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# Causes and Learning Outcomes from a Uniquely Sudden Collapse of a under Construction Road Tunnel in Himalayan Geology: A Case Study

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**ABSTRACT**

In tunnel construction planning, three key aspects are extremely important: geological assessments, continuous monitoring and surveying. Present study deals with the various causes and learning outcomes from a uniquely sudden collapse of a under construction road tunnel in the Himalayan geology. On 12 November 2023, a section of the Silkyara Bend-Barkot tunnel, planned to connect National Highway 134 in the Uttarkashi district of Uttarakhand, India, caved in while under construction. The collapse occurred at around 05:30 IST. Based on the available technical data's during the geotechnical investigation before execution, construction periods and also the data taken after the collapse of the above said tunnel a detail investigation has been carried out to find out the various reasons behind the collapse. It was found that there was major deviation encountered between the actual ground encountered and the detail Project report (DPR). This may be one of the reasons for the failed in planning and execution for the primary support finalization as per the rock classification, which may lead to collapse. Along with that there were lacking in adequate ground deformation monitoring equipment which are necessary for deferent ways of study of the ground deformation or for the study of behaviour of strata to take correction measures during excessive or unusual ground appearance that leads to happening of such sudden incident. This paper also deals with the preventive measures to avoid such incident in sensitive Himalayan region in future such as requirement of professional and experienced consultant during the DPR preparation who interprets the strata with not limited data the additional data should be taken to conclude the report. Providing sufficient time for study of the geology and planning. As this collapse triggered during re-profiling of extreme deformed area, so re-profiling works should not be carried out until breakthrough of the tunnel, it is anticipated that shear joint or Fault zone (a complex geological material made up of fragments that are crushed and ground during a dislocation) was running parallelly above the tunnel crown. Re-profiling should be addressed for the restricted length (Maximum 1 mt.) of the tunnel length and complete the cycle before addressing the next length. The safe egress passage for the workers should be available during execution of re-profiling works. Tunnel collapsed triggered during re-profiling the heading area. An additional tunnel monitoring equipment should be installed to have better understanding of behaviour of rocks. Proper record of Daily Review Meeting (DRM) shall be developed by the competent technical personals and the recommendations/observation shall be documented so that necessary actions should be taken before happening of such incidents.

## 1.Introduction

One of the trickiest and most costly engineering and construction undertakings is tunnelling. The hazards and difficulties associated with tunnel construction have grown significantly as a result of growing demands and the focus on cutting down on travel time between any two locations and cost-efficient during operation.

The Himalayas in Asia are among the youngest mountains in the world; instability issues are a recurring issue in this region, and the rock mass of these mountains is generally weak [1, 2, 3, 4, 5]. From the eastern part of Tibet to the northwest part of Pakistan, these mountains cover an area of around 594,000 km2 [6]. Orogeny, the process by which mountains are created as a result of plate movement and collision, is still taking place there [7,8,9]. Significant stresses are commonly produced by active plate tectonics, and these stresses can usually lead to faulting, shearing, and folding of rock masses. Pressures from plate tectonics in weak rocks further exacerbate the region's geological stability, which is also characterised by complex geological conditions due to highly deformable anisotropic rock mass with significant variation in geological parameters even within a small local area. Furthermore, earthquakes worsen the region's stability problems because this area is in an active seismic zone. Most parts of the Himalayas see significant summer seasonal rainfall, which can either enhance surface runoff or sink into the ground, ultimately leading to mass slides or flows. However, these tunnel projects often face very complex geotechnical and construction challenges due to the poor geological setting and potential uncertainties [10]. Among the specific challenges that have been described are tunnel squeezing [11,12,13], rock explosions [14,15], and shearing [12,16]. Disparities between the actual material encountered and the expected rock mass during the preconstruction and planning stage could also cause serious problems and delays [12,17,18]. The bulk of the studies currently available about this region are related to geological exploration of the construction sites [15,19], although there are some in-depth case studies about specific individual projects [12,17,20], including the previously mentioned reports that primarily concentrate on particular engineering problems or challenges.

Present study deals with the various causes and learning outcomes from a uniquely sudden collapse of a under construction road tunnel in the Himalayan geology. On 12 November 2023, a section of the Silkyara Bend–Barkot tunnel, planned to connect National Highway 134 in the Uttarkashi district of Uttarakhand, India, caved in while under construction. The collapse occurred at around 05:30 IST. Based on the available technical data during the geotechnical investigation before execution ,construction periods and also the data taken after the collapse of the above said tunnel a detail investigation has been done to find out the various reasons behind the collapse. The important observations which was found in the geological investigation report (GIR) during preconstruction were overlooked and not addressed during the design phase of the tunnel. This paper also deals with the preventive measure to avoid such incident in sensitive Himalayan region in future.

## 2.Technical causes behind the Incident and preventive measure to avoid such incident in sensitive Himalayan region:

### *2.1. Disparities between the actual material encountered and the expected rock mass during the preconstruction and planning stage: -*

There was major deviation encountered between the actual ground from the DPR. This may be one of the reasons for the failed in planning and execution for the primary support finalization as per the rock classification, which may lead to collapse. As per DPR the rock class in proposed alignment of tunnel as listed below in table-1

Table 1: Rock class as per DPR Vs Actual at the collapsed area

| Tunnel Chainage (m) | As per DPR/Contract Agreement (CA) | | As per Actual Execution | | Remarks |
|---|---|---|---|---|---|
| | RMR Range | Rock Class/Description | RMR Range | Rock Class/Description | |
| 200-270 | 62-72 | II/Good | 21-26 | IV/Poor | Major deviation encountered |

During the DPR a professional and experienced consultant should be engaged to deal with the such types of unexpected problems encounter specially in sensitive zones like Himalayas to avoid any major incidents. DPR professionals should interprets the strata with not limited datas the additional datas should be taken to conclude the report. Providing sufficient time for study of the Geology, planning and different NOCs in forest

### *2.2 Tectonostratigraphic subdivisions was not addressed during the fixing of alignment of tunnel:*

Geological investigation report (GIR) during preconstruction indicates that the tunnel alignment is in highly active zone of the main central thrust (MCT) and influenced by the several thrust, share zones and fault zones these thrust bare are very active in nature and experienced several moderate to low intensity earthquakes at the shallow depth. There were very fine grained phyllite subjected to low grade metamorphism and deformation as indicated by the preferred orientation of the micaceous minerals. The cleavage is marked by the preferred alignment of sericite and chlorite. The chief mineral constituents being, sericite, chlorite and iron oxide. The abundance of clays in the rock might give the rock a low strength. These important observations were overlooked and not addressed during the design phase of the tunnel.

#### *2.2.1 Face stability analysis of tunnels in Phyllite rock masses:*

Tunnel face mapping is a process that involves recording and analysing the geological features of a tunnel's rock face. It's a key part of mining, tunnelling and dam construction projects. An analysis of tunnel face stability generally assumes a single homogeneous rock mass. However, in this tunnel project the rock masses encountered was Phyllite rock.The RMR system independently assesses the uniaxial compressive strength of intact rock, the rock quality designation (RQD), discontinuity characteristics, groundwater conditions, and the relative orientation of discontinuities to the tunnel axis.

A two-dimensional (2D) analytical model for estimating the face stability of a Phyllite rock tunnel was done in the presence of rock mass stratification. The rock layer thickness on tunnel face stability, tunnel diameter, the arrangement sequence of weak and strong rock layers, and the variation in rock layer parameters at different positions was carried out. The results indicate that the thickness of the rock layer, tunnel diameter, and arrangement sequence of weak and strong rock layers significantly affect the tunnel face stability. Variations in the parameters of the lower layer of the tunnel face have a greater effect on tunnel stability than those of the upper layer. Different RMR and support classes used in various hainages are described in the table-2. Engineering Geological Mapping of tunnel face 200 and 225 is shown in fig-1.

Table 2:- Different RMR and Support classes

| Sl. No | Chainage (m) | RMR | Support class |
|---|---|---|---|
| 1 | 200 | 21 | IV |
| 2 | 203 | 26 | IV |
| 3 | 205 | 24 | IV |
| 4 | 207 | 24 | IV |
| 5 | 209 | 24 | IV |
| 6 | 211 | 26 | IV |
| 7 | 213 | 26 | IV |
| 8 | 215 | 23 | IV |
| 9 | 219.5 | 21 | IV |
| 10 | 221 | 21 | IV |
| 11 | 222.5 | 21 | IV |
| 12 | 224 | 23 | IV |
| 13 | 225.5 | 23 | IV |
| 14 | 227.5 | 23 | IV |
| 15 | 230 | 26 | IV |
| 16 | 232.5 | 26 | IV |
| 17 | 235 | 26 | IV |
| 18 | 237 | 26 | IV |
| 19 | 240 | 26 | IV |
| 20 | 242.5 | 23 | IV |
| 21 | 245 | 23 | IV |
| 22 | 247 | 23 | IV |
| 23 | 249 | 23 | IV |
| 24 | 251.5 | 26 | IV |
| 25 | 254 | 26 | IV |

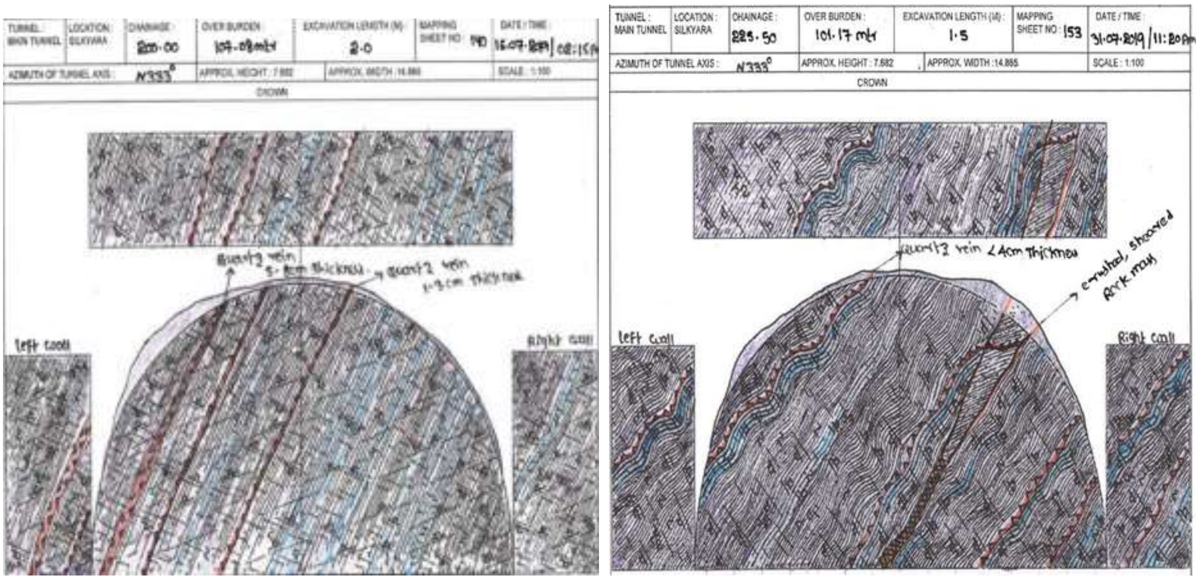


**Fig.1** Engineering Geological Mapping of tunnel face 200 and 225

### *2.3 Lacking in adequate ground deformation monitoring: -*

There were requirement of multiple ground monitoring equipment to be installed for deferent way of study of the ground deformation or behavior of strata to take correction measures during excessive or unusual ground behavior that leads to avoid happening of such sudden incidents.

During study of finding the reasons of collapse it was found that only 3D monitoring datas were available that did not give the complete scenarios of ground behavior. Thus, the complete geotechnical interpretation could not be carried out to tackle or counter the appearing of sudden surprises which are expected to appear in such sensitive Himalayan zone.

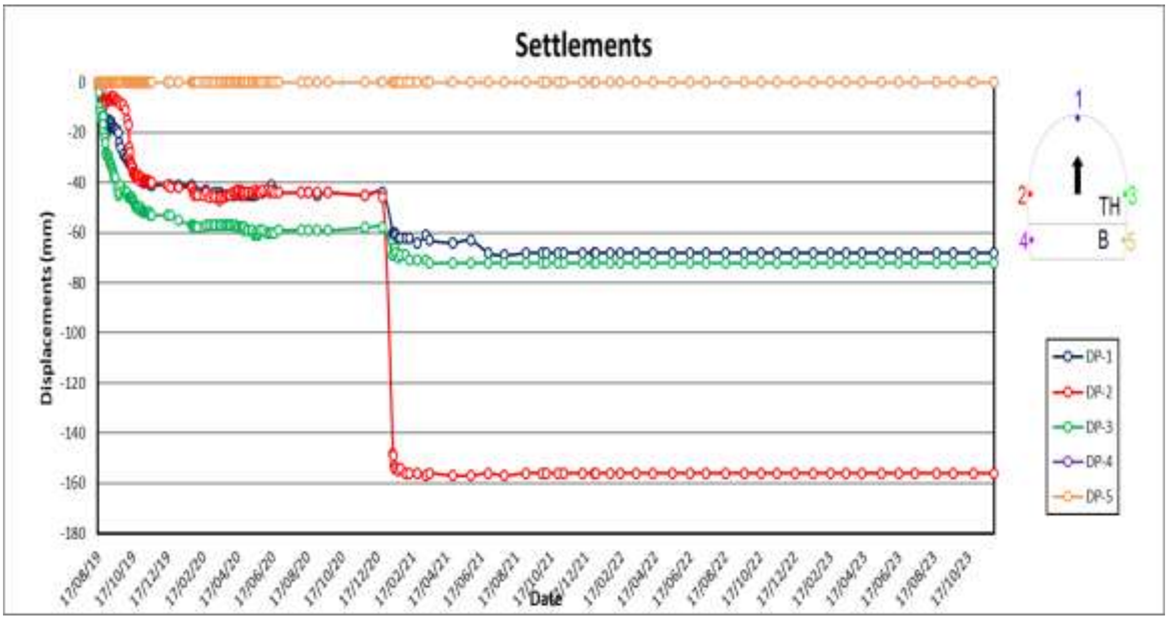


**Fig.2** 3D target settlement graph

Table 3: -Settlements at different locations of cross section of tunnel

| SETTLEMENTS | | | | | | |
|---|---|---|---|---|---|---|
| **SET OF POINTS** | **INDIVIDUAL min** | **INDIVIDUAL max** | **ABSOLUTE min** | **ABSOLUTE max** | **VALUE FOR REPORT** | **AT POINT** |
| DP-1 | -69.000 | 0.000 | | | | |
| DP-2 | -157.000 | 0.000 | | | | |
| DP-3 | -72.000 | 0.000 | -157.000 | 0.000 | **-157.0** | **DP-2** |
| DP-4 | 0.000 | 0.000 | | | | |
| DP-5 | 0.000 | 0.000 | | | | |

Table: -4 status of executed support system

| S.NO | Date of Tunnel Excavation | Chainage | | Pull length (m) | RMR value | Rock Class | Ground Support Class | Support System Installed | Geological Description (Rock Type) |
|---|---|---|---|---|---|---|---|---|---|
| | | From | To | | | | | | |
| **1** | 18.07.2019 | 200 | 203 | 3 | 26 | IV | SC-IV | Rib (ISHB) | Meta siltstone & Chloritic Phyllite |
| **2** | 20.0.7.2019 | 203 | 205 | 2 | 24 | IV | SC-IV | lattice | Meta siltstone & Chloritic Phyllite |
| **3** | 21.07.2019 | 205 | 207 | 2 | 24 | IV | SC-IV | Lattice | Meta siltstone & Chloritic Phyllite |
| **4** | 22.07.2019 | 207 | 209 | 2 | 24 | IV | SC-IV | Lattice | Meta siltstone & Chloritic Phyllite |
| **5** | 23.07.2019 | 209 | 211 | 2 | 26 | IV | SC-IV | Lattice | Meta siltstone & Chloritic Phyllite |
| **6** | 24.07.2019 | 211 | 213 | 2 | 26 | IV | SC-IV | Lattice | Meta siltstone & Chloritic Phyllite |
| **7** | 25.07.2019 | 213 | 215 | 2 | 23 | IV | SC-IV | Lattice | Meta siltstone & Chloritic Phyllite |
| **8** | 26.07.2019 | 215 | 217 | 2 | 21 | IV | SC-IV | Lattice | Meta siltstone & Chloritic Phyllite |
| **9** | 27.07.2019 | 217 | 219.5 | 2.5 | 21 | IV | SC-IV | Lattice | Meta siltstone & Chloritic Phyllite |
| **10** | 28.07.2019 | 219.5 | 221 | 1.5 | 21 | IV | SC-IV | Lattice | Meta siltstone & Chloritic Phyllite |
| **11** | 29.07.2019 | 221 | 222.5 | 1.5 | 21 | IV | SC-IV | Lattice | Meta siltstone & Chloritic Phyllite |
| **12** | 30.07.2019 | 222.5 | 224 | 1.5 | 23 | IV | SC-IV | Lattice | Meta siltstone & Chloritic Phyllite |
| **13** | 31.07.2019 | 224 | 225.5 | 1.5 | 23 | IV | SC-IV | Lattice | Meta siltstone & Chloritic Phyllite |
| **14** | 01.08.2019 | 225.5 | 227.5 | 2 | 23 | IV | SC-IV | Lattice | Meta siltstone & Chloritic Phyllite |
| **15** | 02.08.2019 | 227.5 | 230 | 2.5 | 26 | IV | SC-IV | Lattice | Meta siltstone & Chloritic Phyllite |
| **16** | 03.08.2019 | 230 | 232.5 | 2.5 | 26 | IV | SC-IV | Lattice | Meta siltstone & Chloritic Phyllite |
| **17** | 04.08.2019 | 232.5 | 235 | 2.5 | 26 | IV | SC-IV | Lattice | Meta siltstone & Chloritic Phyllite |
| **18** | 05.08.2019 | 235 | 237.5 | 2.5 | 26 | IV | SC-IV | Lattice | Meta siltstone & Chloritic Phyllite |
| **19** | 06.08.2019 | 237.5 | 240 | 2.5 | 26 | IV | SC-IV | Lattice | Meta siltstone & Chloritic Phyllite |
| **20** | 07.08.2019 | 240 | 242.5 | 2.5 | 23 | IV | SC-IV | Lattice | Meta siltstone & Chloritic Phyllite |

***2.4 Temporary supports were not fixed during tunnel excavation.***

There was no temporary invert executed in the poor reck mass encountered. Closures of inverts/rings were not executed that leads to continue the excessive unusual deformations resulting the instability of excavated ground and leads to collapse of that portion. Immediate temporary inverts/rings closures are a prime importance because rings closures are the most critical structures of the modified horse shoes tunnel that providing the overall stability to the excavated tunnel specially in the Himalayan geology were very weak formations are encountered.

## 3. Conclusion:

1. The remedial measures would have been executed through multi-drift system in three drifts. The design and methodology have to be developed before execution.
2. As gradient of tunnel is opposite to the collapsed portion of the tunnel, accumulated seepage water to be pumped out immediately.
3. As this collapse triggered during re-profiling of extreme deformed area, so re-profiling works should not be carried out until breakthrough of the tunnel.
4. An additional tunnel monitoring equipment should be installed to have better understanding of behavior of rocks.
5. Proper record of Daily Review Meeting (DRM) shall be developed by the competent technical personals and the recommendations/observation shall be documented.
6. Safe egress passage for the workers should be available during execution of re-profiling works.
7. Tunnel collapsed triggered during re-profiling the Heading area, it is anticipated that shear joint or Fault zone (a complex geological material made up of fragments that are crushed and ground during a dislocation) was running parallelly above the tunnel crown.
8. Re-profiling should be addressed for the restricted length (Maximum 1 mt.) of the tunnel length and complete the cycle before addressing the next length.

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