VI INTERNATIONAL TUNNELING FORUM

Bielsko-Biala, 13-15.05.2024

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Silkyara Tunnel Rescue
A Tale of Resilience, Innovation and Survival

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Rescued workers from Uttarkashi tunnel collapse celebrate Diwali after 17 days

DHNS

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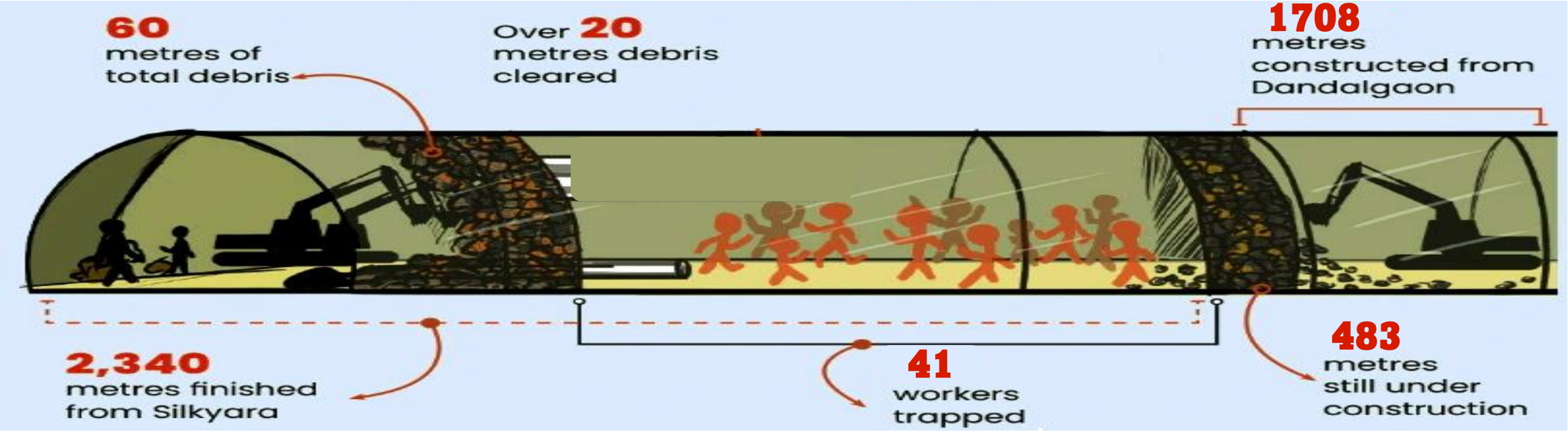
When the entire nation was celebrating the festival of lights on 12th November, everything went dark for 41 workers working at the Uttarkashi tunnel collapse site. Now, after 17 days of misery, the rescued workers and their families burst into celebrations. Take a look!

(Published 29 November 2023, 19:17 IST)

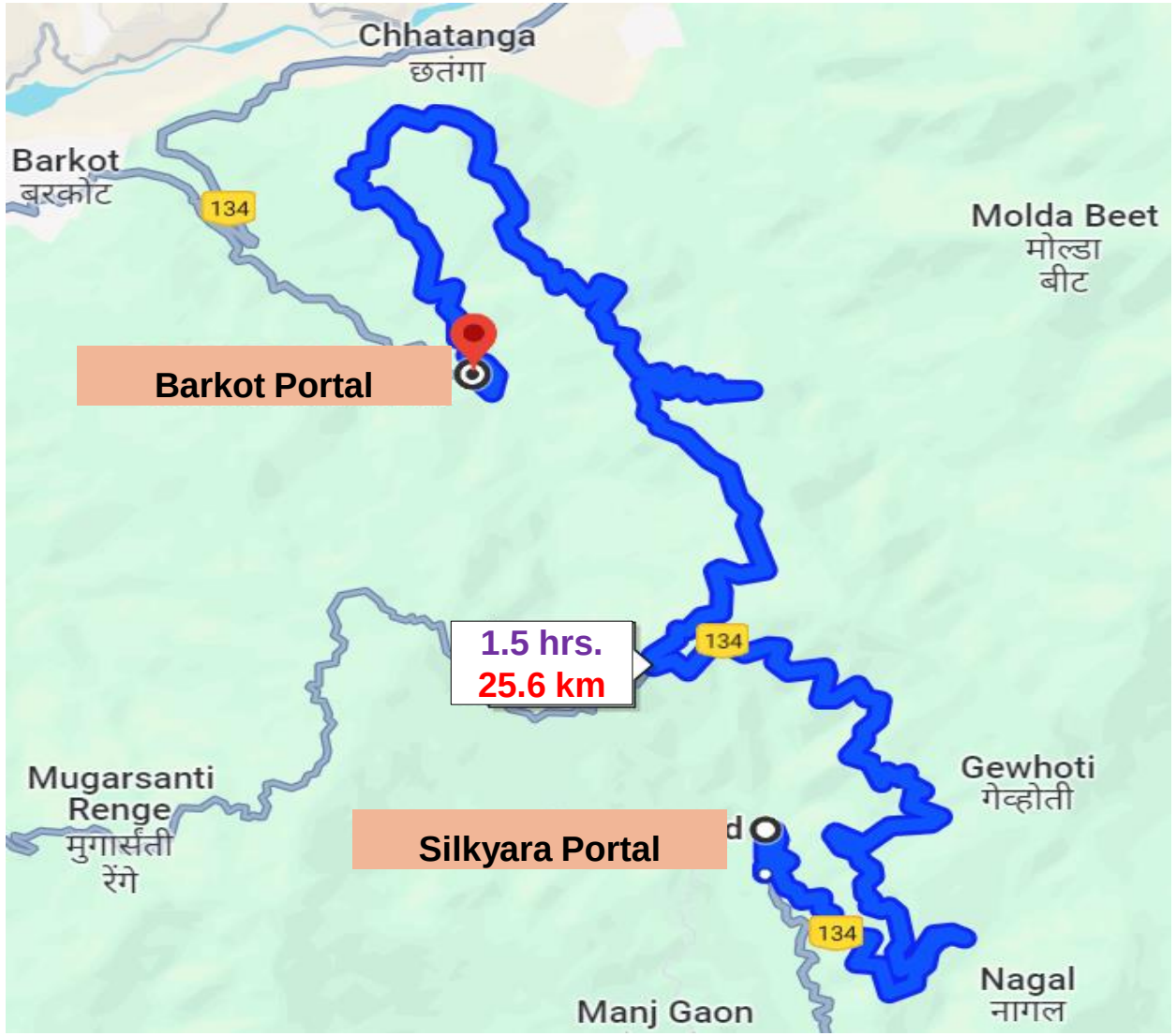
Incident Details

- **Date & Time :**12th November 2023 at 5:30 am,
- **Details**: 60- meter stretch collapsed on the Silkyara side.
- **Concern**: 41 people trapped in the tunnel.
- **Status of entrapped people:** Water supply & electricity available.



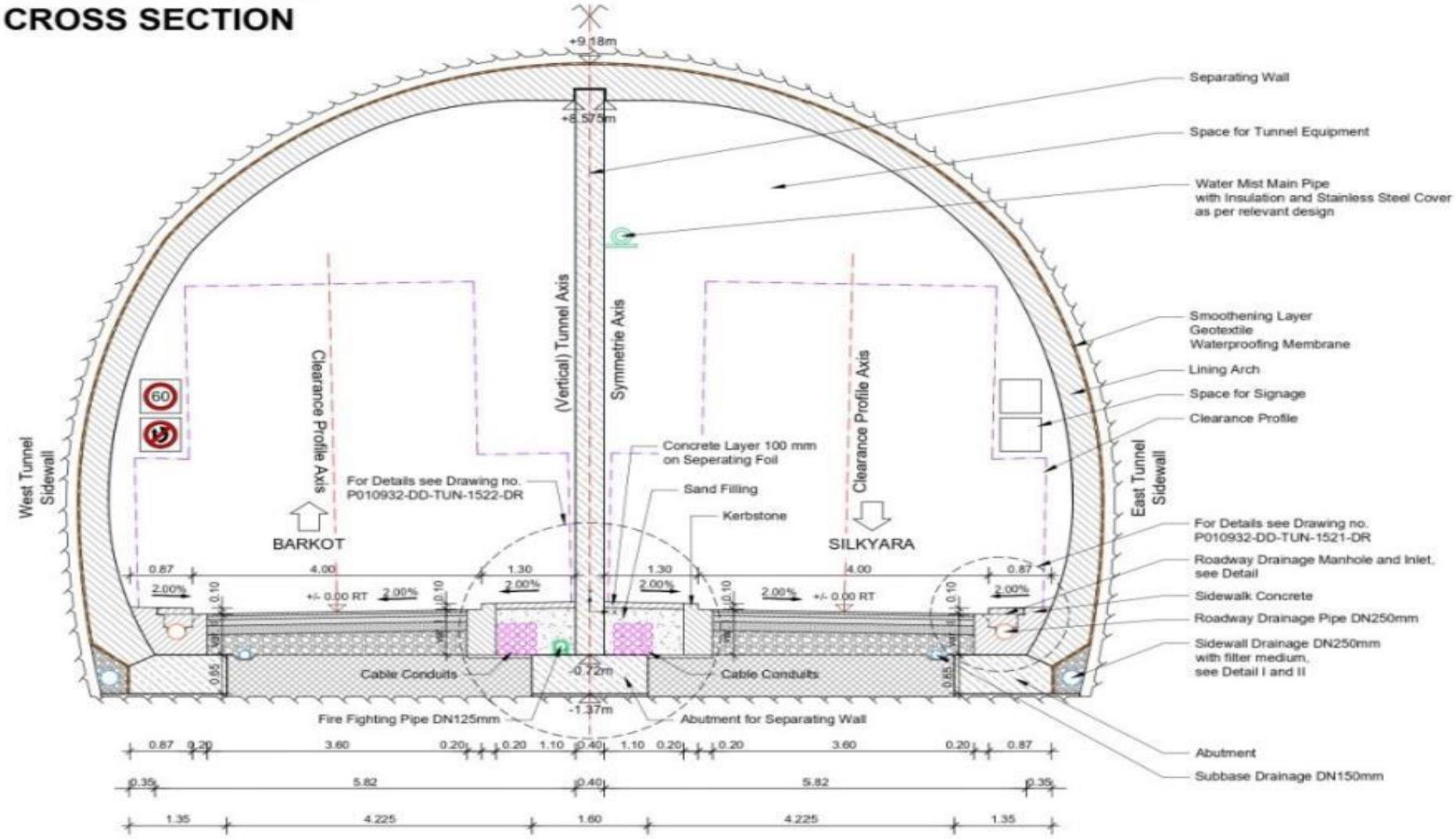
Salient Features of Silkyara Tunnel

Particulars	Details
Project Stretch	2-lane Bi-Directional Silkyara Bend – Barkot Tunnel on NH-134
Project Benefit	Distance 25.6 km reduced to 4.531 km Travel time 1.5 hrs reduced to 10 mins
Project Length	4.86 Km / Tunnel- 4.531 km
Tunnel Configuration	Single tube tunnel with two lanes divided by a vertical partition wall. Excavated diameter 14 m.
Tunnelling Methodology	NATM



Typical Cross Section Silkiyara Tunnel

TUNNEL - WITHOUT INVERT
TYPICAL CROSS SECTION
S 1:50



Geology of the Area

- The tunnel located near major fault line called the Main Central Thrust (MCT), responsible for significant shear stress in the area.
- Additionally, the presence of the Barkot Thrust, another prominent fault line, indicates the likelihood of ‘shear zones’ that could destabilize the tunnel.
- Region witnessed major earthquake in 1991.
- Tunnel alignment runs parallel to the strike orientation of the moderately southwesterly dipping bedrocks; In such tunnels the crown area always remains susceptible to failures;
- Root cause of failure is presence of a shear zone in contact of two moderately weak lithounits

Collapse Explained

- Collapse occurred during reprofiling close to Ch. 270 m from Silkyara end. First collapse at Ch. 240 m. Then at Ch. 250 & 260 m.
- Muck pile spread between Ch 200 to 265 m.
- Face logs: Weak rock consisting of phyllites & meta siltstones. 4 prominent joint sets with clay infillings. Quartz veins of 4-6 cm were found interspersed.
- Lattice girders at 2.5 m c/c distance.
- Stress redistribution during the reprofiling, succeeded with shearing of layers of rock along the joint planes till equilibrium was achieved around good rockmass having more percentage of quartz.

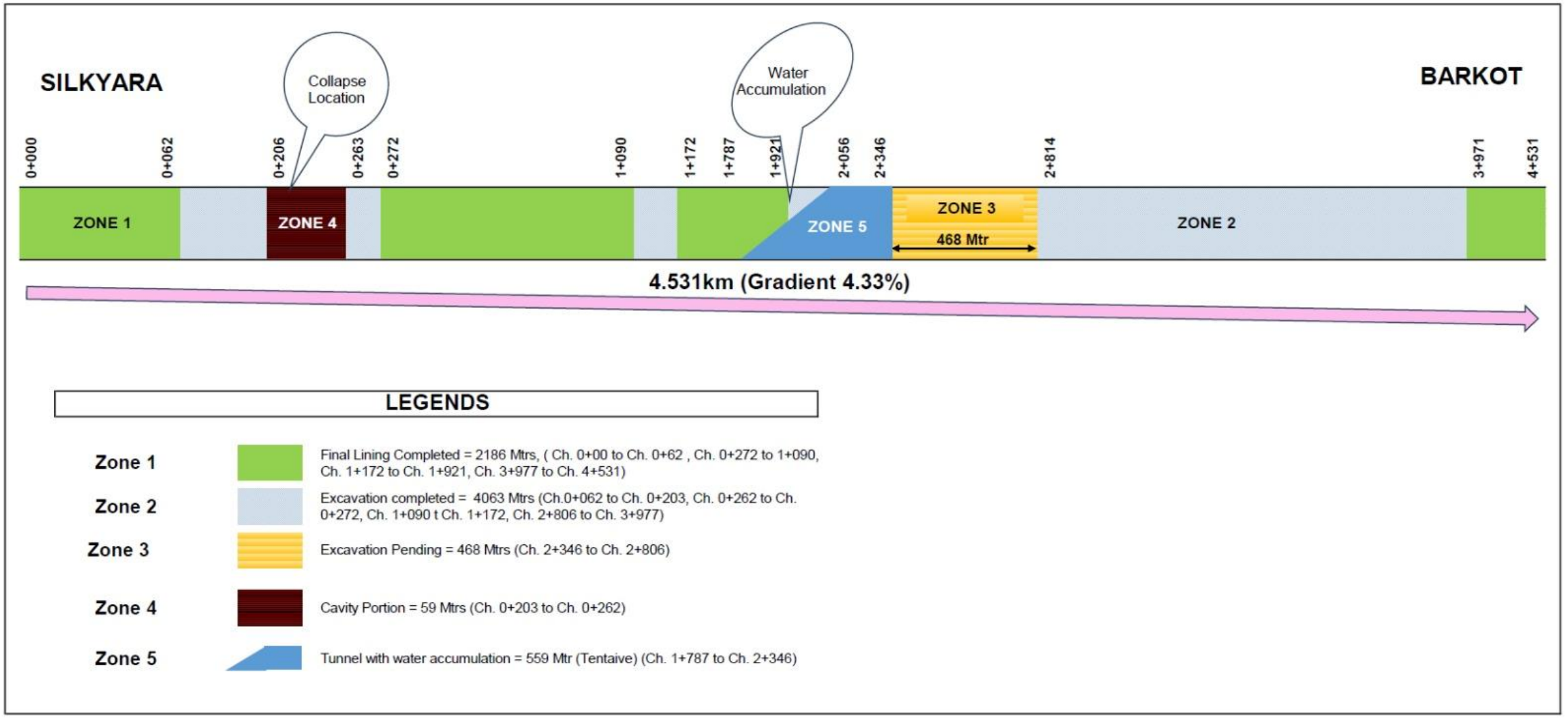
Since Reprofiling was being carried out it is evident that the support erected could not contain the deformations to the desired levels.

Collapse Explained

Physical evidences of collapse b/w Ch. 205 to 260 from Sylkyara end.

1. Highly pulverized fine grade material flown out of the crown: high in silica and silt content which indicates towards metamorphosed siltstones, Phyllites and sills trapped out of dykes.
2. Complete disintegration of supports viz. lattice girders, bolts, pipes etc.
3. No flowing groundwater encountered.
4. Collapse in shear zone in the contact region of meta siltstones and amphibolites.
5. Such large shear zones are natural to occur in the Himalayan geology especially given the seismo-tectonic set up of the region

Zone Wise Schematic Diagram of Silkyara Tunnel



Rescue-Ist Response on 12th November

Chronology of Events

➢ 13th Nov:

- First communication established at 00:05 hrs, safety of workers confirmed.
- Food Items- Dry Fruits, Puffed Rice, Sprouts supplied using compressed air (4-inch MS pipe).
- Decision to push MS pipe **(800mm)** using **Auger Machine.**

➢ 14th Nov:

- Auger machine started MS pipe pushing; observed to be slow.
- Airlift planed for a Powerful Machine
- **High power / sophisticated Auger machine (25 Ton weight)** identified and **airlifted.**
- Horizontal Directional Drilling of Alternate lifeline- 6 inches pipeline planned.

Chronology of Events

➢ 15th Nov:

- Preparation of platform for new Auger machine at the site.
- Drilling of 6 inches diameter lifeline started; attempt failed.

➢ 16th Nov:

- Auger machine started operations after alignment and welding of **900 mm** MS pipe.
- Second lifeline drilling reached up to **41 m.**
- Option for **horizontal boring from side hill and vertical drilling** were explored.

Chronology of Events

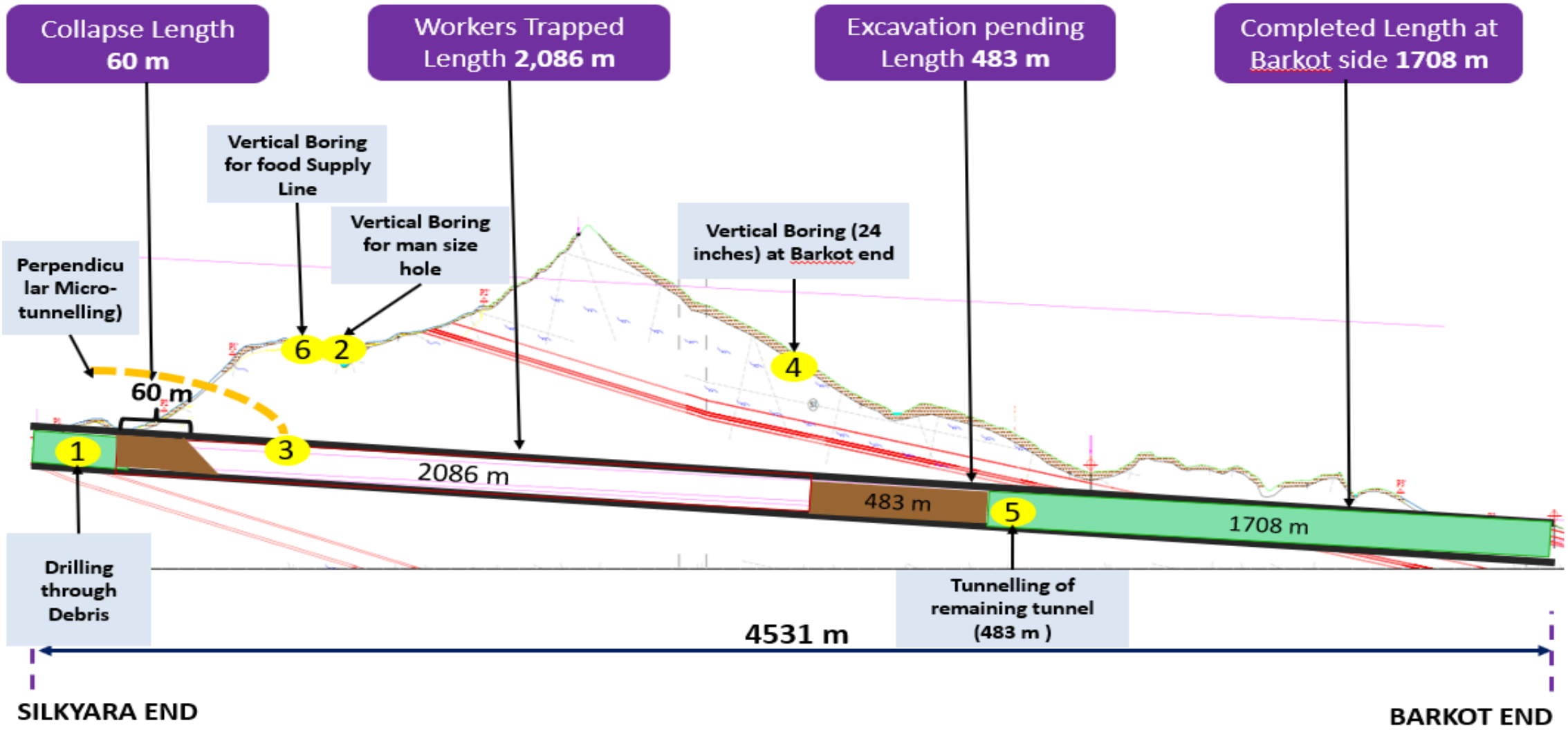
17th Nov:

- Auger Machine encountered obstacles **(Quartzite).**
- **Sudden cranking loud sound heard** in tunnel, 70 mm lateral displacement observed through 3D Target and Total Station.
- **Earthquake of magnitude 3.1 Richter scale in vicinity confirmed**. Rescue operations was **stopped temporarily** as a safety precaution; **Attempt to push Second lifeline failed**.

18th Nov:

- Interaction with the families of stranded workers
- **5** different action plans and the role of various agencies were fixed.
- **Supporting Agencies-** BRO, RVNL, SJVNL, THDC, ONGC, Indian Army, SDRF, NDRF,
- **Assessment of collapsed area by Drone.**
- Third attempt for the lifeline service (6-inch MS pipe) started.

Silkyara Tunnel-Cross Sectional Profile: Action Plans



Chronology of Events

➢ **19th Nov:-**

- **41 m of alternate lifeline** using 6 inches MS pipes completed.
- 95 m Safety passage constructed: Box culverts, hume pipes & 800mm MS pipes used.
- **Action plan-** mobilization of equipment's, machineries & drilling rigs by the agencies.
- **BRO started** the access road. In addition horizontal rescue drift planned.

➢ **20th Nov:**

- Alternate lifeline of 6-inches MS pipe successfully driven.
- Supply of freshly cooked food, essential medicines, utility items etc.
- Proboscope - captured the first video of stranded workers.
- access road completed and site handed over site agencies for drilling of boreholes.
- Geological assessment of terrain for drilling vertical escape route.

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- Proboscope - captured the first video of stranded workers.
- access road completed and site handed over site agencies for drilling of boreholes.
- Geological assessment of terrain for drilling vertical escape route.
- In addition horizontal rescue drift planned in consultation with Indian Army.

Chronology of Events

21st Nov:

- Jacking of 800 mm MS pipes based on telescopic method started.
- Drilling machineries arrived at site.
- Micro tunneling equipment reached. Electrical connection provided for vertical drilling.
- Fabrication for the rescue drift work started.

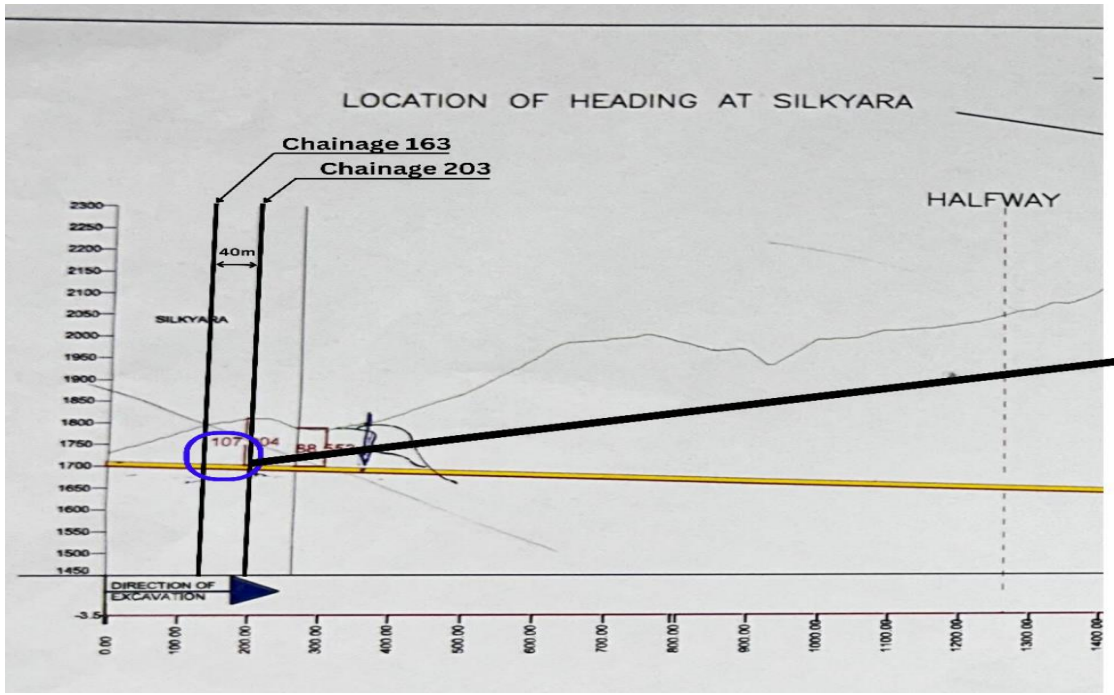
22nd Nov:

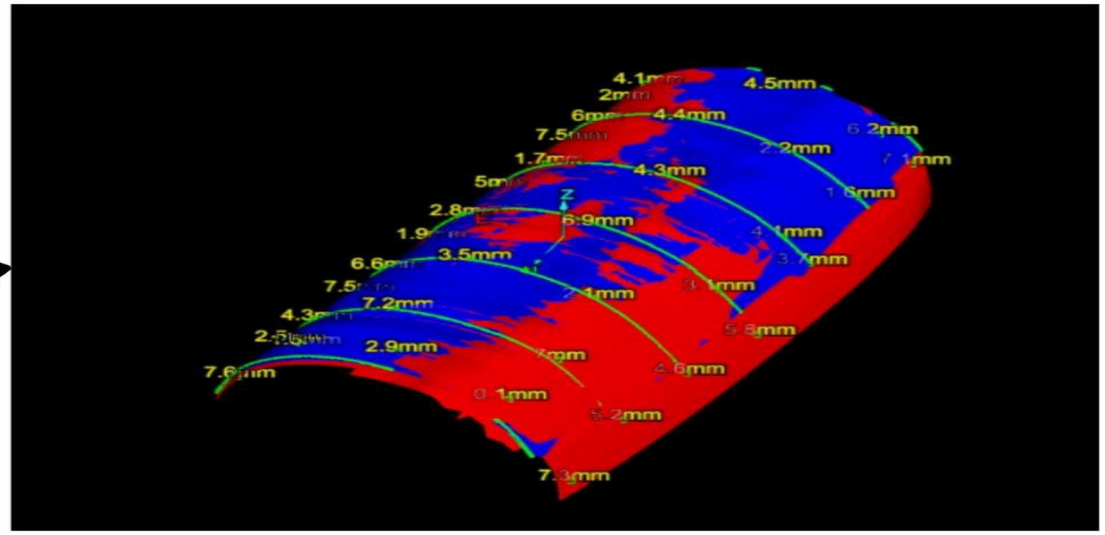
- Metallic obstruction (lattice girder & pipe roofing material) encountered at the length of 44 m.
- Gas cutter team removed the metallic obstructions.
- Alternate communication system with wire connectivity established
- Vertical Drilling machine installed at the site.

Change Detection Report

Using Drone-based LiDAR: Change detection mapping involves superimposing scans taken on various days with the same Ground Control Points (GCP) and simulating the results to calculate the average maximum displacement.

The initial scan performed on 22/11/2023; subsequent scans conducted on 23/11/2023. Average maximum displacement observed is approximately 7mm over a 12-hour interval.





Tunnel Displacement

Sl No:	Section at Chainage	Displacement in B/W Scan 3- 24/11/2023 at 02:00 AM & Scan 4 - 25/11/2023 at 03:00PM	
		Minimum	Maximum
1	203	0.1	17.3
2	193	2.5	18.2
3	183	2.1	18.6
4	173	1.9	16.9
5	163	1.7	17.9
6	153	1.6	18.2
7	143	2	15.9
8	133	0.6	17.2
9	123	1.2	16.2
10	113	1.4	19.1
11	103	0.8	16.3
12	93	0.6	15.3
13	83	1	16.5
14	73	1.5	17.2
15	63	0.7	16.8
16	53	0.3	16.6
17	43	1.2	18.4
18	33	1.8	16.7
19	23	1.7	15.2
20	13	0.5	14.2
21	3	0.8	15.6

LIDAR based 3D Mapping

Chronology of Events

➢ 23rd Nov:

- Pushing of 800mm MS pipe reached 45.8 m.
- Minor vibrations were noted. The Auger was pulled back to re-assess the force.
- Strengthening and grouting of the platform by anchoring, bolting and counterweight.
- GPR study of collapse ahead conducted.

➢ 24th Nov:-

- Cutting of deformed portion of the MS pipes was carried out.
- Auger reassembly completed and reinserted.
- Pushing of pipes stopped due to presence of lattice girder / pipe roofing / shotcrete material.
- GPR report analyzed.

Chronology of Events

- **25th Nov:-**
  - MS pipes pushing stopped due to repeated metallic obstructions. Auger entangled inside pipe.
  - Manual cutting of Auger blades started.
  - 15 days of food stocked
  - Telephone facility provided inside the tunnel
  - Vertical drilling commenced.
  - Plasma Cutter airlifted
- **26th Nov:**
  - Plasma cutter, magna cutter & laser cutting machines arrived on site, however operational difficulties prevented their usage.
  - Cutting of Auger blades using gas cutters was resumed.

Chronology of Events

27th Nov:

- The entire Auger assembly removed; 800 mm MS pipe fully cleared.
- Pushing of pipes along with manual de-mucking started by Rat miners.

28th Nov:

- 59.49 m length MS pipe pushed to get the breakthrough.
- Assisted & confirmed by using Proboscope concurrently.
- Site was handed over to NDRF for evacuation of the stranded workers.
- All the 41 stranded workers were safely **evacuated**.


NRAF
NRIA
TRENCHLE

LIGHT AT THE END OF 17 DAYS: How the rescue was accomplished

After 17 days stuck inside a caved-in tunnel, 41 trapped workers were brought out as 'rat miners' cut through debris in the collapsed Silkyara-Barkot tunnel. The task, which started with excavators and then moved to large drilling machines, ended by having 12 experts crawl inside a tiny hole and cut through the last 12 metres of debris. Here, we take a look at how the final leg of the mission was carried out.

By Amit Bathla

THE FIRST EFFORT: Excavator machine

In the initial hours after the collapse, officials deployed a nearby excavator to try and dig through the debris. While the excavator removed some debris, clearing around 20m, most of the ground gained was lost as more sediments kept dropping down from the ceiling roof.

'Rat miners' to the rescue

As drilling machines were not able to cut through the rocks and metal girders in the debris, officials then deployed their final strategy – sending in 'rat miners' in groups of three. Each group entered the pipe and crawled to the debris. In all 12, rat miners from Uttar Pradesh and Madhya Pradesh were brought in – constituting four alternating teams.

SECOND & THIRD EFFORTS: Drilling through the debris

Once officials realised the excavator would not be able to remove the debris, they requisitioned an auger machine (a machine with a spiral tool can drill holes). The plan was to cut a 800-900mm hole in the debris to evacuate the workers. The first of these machines could only dig 2m before hitting a rock, after which it broke down. A 2nd (and larger) machine was flown in. This was used on-and-off next 10 days, cutting through 45m of the debris.

12 The number of rat miners called in for the job

4X3 They worked in four teams of three. A team was relieved every hour or so by another team so that they could work non-stop, saving time.

Team 1 Team2 Team 3 Team 4

Tools used

- Spades and shovels
- Demolition hammers
- Plasma cutters

0.9 metres/hr
The average speed the workers were able to dig through the debris

THE EVAC PIPE
The diameter of the evacuation passage was around 800-900mm. To get an idea of the width of this passage, it is just as wide as an adult-sized cricket bat held lengthwise

Bringing them out

INSERTING THE EVACUATION PIPE: Once the manual drilling process was complete, 800-900mm wide pipes were pushed into the hole to create a sturdy tunnel wide enough for the trapped workers to be able to crawl out in.

NDRF TEAMS CRAWLS IN: Once that was done, a team of National Disaster Response Force (NDRF) personnel, wearing oxygen kits crawled through the pipe carrying wheel-fitted stretchers, a rope, and oxygen kits.

PARAMEDICS GO INSIDE: Doctors and paramedics were then sent inside, after which they checked the vitals of the trapped workers.

All the workers were then counselled on how to come out of the pipe tunnel.

NDRF's rescue personnel were last ones to come out of the tunnel.

FINAL EVACUATION
A stretcher was tied with ropes on both ends to make a makeshift trolley. One by one, the 41 workers were taken out after being made to lie on the stretcher and pulled out

Graphic: Malay Karmakar and Partho

Backup plans: Other drilling operations

Officials working on the rescue had prepared several other plans for the workers's rescue aside from the site where the cave-in occured.

4 other tunnels were being planned simultaneously to cut into the passage to rescue the workers.

Work on **TWO TUNNELS** had started on the top of the moutain, digging vertically down – the first, going 90m down being dug by SJVNL; and the 2nd, 325m down being made by ONJC

A **THIRD TUNNEL** was being planned aloeg the side by NHIDCL. This one would cut 170m into the mountain from the side to rescue the workers

A **FOURTH PLAN** was to cut 480m through the uncut rocks still left from the tunnel work on the Barkot side

Keeping them fit: A special diet prepared for nutritional needs

Once officials could send in food, Uttarakhand government doctors were posted outside the tunnel to ensure that medical and nutrition needs of the workers were being tended to. Doctors prepared a special diet chart for sustenance of the workers. Since eating heavy solid food immediately after a long period of fasting or deficiency can create gut issues, initially, they were given only light food like khichdi and dalia. Eventually workers will be eased into heavier food items in the coming days, doctors said.

Successful Rescue Operations

A collaborative effort involving the NDRF, SDRF, Army and International resources.
A testament to the dedication & expertise of those involved in saving lives during this challenging situation.

- **Collaboration and Solidarity:**
  1. Seven government agencies including the Prime Minister's Office, Armed Forces and the National Disaster Management Authority (NDMA) worked together.
  2. ITA and other stakeholders also contributed to the rescue efforts.
  3. Miners with experience in tight spaces played a crucial role in the mission's success.

- **Risk Management:**
  1. Risks to both trapped workers and rescue personnel.
  2. By 7th Day, five viable options were explored, including using a high power Auger machine. Unfortunately, the machine broke during drilling.
  3. "Rat-hole mining," expert miners used to clear the last few meters.

Key Lessons Learned

- **Terrain-Specific Approaches:**
  1. Despite differing views on ecological impact, there's consensus on the need for terrain-specific approaches.
  2. Disaster-resilient infrastructure should be designed, considering the unique challenges of each location.
- **Attention to Detail:**
  1. Detailed planning to ensure safety and care of rescued workers.
  2. Leaders should exhibit extraordinary calm and level-headedness when making critical decisions during rescue operations.

- The Silkyara Tunnel collapse serves as a wake-up call, emphasizing the importance of sustainable infrastructure development while preserving the environment. Lessons learned from this distressing ordeal can guide future tunnel rescue missions and infrastructure projects.

Thank You