chainage 150 to 203. Accordingly, pipe-pushing activity has been stopped.

Further, a meeting was called with all officials and other experts from various organizations to take future actions and cope with the situation. On November 18, 2023, senior officers from PMO, MoRTH, State Government, and NHDCIL visited the Tunnel and the top of the tunnel head to take further action. After that, a meeting was organized under Shri Bhaskar Kulbe (IAS) and all senior officers from GoI and State, representatives of various organizations (BRO, RVNL, RITES, SJVNL, THDC, etc.), and tunnel experts. Finally, after discussing various rescue operations options, five plans were decided to evacuate the stranded workers as soon as possible. The line diagram of parallel rescue plans is given below (figure 12), and the details of each plan are subsequently discussed.

Rescue Plan - 1: Strengthening of Tunnel and construction of escape route by NHIDCL (collapse length - 57 m, from Ch. 203 to 260)

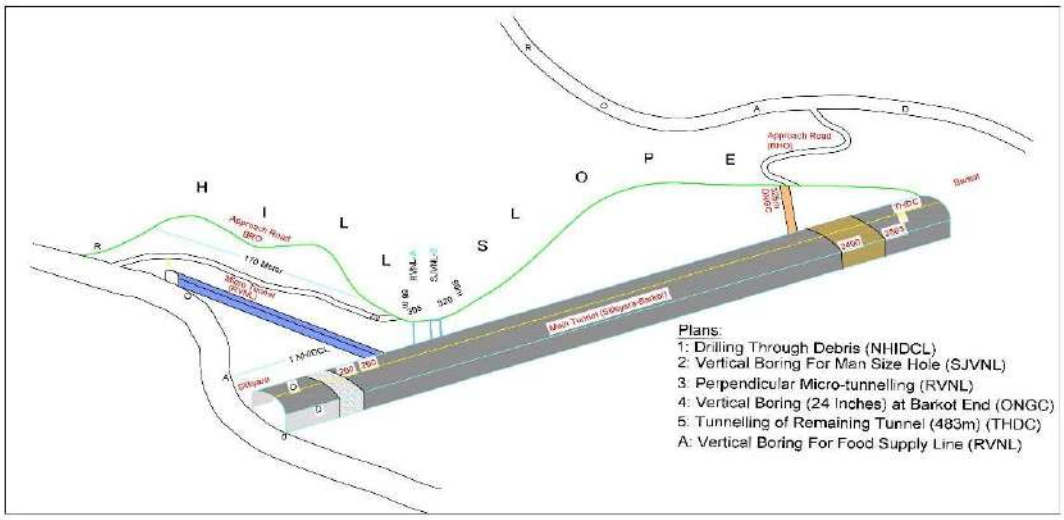

Figure 12: Parallel Rescue Plans

This plan was most optimistic, and a 22-meter length of pipe was already inserted within a week. Moreover, the rescue operation proceeded further by taking more safety and precautionary measures. To provide safe passage to the workforce of pipe pushing activities, starting from near the pipe drilling machine have been created by placing the precast concrete blocks, Hume pipe, and steel pipes for a length of around 87.2 meters up to the safe zone covering an area which is prone to collapse further (Chainage 187 meter to 120 meters) & (Chainage 70 meter to 50 meters). Also, a parallel gantry structure has been fabricated in situ to cover the pipe drilling machine. Additional safety provisions for the erection of false ribs from the face of the Tunnel towards the tunnel exit on the Silkyara side to protect the operational area have been adopted (Chainage 194.50 meters to Chainage 184.50 meters).

As the heavy vibrations were noticed while pushing the 900 mm pipe after 22 meters, it was decided to construct a solid platform and reduce the pushing pipe size to 800 mm diameter for further auger drilling. From 22 to 44.10 meters (8th pipe of 6 meters) in length, the pushing of 800 mm pipes was smoothly done without any obstructions until November 22, 2023. But while inserting the 9th pipe, a metallic object (Lattice girder rib) was encountered in the front of the pipe, and further insertion could not proceed. For cutting the same with gas cutters, the NDRF/SDRF team was deployed, and on the afternoon of November 23, 2023, the lattice girder

rib cutting was completed using the gas cutters. Subsequently, the trenchless team entered the pipe manually twice to confirm the clearance of the rescue pipe. Pushing of the 9th pipe started, and the pipe reached an additional 1.8 meters, but again, vibrations were noted, so the auger was pushed slightly back to re-assess the force to be applied. Obstructions were observed. A bent part of the fore pole (pipe) from the tunnel lining was struck in the auger assembly, which led to vibration. The platform for the auger machine has been strengthened using an accelerating agent for the rapid hardening of concrete.

Further, the auger was required to pull back completely to assess any other damage to the pipe. On November 24, 2023, the auger was pulled out, and to assess any other metallic obstructions in the line of pushing pipe, the Ground Penetration Radar (GPR) test was carried out. Welder's team again went inside the pipe to cut the bent pipe. After cutting the damaged, bent pipe, auger reassembly was completed, and all augers were inserted. Pushing of the 10th pipe (4.7 meters in length) started on the afternoon of November 24, 2023, and a length of 2.2 meters was inserted by the evening, resulting in a total inserted length of 46.9 meters. The obstruction has again stopped the pushing of pipes.

On November 25, 2023, pulling back the auger started, and after pulling back the 15-meter length of the auger, the auger joint broke. Various equipment was used to pull out the rest of the 32-meter auger left inside the pipe, and strategies have been worked out. Initially, manual cutting of auger blades was applied, but observing the delay in cutting, other options were also considered. DRDO team was deployed from Hyderabad with a plasma cutter machine on November 26, 2023, but due to operational difficulties at the site, plasma cutters were not utilized. Further, to assist in cutting the auger blades and shaft, ONGC has also arranged a Magna Cutter machine. The ONGC also mobilized the identified workforce from Rajahmundry to the Silkyara site to assist in cutting augur blades and shafts.

During the cutting procedure, it was observed that manual cutting using gas cutters is the most efficient working; therefore, the gas-cutting process was resumed. On November 27, 2023, the whole length of the auger was removed. After this visual, the welders found that the cutter of the auger had been entangled with lattice girder bars, which damaged the 1.5-meter length of the 800-meter passage pipe. The remaining pipe length has been removed by gas cutting along with the obstruction caused by lattice girder, reinforcement, etc. The process was completed by the evening of November 27, 2023. After that, the shotcrete lump in front of the pipe has also been broken into pieces manually using a rock breaker.

Analyzing the fact that pushing the pipe in the debris continuous obstructions can again damage the auger machine, which may lead to further delay in the rescue operation. The officials and experts decided the remaining length of pipe pushing to be achieved by manual excavation followed by the pushing of pipes. A specialized manual 'Rat Miners' excavation team has been deployed for further excavation through the 800 mm pushing pipe. The desired length of pipe insertion and breakthrough to reach the trapped workers was achieved by the evening of November 28, 2023. All 41 stranded workers are rescued safely by the NDRF and other response agencies.

Rescue Plan - 2: 1.2-meter Diameter Vertical Drilling of Borehole by SJVNL at Silkyara end

After observing a few cavities and weak zones from chainage 150 to Chainage 203 and the likelihood of further collapse inside the Tunnel, experts have decided on another option of 1.2-meter diameter vertical drilling of the borehole from the top of the Tuerts. BRO has assigned the work to prepare an access road over the drilling site. The drilling work was given to SJVNL by the use of a drilling rig machine. The marking of the drilling point over the Tunnel has been finalized at Chainage 305 L/S after a discussion with GSI, RVNL, and ONGC experts. To complete the road survey was taken by the BRO with the help of a drone. BRO has completed the access road and handed over the site to SJVNL on November 20, 2023. Drilling machinery arrived at the site at night on November 21, 2023, and the platform for launching the drilling machine was completed on November 23, 2023. The drilling rig of the machine was transported from the tunnel portal to the drilling site, and drilling was started on November 26, 2023. The vertical drilling through this borehole has achieved a 41.96-meter length till the breakthrough from pipe pushing on November 28, 2023.

Rescue Plan - 3 (A): 170-meter Tunnel construction by RVNL

From the left side of the Tunnel at Silkyara's end, a 170-meter parallel rescue tunnel was planned. The task was assigned to RVNL with the support of NHDCIL and local administration. NHDCIL and the water supply department have ascertained water availability. Equipment and machinery were airlifted from Nashik. The tunnel construction platform was constructed, and this work was completed only on November 28, 2023.

Rescue Plan - 3 (B): Vertical drilling (8") by RVNL at Silkyara end

Envisaging the threats of failure in various rescue operations, another life support project has been planned through a vertical drill hole over the Silkyara tunnel end at Chainage 320. The vertical drilling of an 8" pipe was given to RVNL. BRO has completed the access road of 1150 meters and handed it over to RVNL on November 20, 2023. Also, an electric connection has been provided to RVNL. The machine for vertical drilling has been towed to the location by BRO. The platform for the drilling rig was completed on the morning of November 26, 2023, and drilling was started immediately after this. A total length of 72 meters was drilled till November 28, 2023.

Rescue Plan - 4: 24" Vertical Drilling at Barkot End by ONGC

The other end of the Tunnel on the Barkot side was also taken as one option for the rescue operation. The ONGC team has taken responsibility for vertical drilling at Barkot's end. The team head of drilling with experts visited the site on November 20, 2023. After the reconnaissance survey, BRO has prepared the road alignment to reach the drilling site. ONGC has transported the air drilling rig from Indore. All the associated material of the air hammer drilling rig was mobilized by ONGC and on standby at Rishikesh for further instructions, waiting for BRO's finishing of the approach road. Out of the 5000-meter road stretch, the BRO team has completed 1050 meters of approach road by November 28, 2023. Further operation was stopped because of the breakthrough at Silkyara's end.

Rescue Plan - 5: 483-meter tunnel construction by THDC at Barkot end

The escape tunnel from Barkot's end was considered one option to rescue the trapped workers. The total length of the uncompleted Tunnel at this end is 483 meters. THDC was allocated this task to make an escape tunnel. THDC made a site assessment and brought their workforce and machinery. Micro-tunneling machines were mobilized, and a rib cage of 2mx2m was started. THDC started drifting work at the Barkot end, and the first blast for the Tunnel was done on November 20, 2023. After each blasting, mucking was done, and drilling for rock bolts and rib erection work in the portal area was executed. This option took more time, and till November 28, 2023, the executed length of drift was only 13.20 meters. Fabrication work of 18 numbers of ribs has been completed during this time span.

Rescue Plan - 6: Creation of side Drift inside Tunnel through the debris at Ch. 203 by Indian Army

From the right end of Silkyara, drift inside the Tunnel through the debris ay Chainage 203 was considered, and the army was deputed for design and fabrication work. The section of 1.2mX1.5m design has been finalized, and fabrication started on November 21, 2023, by army welders. 22 numbers of frames have been fabricated and completed by November 28, 2023.

9. Deployment of Manpower, Resources, Expertise and Technical Knowhow in Rescue Operations

In the aftermath of the collapse of the Silkyara tunnel, the state government immediately activated the incident response plan. The State Emergency Operation Centre (SEOC) and District Emergency Operation Centre (DEOC) are continuously in touch with officials of NHIDCL and contractor M/S Navyuga Construction. The rescue efforts focused on the 2 km section of the Tunnel, with completed concrete work ensuring the workers' safety. Various government agencies worked tirelessly on each assigned specific task to ensure the safe evacuation of the workers. National and international experts were also mobilized at the site to advise on the rescue operation.

The state government launched Operation "Zindagi" (means life) to save the trapped workers. Continuing their unwavering commitment to saving lives, the Central and State governments have actively engaged in the rescue operations at the Silkyara Tunnel in Uttarkashi, where 41 workers were trapped. The district administration of Uttarkashi has set up an onsite disaster operation center with all other line departments supporting the rescue operation. The District Magistrate (DM) and Superintendent of Police (SP) of Uttarkashi stayed at the Silkyara site and continuously monitored the rescue operation. Secretary, Disaster Management & Rehabilitation, Government of Uttarakhand, reached the site immediately after the event. SDRF, BRO, ITBP, Health, and Police reached the site, and the government of Uttarakhand has formed a six-member expert committee to investigate the cause of the tunnel collapse. The support provided to state government departments is given below and annexed at end of this report *(Annexure C & D).*

9.1 State Disaster Response Force (SDRF)

Immediately after the tunnel collapse incident, the state government positioned SDRF at the site. Commandant SDRF and around 56 skilled SDRF personnel were deployed onsite to evacuate 41 trapped workers safely. SDRF sent various types of machines and equipment with sufficient quantity onsite. The expertise and technical knowhow deployed during the entire operation by SDRF in the Silkyara Tunnel collapse are as follows:

- **Search and Rescue:** Proficient SDRF search and rescue teams worked in the rescue operation, dealing with confined spaces and extracting individuals from collapsed structures.
- **Communication setup:** SDRF has established a modified and prompt communication system through which regular communication has been made to the trapped workers.
- **Logistic Management:** SDRF's skills in managing resources, equipment deployment, and swiftly coordinating personnel on site were a great boon.
- **Emergency Response Planning:** SDRF's expertise in creating and executing emergency response plans helped during the final evacuation of trapped workers through the escape mini tunnel.
- **Leadership Communication:** Communication between leaders and government officials of different agencies to coordinate and strategize rescue operations.
- **Collaborative Rescue Operations:** Joint operations involving specialized teams like SDRF, NDRF, NHIDCL, ONGC, etc., with the deployment of specific equipment.
- **Counseling and Morale Boosting**: SDRF provided psychological support and counseling to the trapped individuals to maintain high Morale during the crisis.
- **Safe Extraction:** SDRF utilized trolleys and specialized equipment to extract trapped workers safely.

9.2 State Police

The state police force has worked brilliantly to maintain law and order and manage traffic plans near the Silkyara tunnel. SP of Uttarkashi district himself made his availability at the rescue site along with all subordinate officers and police personnel. Police have set up a unified command center (Police Control room) at the site. The details of activities carried out by the police force are as follows:

- **Control room setup:** 14 technical personnel deployed for the police control room for smooth communication and coordination between central agencies and field units, providing handsets and static police wireless.
- **Police Chauki (Outpost):** A dedicated police chauki near the Silkyara tunnel was established. The police also set up the tented accommodation and mess.
- **Access Control:** Unified ID cards were issued by the police to identify the right person and can only be entered by the site.
- **Maintenance of law and order:** Deploy local volunteers/ Apda Mitra amongst the villagers to bond the trust deficit and respect the local deity (Baukhnag Devta). A local intelligence unit has been activated for effective law and order control.
- **Providing Green Corridor:** Deployment of traffic police 24*7 in narrow and sliding patches with practical communication sets and deployment of road opening machines (JCBs) for muck removal in sliding zones.
- **Management of Media:** Continuous and authentic content has been provided to avoid adverse reporting. A separate media gallery has been set up near the incident site to facilitate the media personnel. Proper access control was in place for media personnel. Also, effective social media monitoring teams were deployed to keep a check on rumors and fake news.
- **Safe Passage of Rescued Workers & Ambulances up to CHC Chinyalisaur:** A 'Green Corridor' was provided by police with an uninterrupted hilly route. The rescue ambulances were sent in 'Convoys' with proper escort and tail vehicles. Properly armed police operated the health center at Chinyalisaur, and effective monitoring with drones was carried out.
- **Access Control for Mobile and Cameras:** Proper sign boards were in place, and a mobile collection center was set up at the main gate of the Tunnel.
- **Contingency Helipad:** The police team has set up a contingency helipad at Syalana, nearly 7.5 Km from the incident site, foreseeing the requirement in the rescue operation.

9.3 State Health Department

After the aftermath of the event, state medical teams were positioned near the tunnel site. A specialist team of doctors was deployed at the site with all relevant para medical staff and life support ambulances. The nearby medical facilities at CHC Chinyalisaur and the district hospital

of Uttarkashi were made ready to tackle any adverse situation. The following tasks were carried out by the department:

- **Regular Site Visit:** The team of the specialist medical team regularly visited the tunnel site. Counseling was done by a Physician and two Psychiatrists twice daily for the trapped personnel, and as per advice, medicines were accordingly provided to the trapped workers.
- **Emergency Services and Counselling:** Regular 24*7 OPD with emergency services was conducted near the tunnel site for the persons of different departments on duty, media staff, and staff of the tunnel company. Also, counseling and assurance of family members of the trapped persons was done regularly. Diet for the trapped workers was provided as per the advice of a specialist.
- **Medical Relief Post (MRP):** A temporary 08-bed Medical Relief Post (MRP) was established inside the Tunnel at a safer location with appropriate equipment, infrastructure, and personnel deployed. All 41 trapped workers after the rescue were examined at MRP by the team of specialists and, after that, shifted via ambulance to CHC Chinyalisaur for appropriate management.
- **Ambulance Support**: 43 ambulances (10 ALS and 33 BLS) with well-equipped and trained staff were stationed near Silkyara. An Air Ambulance facility was also deployed at Chinyalisaur helipad. The AIIMS Rishikesh specialist also examined the trapped workers before being handed to the respective state authorities and family members.

9.4 Public Works Department

The Public Work Department (PWD) has regularly provided workforce and machinery support during the rescue operation. The engineering division of Uttarkashi/ Bhatwari consisted of an executive engineer, assistant engineers, and junior engineers managing the transit of various officers and experts from various agencies at the site. PWD was also communicating with the families of workers trapped inside the Tunnel. The PWD accomplished the following works:

- **Deployment of machines:** During the rescue operation, different heavy machines were deployed at the site; therefore, PWD did the immediate road widening and clearing of road works.
- **Construction of Temporary Helipad:** PWD constructed a temporary helipad at Syalana, nearly 7.5 Km from the incident site.

9.5 Water Supply Department

The water supply department provided support on drilling works. Senior officials of the department were deputed in the rescue operation work. The following tasks have been carried out by the water department (Uttarakhand Jal Sansthan & Uttarakhand Peyjal Sansadhan Vikas & Nirman Nigam):

- **Availability of MSERW Pipes:** A sufficient number of 900mm diameter and 800mm diameter MSERW pipes were available from Ghaziabad (UP).
- **Auger Machines:** The water department provided the auger machine with parts and other accessories.
- **Tubewell Drilling and Water Supply:** A 3300-meter-long and 90mm diameter pipeline was established for the vertical boring machine. Also, the department has ensured the availability of drinking water for various rescue teams and people working day and night at the site.

10.Progress Monitoring of Rescue Operation

Senior officers from PMO, MoRTH, State Government NHIDCL, Army, and various tunnel expert agencies were present during the rescue operation. The experts monitored the progress of work with their total effort. Central government agencies, State government departments, district administration, India Army, NDRF, SDRF, BRO, THDC, ONGC, RVNL, SJVNL, RITES, and other experts have closely monitored the rescue operation. Mr. Arnold Dix from Australia (President of the International Tunneling Association), Nigi Writiz (Tunnel Safety from the UK), and Chris Cooper (Micro Tunneling Expert-UK) also provided their expert advice to the various agencies engaged at the site during the rescue operation. Hon'ble Chief Minister of Uttarakhand and General (Dr.) V.K. Singh (Retd.) Hon'ble Union State Minister for Road Transport & Highways and Civil Aviation, personally monitoring the rescue operation. Many PMO and State government senior officials also visited the site, provided their support, and advised during the operation for early evacuation.

11. Challenges encountered during the Silkayara Tunnel Rescue operation.

Silkyara tunnel rescue operation is unique and faces many challenges. The standard rescue operation procedure did not help much because they encountered several obstructions during the rescue operation. Also, the site location is in a fragile Himalayan mountainous region that caused unidentified hurdles. Some of the challenges that occurred during the rescue operation are listed below: -

1. The Tunnel has confined spaces and limited access points, making reaching the affected area challenging for the rescue team.
2. Due to the absence of a senior team lead official or technically competent person in the initial phase of the rescue operation to decide the search and rescue methodology, the operation was delayed. This also made timely media briefings difficult.
3. Further collapse occurred during the initial removal of debris, adversely affecting the rescue operation.
4. Poor telecom connectivity at the site hindered smooth communication and coordination. The issue was resolved after a week by augmentation of network strength with the intervention of district administration and DOT.
5. Due to the non-availability of specialized equipment near the incident location, the initial few days were spent determining the required mobilization of resources. Handling logistics at the site was the major challenge in the rescue operation.
6. Transportation of some heavy machines and equipment was a significant challenge, considering the narrow road stretches, chronic slide zones, and steep gradients.
7. Rescuers initially faced uncertainty about the conditions inside the collapsed Tunnel, including potential hazards such as hazardous materials, electrical issues, or unstable structures. Cold weather at the incident site, especially at night, posed a challenge.
8. During the rescue operation, dignitaries and senior officers visited the incident site, which was managed with limited resources.
9. It is a big challenge to work against time to reach and extract trapped individuals while ensuring their safety.

10. The risk of further collapse of the Tunnel reveals the safety of rescue teams. Managing the risk of additional collapse or instability raises concerns while planning the rescue operation.
11. Addressing the psychological impact on trapped individuals and rescue teams during the crisis was one of the critical tasks during the operation.

12.Innovations/ Measures Undertaken during Rescue Operation:

The Silkyara tunnel rescue was a unique operation, and numerous innovations and measures were undertaken during the rescue work. These innovative approaches and collaborative efforts played a crucial role in successfully conducting the rescue operations. A few solutions have been used for the first time and complemented the efforts. A few of them are enlisted below:

1. Underwater cable arrangement: SDRF has innovatively used underwater cables inserted through pipes to facilitate worker communication.
2. Use of different sizes of MS pipe: During the insertion of 900mm diameter pipes, some vibrations were noticed, which obstructed pipe pushing work. Experts thought wisely and later used the safe pipe length of inserted 900 mm lesser diameter 800 mm pipes were pushed to avoid the other obstructions.
3. Parallel Rescue Approaches: For the first time in the tunnel rescue operation, parallel approaches were worked out, and each possibility was explored to save the lives of trapped workers.
4. Rescue inside the pipe: Trapped workers were extracted safely using specialized rescue equipment and stretcher trolleys inside the pipe.
5. Joint Rescue Operations: Collaborated with multiple teams like SDRF, NDRF, PSUs, private agencies, etc., for combined and synchronized rescue efforts.
6. Leadership and Counselling: The Government has worked holistically to make a successful rescue operation. Commitment from the top to bottom was shown in each and every step of the rescue operation. Leaders and senior officials were provided counseling and boosted the Morale of trapped workers and rescue personnel.

13.Lessons learned in the Silkyara Tunnel Rescue operation.

Many important lessons are learned to tackle similar types of rescue operations in the future. Some of these lessons, but not limited, are given below:

1. Keep the inventory details updated during work planning (especially details and availability of Machines), which can be used in an emergency.
2. Identify and develop a temporary helipad facility near the significant/essential work sites, which can be used during emergencies.
3. Ensure the primary medical facility is near the work site during the commencement of work.
4. Identify the nearest Railhead and transportation facilities of heavy machinery to the work site. If there is any bottleneck at several locations on the highway, then maintain a record and take necessary remedial measures by the respective departments to transport these machinery.
5. Identify all resources (workforce and machines) in the government, public sectors, and private agencies regarding their expertise and strength.
6. Ensure the workers engaged in such projects must be highly skilled and experienced. Also, keep the detailed information (inventory) of such skilled workers.
7. Emphasized stringent safety protocols in tunnel construction to prevent such mishaps.
8. Implement regular inspections and tunnel infrastructure maintenance to detect and promptly address potential risks.
9. Different telecom service providers must provide a robust telecommunication system at the work site.
10. Install robust and redundant communication systems within the tunnels for uninterrupted emergency communication.
11. Ensure sufficient stock of technical materials such as Hume pipe, transformers, steel pipes, HDPE pipes etc., and emergency funds for immediate response in a disaster/emergency.
12. The cause of the Silkyara tunnel collapse is a landslide, and the provisions of DM Act 2005 can be utilized for notification and fund allocations.

14.Areas of Improvements

Silkyara Tunnel is situated in the middle Himalayan range, and the area is geographically challenging. The rescue work of trapped workers in the Tunnel exhibits areas where the related agencies and government should focus. Addressing these areas would significantly enhance the safety measures and emergency response capabilities in future tunnel-related incidents.

1. **Tunnel Safety Standards:** Strengthening the safety standards in tunnel construction and maintenance to prevent such collapses. More Stringent measures should be part of tunnel design, specifically in mountainous and fragile regions.
2. **Infrastructure Stability:** Ensuring structural stability and regular inspections of tunnel infrastructure to mitigate the potential risks.
3. **Advance Early Warning System:** To measure the vibrations and minor strains inside the tunnel line, improvised and automatic detectors or gauges should be installed. These detectors will be connected to an early warning system inside the Tunnel so that sirens can be blown without any manual intervention if the threshold level of vibrations/strains is recorded.
4. **Emergency Response Planning:** Enhancing emergency response plans more tailored explicitly for tunnel collapse, including swift and rapid communication setups and better coordination among the rescue teams.
5. **Workers Training**: The construction agency and related department will impart extensive training to workers regarding safety protocols in case of such eventualities.
6. **Communication System:** The development of more robust and fail-safe communication systems within the tunnels will certainly facilitate swift coordination during the crisis. The proper arrangement of internet connections inside the Tunnel is essential to tunnel planning in remote areas.

15.Concluding Remarks and Recommendations

Tunnel collapses in the Indian Himalayas underscore the need for a holistic and proactive approach to tunnel construction. The region can mitigate the risks associated with Tunnel collapses by addressing geological challenges, improving construction practices, and implementing rigorous monitoring and maintenance. As the demand for infrastructure development continues, prioritizing safety and resilience in tunnel construction is paramount for the region's sustainable growth. The recent collapse incident at the Silkyara tunnel site has

raised critical geological and construction concerns and questioned orthodox rescue operation plans. Several technical, managerial, and administrative observations/recommendations are outlined below to comprehensively understand future risk mitigation and improve preparedness for tunnel rescue operation methods.

1. **Specific SOPs:** Project-specific Standard Operating Procedures (SOP) for such incidents/accidents should be formulated, and the workers will be provided with proper training.
2. **Technical Advisory Committee (TAC):** Constitution of Technical Advisory Committee (TAC) consisting of GSI, technical agencies like NGRI, Wadia, etc., and experts of geotechnical and underground works agencies (ONGC, RVNL, etc.). Ensure the visit of TAC at regular intervals, and the committee's recommendations must be followed up.
3. **Comprehensive Emergency Plans:** Develop detailed and scenario-specific emergency response plans tailored for Tunnel collapses, focusing on rapid communication, coordinated rescue operations, and leadership strategies.
4. **Interdepartmental Coordination Committee:** Form an Interdepartmental coordination committee at the National, State, and district levels for regularly monitoring critical infrastructural projects, especially in fragile Himalayan regions.
5. **Safety Guidelines:** Form guidelines for safety measures in underground works and regular checks/review of safety standards at the district/State level technical committee.
6. **Geological Cross-Section Analysis:** The geological cross-section reveals the intersection of three joint sets at 250m from the Silkyara portal, indicating a potential risk of wedge formation and roof collapse.
7. **Presence of Rock Bolts:** During the site visit, the presence of rock bolts was observed. These bolts reinforce and stabilize the rock mass, contributing to overall tunnel safety.
8. **Absence of Subsidence or Movements:** Notably, there were no indications of subsidence or movements at the top of the collapsed section, suggesting that the collapse might be localized.
9. **Detailed Geotechnical and Geophysical Investigation:** The Design Project Report (DPR) lacks detailed geotechnical and geophysical investigations. Future projects should prioritize comprehensive site studies to minimize unforeseen geological surprises.

10. **Comprehensive Geological Surveys:** Conducting thorough geological surveys before initiating tunnel projects is critical. This includes assessing rock formations, seismic activity, and potential risks to ensure that tunnels are designed to withstand the geological challenges of the region.
11. **Real-Time Instrumental Monitoring:** A critical gap is a lack of real-time instrumental monitoring for deformation and stress measurements. Implementing a continuous monitoring system can provide early warnings and enhance overall safety.
12. **Analysis of Instrumentation Data:** Utilizing data from installed instruments, such as multi-head extensometers, load cells, and strain gauges, can provide insights into squeezing rates and deviations from expected outcomes.
13. **Manual Monitoring vs. Real-Time Monitoring:** Manual monitoring, conducted periodically, may not provide timely insights into evolving situations. Shifting towards real-time monitoring can offer proactive responses to dynamic conditions within the Tunnel.
14. **Real-Time Warning System:** Installing a real-time warning system with Wi-Fi-enabled data transmission for continuous tunnel deformation monitoring is recommended. This system can serve as an early warning mechanism for potential risks. These days, various advanced techniques are available for real-time monitoring.
15. **Implementation of an Alarm System:** Incorporating an alarm system for evacuation is essential to ensure the safety of workers in the event of a collapse.
16. **Evaluation of Previous Collapse Measures:** Assessing measures taken after the previous collapse incident is essential for learning and improving safety protocols.
17. **Identification of Collapse Causes:** Determining the cause of the collapse is paramount for implementing preventive measures in future tunnel constructions.
18. **Consideration of Collapse Scenarios during Construction:** Evaluating collapse scenarios during construction phases is crucial for pre-emptive planning and risk mitigation.
19. **Evacuation Plan Provision:** Implementing an evacuation plan, such as installing concrete Hume pipes, is essential to facilitate quick evacuation in the event of a collapse tragedy.
20. **Adherence to Construction Standards:** Strict adherence to construction standards and the use of high-quality materials are imperative. Robust quality control

measures during the construction phase can significantly reduce the risk of structural failures.

21. **Prescribed Rate of Tunnel Excavation:** Adhering to the prescribed rate of tunnel excavation is vital to maintaining stability and preventing unforeseen ground deformations.
22. **No Compromise with Safety:** Safety should never be compromised to meet the completion targets. Prioritizing safety measures is paramount in tunnel construction projects. Hence, a detailed Silkyara-Barkot road tunnel safety audit is essential.
23. **Seismic Design Considerations:** Given the seismic activity in the Himalayan region, tunnels must be designed with seismic considerations in mind. Implementing state-of-the-art seismic design practices can enhance the resilience of tunnels to earthquakes.
24. **Geological Surprises and Regular Inspection:** Recognizing the possibility of geological surprises, design engineers should conduct regular inspections to identify deviations and implement corrective measures.
25. **Investigation of tunneling Sequence:** Investigating the tunneling sequence and time gaps between excavation, primary support installation, and final lining completion is crucial for understanding ground deformation dynamics.
26. **Exploration of Critical Geological Features:** The number of boreholes during the DPR stage appears insufficient. Conducting more exploratory boreholes and geophysical investigations can identify critical geological features and minimize risks during construction.
27. **Regular Monitoring and Maintenance:** Establishing a comprehensive system for monitoring the structural health of tunnels post-construction is crucial. Regular inspections, maintenance, and timely repairs can prevent minor issues from escalating into significant structural problems.
28. **Public Awareness and Preparedness:** Increasing public awareness about the risks associated with tunnel construction in the Himalayas is essential. This includes educating local communities about safety measures, evacuation procedures, and the importance of adhering to guidelines during construction.
29. **Specialized Rescue teams:** Specialized Rescue training in case of tunnel collapse to the personnel of Army/NDRF/ITBP/SDRF/Police.
30. **Compliance with labor laws:** Ensure proper compliance with labor laws/welfare at the work site.

Addressing the challenges associated with Tunnel collapses in the Indian Himalayas requires a comprehensive approach that involves improved planning, construction practices, and ongoing maintenance. The proposed recommendations aim to address the gaps identified in the Silkyara tunnel project, enhance safety measures, and inform future tunnel constructions in challenging geological conditions.

Annexure "A" Silkyara Tunnel Site Photographs

In Figure 1, ample security measures have been implemented at the entrance gate of the tunnel, ensuring a robust presence to safeguard the area.

Figure 2 illustrates a prompt and coordinated response from various departments at the site.

Figure 3 illustrates the Help Desk and USDMA desk designed to provide prompt support and facilitate coordination.

Figure 4 depicts the Silkyara Site Control Room established by DDMA Uttarkashi.

In Figure 5, the images of the upper portion of the tunnel provide a visual representation, showcasing the total length of the tunnel at 4550.501 meters.

The figure 6, displays an aerial view captured by a drone, offering an overview of the surrounding area.

Figure 7 illustrates the conditions within the tunnel on December 14, 2023.

Figure 8 shows the Horizontal Auger Machine arriving at the tunnel site and strategizing for establishment.

Figure 9 Planning is underway for the removal of debris, and the procedure is being explained.

In Figure 10, dated December 14, 2023, the Auger Machine Blade has been positioned to facilitate horizontal drillings, marking a significant step in the operational process.

Figure 11 captures the commencement of the Augur Machine's operation, signalling the initiation of its functional activity.

Figure 12 captures the commencement of the Augur Machine's operation, signalling the initiation of its functional activity.

In Figure 13, the initial pipe has been connected and seamlessly inserted, marking a pivotal stage in the bindings process.

In Figure 14, a successful communication link has been established with individuals who were trapped, this operation was signifying a crucial achievement in the rescue operation.

Figure 15 depicts the provision of food supply facilitated by the use of packaged bottles.

In Figure 16, the process involves transferring packed food bottles from one end to the trapped end, illustrating a systematic procedure for delivering sustenance to the affected area.

Figure 17 portrays the deployment of an ambulance at the site location, ready to stand by and respond promptly to any updates or emergent situations.

In Figure 18, the site is portrayed with a red-coloured circle highlighting a subtle water seepage from the ground. This minor concern was addressed promptly at that specific moment.

Figure 19 illustrates the final phase of manual mining, providing a visual representation of the mining activities carried out manually in the concluding stage.

Figure 20, The occurrence of a metallic obstruction is depicted during the process of horizontal drilling. This visual illustrates a hindrance in the drilling operation caused by a metallic object, highlighting the challenges and considerations involved in the drilling process.

In Figure 21, The image showcases the health facilities available at the site for the well-being of those affected. the medical team is prepared, and beds have been arranged to accommodate all individuals who were trapped.

Figure 22 depicts The Honourable Chief Minister, UK, conducting press conferences. In this image, the Chief Minister is graciously addressing the media, providing valuable information and updates.

Figure 23 The esteemed Chief Minister of Uttarakhand, accompanied by a medical professional.

In figure 24, The respected Chief Minister of Uttarakhand is engaged in a comprehensive assessment of the overall management.

In Figure 25, the esteemed Chief Minister of Uttarakhand is shown communicating with a trapped individual, providing encouragement to persevere and maintain mental resilience during challenging circumstances.

In Figure 26, an additional plan is concurrently in progress, demonstrating simultaneous operations. This visual showcases the execution of multiple plans concurrently to achieve efficient and coordinated work.

Figure 27 displays an individual arriving from inside the collapsed Silkyara Tunnel.

Figure 28 captures a scene of hope and joy for everyone involved in this mission.

In the Figure 29, The esteemed Chief Minister of Uttarakhand and a Central Minister from the Government of India are depicted in a meeting with the rescued individuals.

Annexure "B" Chronology of Rescue Operation in Silkyara Barkot Tunnel Collapse

S.No.	Date	Activities and tasks
1.	12.11.2023	• Around 05:30 AM collapse occurred from Ch. 203 to 260. • 41 personnel trapped inside tunnel. • Excavation of debris started. • Cavity of around 10 m above the crown observed on left side of Tunnel.
2.	13.11.2023	• On night 12-13 November options for evacuation adopted. • Excavation of lose muck • Pushing of 800/900 dia MS pipe with help of Hydraulic Jack/ Auger machine. • 4 inch existing water pipeline activated, oxygen and dry fruit pumping started as immediate life sustaining activity. • Hon'ble CM of Uttarakhand along with Chief Secretary visited the site. • Secretary, Disaster Management & team visited site. Directed MD Pey Jal Nigam (Uttarakhand)to organize nearest available Augering Machine.
3.	14.11.2023	• First Auger Machine deployed found incompatible with site requirements. • High power Auger machine (American Auger) had been identified at Delhi and prepared for Airlift.
4.	15.11.2023	• Auger Machine was airlifted from Palam airport in 3xC-130 aircraft, landed at Chinyalisaur (ALG). • Auger Machine was transported to site on trailers for assembly.
5.	16.11.2023	• Auger machine started operations after alignment and pipe welding. • General (Dr.) V K Singh, MoS, RTH& Civil Aviation and Secretary, MoRTH visited the site.
6.	17.11.2023	• 22 m of 900 mm GI pipe pushed in to debris using Auger Machine using 04 Nos of pipes. • Around 02:45 PM sudden loud sound heard around the tunnel

		cavity & 70 mm displacementobserved through 3D Target and Total Station. • Rescue operation temporarily stopped as a safety precautions & observation.
7.	18.11.2023	• Existing lifeline shifted to safe place. • Safe passage provided to food supply point. • Meeting under the chairmanship of Shri Bhaskar Kulbe along with senior officers of PMO, BRO,RVNL, SJVNL, THDC, ONGC and NHIDCL organized. • 5 action plans were formulated.

(A) Rescue Action Plan-1:

Strengthening of tunnel & construction of escape route by NHIDCL

(collapse length -57 m, from Ch. 203 to 260)

S.No	Date	Activities and tasks
8a.	**19.11.2023**	• 41 m of Alternate Lifeline using 150 mm diameter pipes inserted. • Safety passage of 65-meter length (from Ch. 187 m to Ch. 120 m) Consisting of Box Culverts, Hume Pipes and Steelpipe constructed.
9a.	**20.11.2023**	• Completion of Alternate Lifeline pipe completed after insertion of 57 m. • Food inserted inside tunnel.
10a.	**21.11.2023**	• Food inserted inside tunnel through life line-2. • 3 Nos pipes of 6m length each800 mm diameter and 4th pipe of 2.67m inserted in the debris through existing 900 mm diameter pipe.
11a.	**22.11.2023**	• Auger drilling started at 0045 Hrs on 22.11.2023. 8th pipe of 6 m length has been inserted at 1615 hrs. The total length of pipe inserted is 44 meters. • Metallic object (Lattice girder rib) is encountered in the front of the pipe and the pipe could not be insertedfurther. For cutting of the same with gas cutters, the NDRF/SDRF team were mobilized. • Modified communication system with wire connectivity has already been developed by SDRF and through which clear

		communication are being made regularly. • People inside reported that they are safe.
12a	**23.11.2023**	• Pushing of 9th pipe started at 1310 hrs and the pipe reached to additional 1.8meter. • Minor vibration was noted, so Auger was pushed slightly back to re-assess the forceto be applied. • Strengthening of Platform for Auger Machine started and completed.
13a	**24.11.2023**	• Cutting of bent pipes. • Auger reassembly completed and all augers reinserted by 1430 hrs. • Pushing for 10th Pipe (4.7 m length) started at 1625 hrs on 24.11.2023 and a length of 2.2m was inserted up-to 1715 hrs on 24.11.2023 resulting in total inserted length of 46.9 m. • After this obstruction was observed, pushing of pipes had to be stopped.
14a	**25.11.2023**	• Pulling back of Auger was initiated and during the pulling back of the Auger using Auger machine its joint at 15 m length got broken. • Manual cutting of Auger blades for pulling out Auger started. 23.1 m length of Auger has been pulled out. • Erection of False Ribsfrom face of Tunnel towards Tunnel exit on Silkyara Side to protect the Operational area (Chainage 194.50 to Chainage 184.50) – • Erection of Ribs started at 1950 hrs.
15a	**26.11.2023**	• DRDO Team from Hyderabad with Plasma Cutter has arrived at site. Cutting ofAuger with Plasma cutter started at 0400 Hrs • Cutting using Plasma Cutter had to be stopped due to operational difficulties at site and cutting using Gas cutters resumed at 0710 hrs. • Magna rod cutter machine (from ONGC) reached site at 1000 hrs on 26.11.2023. Demonstration of the working of machine was conducted at 1300hrs. The equipment has been kept at standby. • Auger of length up to 44.48 meter pulled out as on 2310 hrs. Erection of Rib for operational area ongoing.

16a	**27.11.2023**	• Auger of length up to 46.90 m pulled out. • Erection of 8 numbers of Ribs for operational area completed. Manual pushing of pipes after completion of cutting of damaged pipes started at 1545 hrs. • 1.9 m of 800 mm pushed using manual excavation and pushing by Auger machine.
17a	**28.11.2023**	• Pushing of 800 mm pipe after manual excavation in a length of 10.19 m completed on 28.11.2023 at 1305 hrs. • **Total pipe of 57.79 m length pushed up to 1600 hrs. Manual excavation continued followed by pushing of pipes and pipe has been inserted successfully up to the desired length at around 1920 hrs and the site has been handed over the NDRF for further rescue operation in assistance with the District Administration.** • All 41 workers are rescued safely.

(B)Rescue Action Plan -2:

1.2-meter diameter vertical drilling of bore hole by SJVNLat Silkyara end

S.No.	Date	Activities and tasks
8b	**20.11.2023**	• BRO completed access road and hand over site to SJVNL by 2200 hrs. on20.11.2023.
9b	**21.11.2023**	• Drilling Machineries arrived at site.
10b	**22.11.2023**	• Drilling Machineries installed at site.
11b	**23.11.2023**	• Additional Drilling Machineries arrived at site. • Platform for launching of drilling machine has been completed. • Marking of drilling point over the tunnel has been finalized at Ch. 305 after discussion with GSI, RVNL & ONGC. • Assembly of machine started at 1915 hrs.on 23.11.2023.
12b	**24.11.2023**	• Assembly of machines ongoing.
13b	**25.11.2023**	• Drilling rig of machine transported from tunnel portal to drilling site.
14b	**26.11.2023**	• Drilling started at 1205 hrs and 28.60 m of vertical drilling completed.
15b	**27.11.2023**	• Vertical drilling up to a cumulative length of 39.23 m completed.
16b	**28.11.2023**	• Vertical drilling up to a cumulative length of 41.96 m completed. • Drilling workstopped at 0945 Hrs.

		• Backfilling started after breakthrough of Plan-1.
17b	**29.11.2023**	• Backfilling continued.
18b	**30.11.2023**	• Backfilling completed at 1700 Hrs.

(c) Rescue Action Plan -3:

(C-I) 170 meter Tunnel construction by RVNL-

S.No.	Date	Activities and tasks
8c-I	**20.11.2023**	• Platform Construction started. Survey of site completed.
9c-I	**21.11.2023**	• Equipment from Nashik reached site at 1500 hrs. •
10c-I	**22.11.2023**	• Remaining equipment from Delhi have also reached at site.
11c-I	**23.11.2023**	• Work kept on hold.
12c-I	**24.11.2023**	• Work kept on hold.
13c-I	**25.11.2023**	• Work kept on hold.
14c-I	**26.11.2023**	• Work restarted. Platform construction under progress.
15c-I	**27.11.2023**	• The work of making of Platform completed. • Reinforcement & concreting workis under progress.
16c-I	**28.11.2023**	• Reinforcement & concreting work is under progress. • Work stopped at 1900 Hrs.

(C-II) Vertical drilling (8") by RVNL at Silkyara end.

S.No.	Date	Activities and tasks
8c-II	**20.11.2023**	• BRO completed access road upto RVNL site 1150 meter.
9c-II	**21.11.2023**	• Electric Connection has been provided to RVNL.
10c-II	**22.11.2023**	• Machine for drilling towed to location by BRO.
11c-II	**23.11.2023**	• Platform under construction.
12c-II	**24.11.2023**	• Platform under construction.
13c-II	**25.11.2023**	• Platform for vertical drilling has been completed.
14c-II	**26.11.2023**	• Vertical drilling started at 0400 hrs. • 72 m of vertical drilling completed. • Vertical drilling stopped due to machine breakdown. Drilling work stopped at 1800 Hrs.
15c-II	**27.11.2023**	• Vertical drilling to resume.

16c-II	**28.11.2023**	• Vertical drilling to resume after breakthrough of Plan-1 the backfillingstarted.
17c-II	**29.11.2023**	• Backfilling completed at 1300 Hrs.

(D)Rescue Action Plan -4:

24" Vertical Drilling at Barkot End by ONGC

S.No.	Date	Activities and tasks
8d	**20.11.2023**	• ONGC drilling team visited the site.
9d	**21.11.2023**	• Preparation of report by ONGC ongoing.
10d	**22.11.2023**	• Air Drilling Rig from Indore has reached site.
11d	**23.11.2023**	• Preparation of report by ONGC ongoing. • Survey has been completed by BRO. • Equipment of BRO placed at starting point and construction of approach track has started.
12d	**24.11.2023**	• 950 meter of access road has been constructed out of 5000 meter.
13d	**25.11.2023**	• ONGC material and men identified for mobilization from Rajahmundry to Silkyara for assisting in cutting the Augur blades and shaft reached Rajahmundry Airport. • Arrangements for their Air lift are in progress.
14d	**26.11.2023**	• All the associated material of Air Hammer Drilling Rig mobilized by ONGC arein standby at Rishikesh. • For assisting in cutting the Auger blades & shaft, ONGC has also arranged a 'Magna cutter' machine. • Team with machinery reached at site at 1000 hrs.
15d	**27.11.2023**	• All the associated material of Air Hammer Drilling Rig mobilized by ONGC arein standby at Rishikesh.
16d	**28.11.2023**	• All the associated material of Air Hammer Drilling Rig mobilized by ONGC arein standby at Rishikesh. Work stopped at 1900 Hrs.

(E)Rescue Action Plan -5:

483 meter tunnel construction by THDC at Barkot end

S.No.	Date	Activities and tasks
8e	**20.11.2023**	• THDC made site assessment & brought their manpower and machinery.

		• Micro tunnelling machines mobilized. • Micro tunnelling (1.5 m x 2.0 m) started. First Blast for Tunnelconducted.
9e	**21.11.2023**	• Second blast was taken first resulted in total 6.4 m drift followed by wire mess laying initial layer of shotcrete applied. • Preparation of second layer of shotcrete is in progress. Pull length is on progress. • Further mucking is in progress.
10e	**22.11.2023**	• 4th blast taken at 1225 Hrs on 22.11.2023 for a pull length of 1.20 meter. • Total executed length of drift is 9.10 meter.
11e	**23.11.2023**	• Shotcreting ongoing. • Drilling for rock bolts and rib erection work in portal area in progress.
12e	**24.11.2023**	• Rib erection for 9.10 meter completed and additional Rib Fabrication work is in progress.
13e	**25.11.2023**	• Rib Fabrication under progress.
14e	**26.11.2023**	• 5th blast taken at 0225 hrs for a pull length of 1.5 m. • Total executed length of drift is 10.6 m. • Fabrication work of 18 numbers of ribs has been completed.
15e	**27.11.2023**	• 6th blast has been taken at 0615 hrs for a pull length of 1.3 m. • Total executed length of drift is 12 meter. • Mucking in progress.
16e	**28.11.2023**	• 7th blast has been taken at 0500 hrs for a pull length of 1.20 m.Total executed length of drift is 13.20 m. • Mucking in progress. • Work stopped at 1100 Hrs.

(F) Alternate Safety passage (Rescue Plan 06)

Creation of side Drift inside Tunnel through the debris at Ch. 203 by Indian Army

S.No.	Date	Activities and tasks
8f	**20.11.2023**	• Design completed.
9f	**21.11.2023**	• Fabrication started by Army welders. • 02 frames have been fabricated

10f	**22.11.2023**	• 08 numbers of frames have been fabricated.
11f	**23.11.2023**	• 10 numbers of frames have been fabricated and 5 numbers are under process.
12f	**24.11.2023**	• 18 numbers of frames have been fabricated.
13f	**25.11.2023**	• 22 numbers of frames have been fabricated.
14f	**26.11.2023**	• Fabrication of frames under progress.
15f	**27.11.2023**	• Fabrication of frames started for new section.
16f	**28.11.2023**	• Fabrication of frames started for new section. • Work stopped at 1900 Hrs.

Annexure “C” Manpower, Resources, Expertise and Technical knowhow deployed as per timeline

Sr. No.	Date	Agency / Department	Machinery/ Equipment's deployed	Manpower deployed	Technical/ Admin personnel deployed	Experts engaged	Total Manpower	Work done
1	12/11/2023	Health	DH/CHC Medical Unit- 9 Bed, Ambulance- 43, Oxygen cylinder-16, Oxycare-50, Medical Instrument, medication, Official Vehicles - 01	Ambulance driver /others- 47	Staff nurses-15, paramedics/lab technicians-26, Pharmacist and X-RAY Technicians-45	Doctors-22	155	Immediately established 8 bedded temporary hospital at the operation site with lifesaving medicines /equipment, frequent teleconsultation with Stranded workers round the clock and at the time of evacuation of stranded workers established another 08 bedded temporary hospital inside the Tunnel. At Community Health Centre (CHC) Chinyalisaur arranged 41 bedded special wards.
2		Police	Search and Rescue Equipment, Search Light, Tent-2, Official Vehicles - 14.	HC-20, CON-45, PAC- 85	SP-1, CO-3, INSP-08, SI-12, ASI-15		189	Responsible for maintaining law & order at Silkyara Tunnel site/different helipads/air strip/hospital and manage crowd control. Establishment of Police Control room, temporary police chowki and check post barrier at operation site.
3		SDRF	Search and Rescue Equipment, Search Light, Inflammable tower (Aska)-2, Pelican light-2 communication system in tunnel, Official Vehicles - 07	33 Search and rescue staff	5 officers	Communication device expert-1	39	Search and rescue work
4		NDRF	Cutter & Search and Rescue Equipment, Search Light, Tower light- 2, Official Vehicles - 8	59 Search and rescue staff	3 officers		62	Search and rescue work

5		ITBP 35BN	Search and Rescue Equipment, Search Light, Official Vehicles - 01	16 Search and rescue staff	1 officer		17	Tunnel Entrance & Crowd Management
6		ITBP 12BN	Rescue Equipment with lifesaving medicine, Ambulance-1, Official Vehicles - 03	55 Search and rescue staff with medical representative	5 officers		60	Tunnel Entrance & Crowd Management
7	12/11/2023	Fire	Fire tender-4, Mini tendre-3, rescue van-1, Search and Rescue and fire safety Equipment, Search Light, Official Vehicles - 01	24 Fire Man			24	Ensure fire safety arrangement at incident site as well as at helipad/air strip and site temporary hospital and CHC Chinyalisaur
8		Police wireless	VHF Static -08, Rescue- 4, VHF H/H -32, Heavy Duty battery-4, Official Vehicles - 01	HC-04	3 officers		7	Wireless communication and function the police control room at site.
9		DDMA/District Administration	Silkyara Site control room, Help Desk, District Emergence control room, walkie-talkie- 30, Inflammable tower (Aska)-8, Pelican light-13, tents-06, bedding, blankets, firewood for night duties, Official Vehicles - 42	113 Staff	17 Officers	Geologist-1	130	Coordinated with experts/specialists from other state/department, state government for helicopter for experts/specialists during the operation. Coordination among different Rescue agencies as well as collect updated progress. Assist requirement by Rescue agencies. Arranged stay, transportation and site visit of expert and VIP's, organized meeting among agencies, experts, and officials. Arranged machinery and other equipment's of all agencies. Establishment Site control room, Help Desk, District Emergency Operations Centre, CCTV control room, video conference system at site. Allotted ID cards for all Agencies. Maintaining

								documents and preparing reports.
10		USDMA/State Govt. officials	USDMA formed a committee and state govt. depute a senior officer for better coordination in different agencies also deputed some officer from other state to help the district administration. Official vehicle -07	14 Staff	10 Officers	Geologist/ Specialist-8	32	At first USDMA formed a committee of 7 expert/scientist of different agencies to inspect incident site for farther rescue action. After that state govt. depute a senior officer for better coordination in different agencies also deputed some officer from other state to help the district administration.
11	12/11/2023	Uttarakhand Peyjal Nigam	steel pipe 900 MM (46Mtr), steel pipe 800 MM (66Mtr), Ogar machine 25 HP, Submersible Pump 5HP, HDPE pipe-800 Mt, Electricity Wire 150 Mt, Truck -3, Official Vehicle -03	3 staff	4 Officer	senior officers-2, Expert-1	10	At first supply 800mm and 900mm steel pipe from Haridwar/ Dehradun/Ghaziabad and installed 25 HP Ogar machine for drilling escape tunnel.
12		DSO UTTARKASHI	Food Arrangement for all search and rescue persons and staff at the incident site, Official Vehicles - 01	10 Staff	11 officers		21	Arrangement of food for the rescue worker experts/specialists as well as for the workers family members. Also responsible for the arrangement of fuel to the vehicle/machines involved during the operation and food for the people involved in the operation.

13		Information Department	Media centre, Photographers & Videographer, Official Vehicles - 01	2 staff	1 officer		3	Responsible for media management, issuing regular press brief. Coordinating with all national and local media representee at operation site as well as other site of incidence.
14		NH, PWD BARKOT	Compressor- 01, Excavator with Breaker- 01, JCB-01, Hydra-01, DG 30 Kva-1, Grader-1, Roller- 1, Dumpers-2, Water Tanker-1, Official Vehicles -02	6 other staff	officers -02		8	Maintain and activated temporary Helipad near the incident site (Syalana) and provided expert engineers at the operation site. Provided local resources/machineries, maintenance of Helipad near Syalana. Helped with heavy machinery movement.
15		UJVNL, Uttarkashi	ROC Drilling Machine-01, Hydra Crane - 01, trailer - 01, 16 rooms UJVNL guest house, Official Vehicles - 07		Executive Engineer-06, Assistant Engineer-05, Junior Engineer-01	Drilling Expert - 03	15	Worked as Nodal officers shift-wise remain present at site as per order of DDMA and coordination among different Rescue agencies as well as collect updated progress. Assist requirement by Rescue agencies. Arranged site visit of drilling expert organized meeting among firm and officials of NHIDCL. Machinery arranged from Lakhwar Multipurpose Project of UJVN Ltd. Also arrange accommodation and logistic for govt. officials, Expert and Specialist at departmental guest house.
16	12/11/2023	PWD, Uttarkashi/ Bhatwari	Excavator- 01, JCB-04, Official Vehicles - 02	12 staff	4 officer		16	Constructed and temporary Helipad near the incident site (Syalana). Worked as Nodal officers shift-wise remain present at site as per order of DDMA and coordination among different Rescue agencies as well as collect updated progress. Assist requirement by Rescue agencies.

17	13/11/2023	UPCL	1- CABLES (2X6MM SQ) = 200 MTRS. 2-CABLES (2X6 SQ MM) =400 MTRS. 3- LED LIGHTS- 06 No. 4- 24 NOS, 70-WATT LED LIGHTS. 5- Aluminium cables (2X6 SQ MM) 800 Mt. 6- Flood light (4X240). 7- Aerial bunch cables (3X35SQ mm)1.5 Km. 8- LED Street light 70 wat 06No. 9- LED tube light-1 No. 10- Transformer -02 (500 and 400 KVA). 11- 11 KV line 300 Mt. 12-Official Vehicle-03	26 Employee/Lineman/Line Coolie	6 officers		32	Provided electricity at the vertical drilling site, approach road and provided electricity to the micro TBM.
18		Telecom Agency (BSNL, JIO, VODAFONE, AIRTEL)	All accessories for Strengthening of Telecommunication and internet connectivity, Official Vehicles - 04	8 technical staff of all agencies	2 officers		10	Establishment and Strengthening of Telecommunication and internet connectivity at incident site, CHC Chinyalisor and intercom facility tunnel site.
19	13/11/2023	Road Transport Department	Arrange 20 No. of trailer and 12 taxi/maxi cab as per demand of district administration and working agencies, Official Vehicles - 02	12 staff	officers -02		14	Arrange 20 No. of trailer and 12 taxi/maxi cab as per demand of district administration and working agencies for transportations of heavy machines and expert/Specialist/VIP form different places at time to time.

20	14/11/2023	Social Welfare Department	Tents and barricades, Official Vehicles - 01	01 staff	officer- 1		2	Arrangement of tents and barricades for media centre and rescue personals in incident site.
21	15/11/2023	CD PWD Chinyalishor	Tipper-1, Official Vehicles – 02	2 staff	officer- 1		3	worked as nodal officer at Chinyalisor air strip and arrange unloading and lodging of heavy machinery and equipment from airstrip to incident site.
22		BRO	BD-50 - 02 No, Excavator - 02 No, Hydra- 02 No, Trailer -03 No, T/LC —08 No, Precast Box Culvert Segment VariousSize - 50 No, Hume pipe 900 mm Dia NP-4- 18 Nos, Diesel-3880 Litre, Official Vehicles -03	GREF Subordinates/CPLs-170	officer- 08		178	Prepared road at drilling site.
23	18/11/2023	District Truism officer/Soil conservation officer/Labour officer (Logistic & family welfare)	Bus -01, Official Vehicles - 03	03 staff	3 officers		6	Nodal for accommodation provided to relative and families of Stranded workers also providing food warm clothing, shoes, and communication facilities etc. Also arrange accommodation and logistic for other govt. officials, health worker and different states nodal officer.

24	20/11/2023	Jal Sansthan Uttarkashi	HDPE pipe 90mm (1500Mtr), HDPE pipe 75mm (500Mtr), HDPE pipe 40mm (500mtr), Electric fug-01No, Union (65mm)-10No, Union (80mm)-20No, GI Reducer (80×65)02No, T&P Dia (80×65)-02No, 36" Wrench-02No, 24" Wrench-02No, Hexe Frame with blad-02No, Washpetion-01 No, Cistern-01No, Welding Machine with Generator-01, Boring Machine for 125 Dia Dia bore, Tanker - 02, Official Vehicles - 02	Labour-30,	Executive Engineer-01, - Assistant Engineer-02, Junior Engineer-03, Fitter-10		46	As per requirement from RVNL, 500 LPM capacity of water supply was created. 2899 m pipeline was laid. 300 LPM by means of Gravity and rest 200 LPM arranged by means of pumping and laid 500m additional pipe line for the same. Arranged Boring machine and Drinking water facility with the help of 02 Nos Tankers continuously at site.
	Total manpower deployment						1079	

Annexure "D" Manpower and Resources deployed at Silkyara, Uttarkashi for Collapse Incident Rescue Operations

S.N.	Department	Item/Particular	Qty/Unit	Days of Deployment
1	**State Disaster Response Force**			
	Manpower	Commandant SDRF alongwith around 56 skilled SDRF personnels		All day
	Resources	Descender	20	--do--
		Jumar	20	--do--
		Pulley Single	10	--do--
		Pulley Tendom	10	--do--
		Pulley Double	10	--do--
		Mitton	60	--do--
		Seat harness	20	--do--
		Full body harness	10	--do--
		Carabineer plane type	30	--do--
		Carabineer screw type	60	--do--
		Tap seiling	20	--do--
		Long seiling	50	--do--
		Short seiling	29	--do--
		Rope	20	--do--
		Knee pad	50	--do--
		Heavy duty gloves	20	--do--
		Stretcher hard with strep	06	--do--
		Folding stretcher	08	--do--
		Multi purpose stretcher	18	--do--
		Go pro camera	10	--do--
		BLC camera	01	--do--
		Come along	02	--do--
		Binocular	04	--do--
		Rolls light double head	06	--do--
		Pelican light	06	--do--
		Dragon light	08	--do--
		Power Ascender	01	--do--
		Rope launcher	01	--do--
		Angle cutter	06	--do--
		RR saw	06	--do--
		Bolt cutter	06	--do--
		Bullet chain saw	04	--do--
		Chain saw	06	--do--
		Sowel	08	--do--
		Pigmoteck	08	--do--
		Gum boot	20	--do--
		Helmet	41	--do--
		Head torch	41	--do--
		Crow bar	08	--do--

		Pri bar	08	--do--
		Chipping hammer	04	--do--
		R P saw	04	--do--
		Wood cutter	04	--do--
		Vehicle	08	--do--
		Aska light	02	--do--
		Search light	10	--do--
		Thermal imaging camera	01	--do--
		Come along	01	--do--
		Fire suit	03	--do--
		Fire helmet	03	--do--
		Fire boot	03	--do--
		Under Water Comminication System (O.T.S.)	01	--do--
2	**Uttarakhand Jal Sansthan, Dehradun**			
	Manpower	Executive Engineer, Assistant Engineer, Junior Engineer & other technical staff		
	Resources	Drinking water pipe line	3300 mtr length with 90mm diameter	
		Water Tanks	02	
3	**Uttarakhand Peyjal Sansadhan Vikas evam Nirman Nigam, Dehradun**			
	Manpower	Er. S.C. Pant, Managing Director, Er. Deepak Malik, Superintendent Engineer, Er. Anju Kaushik, Superintendent Engineer		
	Resources	MSERW pipe	08 nos of 48 mtr length with 900 mm diameter	
		MSERW pipe	11 nos of 66 mtr length with 800 mm diameter	
		Rail	03	
		Pin box	01	
		Auger machine	01	
		Auger 800 dia	04	
		Hydraulic jack	02	
		Hose pipe ½"	10	
		GI pipe	02	
		Round pin	02	
		Square pin	02	
		Power pack	01	
		Starter of auger machine	01	

		Thrust plate	01	
		Tool box	01	
4	**Health Department**			
	Manpower	**Tunnel Site:**		
		Physician	01	All day
		Chest Physician	01	--do--
		Anaesthetist	01	--do--
		Eye Specialist	01	--do--
		Psychiatrist	02	--do--
		Medical Officers	11	--do--
		Pharmacists	09	--do--
		Nursing Officer	01	--do--
		Ward Boys	02	--do--
		Eye Technician	01	--do--
		CHC Chinyalisaur:		
		Physician	03	All day
		Surgeon	02	--do--
		Anaesthetist	01	--do--
		Eye Specialist	01	--do--
		Psychiatrist	02	--do--
		Medical Officers	12	--do--
		Staff Nurses	14	--do--
		Eye Technician	01	--do--
		Lab Technician	03	--do--
		X-Ray Technician	01	--do--
		Pharmacists	07	--do--
		Regular medical staff		--do--
		District Hospital, Uttarkashi		
		Well requipped General Wards, CCU, ICU, Pathology Lab, Blood bank, Ultrasound, CT scan with specialist team 24x7		All day
	Resources	Ambulances (well equipped with trained staff) (33 from '108' and 10 from Health Department) (out of 43- 10 ALS and 33 BLS)	43	--do--
5	**Public Works Department**			
	Manpower	Executive Engineer, Assistant Engineer, Junior Engineer		All day
	Resources	Excavator with breaker		12
		Compressor		08
		Hydra		02
		JCB		02
		DG 30 Kva		11
		Roller		03
		Grader		02
		Dumpers		01
		Water Tanker		17

6	**Police Department**			
	Manpower	SP	01	All day
		Dy SP	03	--do--
		Inspector	11	--do--
		SI	22	--do--
		ASI	16	--do--
		HC	35	--do--
		Const.	90	--do--
		PAC	82	--do--
		Fire	24	--do--
		Local Volunteers/Aapda Mitra	20	--do--
		Technical personnel for Police Control Room	14	--do--
	Resources	Vehicles (for "GREEN CORRIDOR" system-smooth passage of manpower, machinery and VVIPs)	32	--do--
		Two wheelers	10	--do--
		Fire tenders (Fire and Emergencey Services)	03	--do--
		Setting up of Police Chowki (Outpost)		--do--
		Setting up of Police Control Room		--do--
		Setting up of Contingency Helipad at Syalna		--do--