RESEARCH WORK CARRIED OUT IN CSIR-CENTRAL INSTITUTE OF MINING AND FUELS RESEARCH, DHANBAD, INDIA

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1. INTRODUCTION

The Roorkee Regional Research Centre of CSIR-Central Institute of Mining and Fuel Research (CIMFR) Dhanbad has been carrying out research work in various areas of design and construction of tunnels and underground space. Broadly, the research areas include estimation of rock mass behaviour, rock excavation, support design and monitoring etc.

CSIR-CIMFR Roorkee Centre has taken up many projects in past 35-40 years, including the challenging tunnelling projects of national importance through fragile rocks of Himalaya and other parts of India. These projects have helped in developing the approach to estimate the ground conditions likely to be encountered during the tunnel construction including the squeezing ground condition, tunnelling through mixed rock masses having different uniaxial compressive strength, estimation of support pressure, evaluation of supports using the tunnel monitoring and improving the state-of-the-art of tunnel design and safe rock excavation technology. In addition to this, CSIR-CIMFR Roorkee Centre has also contributed in the state-of-the-art in the fracture toughness of rocks under sub-zero temperature and physico-mechanical properties of rocks at high temperatures. To highlight the research work, some of projects are briefly discussed in the following paragraphs.

2. RESEARCH WORK

2.1 Study of Fracture Toughness of Rocks at Sub-zero Temperature

Developed indigenous facility for rock testing at sub-zero temperature upto -70^{o}C and studied fracture toughness of seven rocks viz dolerite, basalt, sandstone, limestone. Dolomite, quartz-mica schist and quartzitic-calc-biotite schist at sub-zero temperatures upto -50^{o}C using International Society for Rock Mechanics (ISRM) suggested Cracked Chevron Notched Brazilian Disc (CCNBD) method (Figs.1-3). The study was carried out in connection with effect of movement of military vehicles on rock slopes in Alaska region for Cold Region Research Laboratory (CRREL), USA. The study reveals that fracture toughness (K_{IC}) values increases with decrease in temperature for all the tested rocks and this values increases at faster rate for the high moisture content rocks except schists (Dwivedi et al., 2000).

The research work has been published in Indian and international journals.

Fig.1 (a) - Laboratory testing of rocks at sub-zero temperature

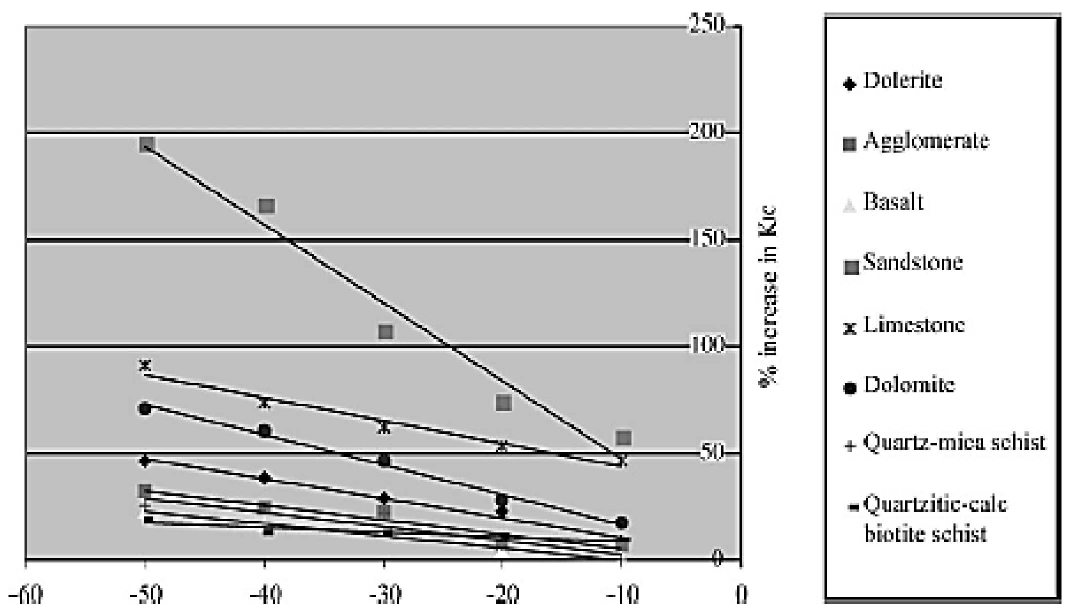

Fig.1 (b) – Percentage increase in K_{IC}-values of rocks with temperature

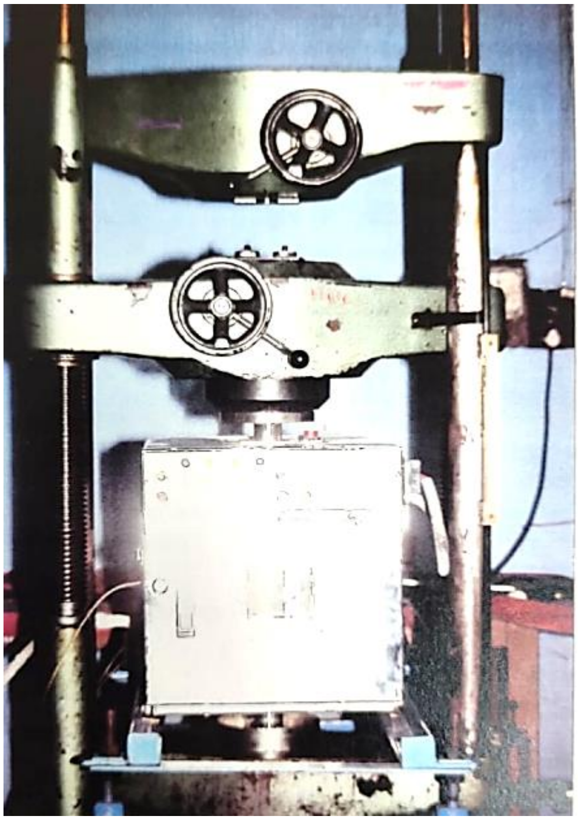

Fig.2 - Close view of environmental chamber for cooling the rock specimens for testing

Fig.3 - 𝓍 - shaped fracture pattern

2.2 High Temperature Testing of Rocks for Geological Nuclear Waste Repositories

Development of nuclear power is a very important source of energy to fill the demand-supply gap of energy because one day or another, the limited hydrocarbon resources will exhaust, which contribute more than 85% of energy demand in India. The principal technical disadvantage of nuclear power is that it produces high-level radioactive waste (HLW). Although the level of radioactivity of the waste decays over time, it remains dangerous for such a long period that it must be isolated from the living environment, or biosphere, until it has decayed to levels that pose no significant risk to health. Initial attention focused on isolation of the two most energetic radioisotopes, strontium (90Sr), and cesium (137Cs). Both of these isotopes have half-lives of approximately 30 years, and the required period of isolation should be of the order of 300–600 years. Placing the waste in suitable underground rock formations is one of the early options proposed as a way to remove the radioactive waste from the biosphere. Since moving groundwater is the primary pathway by which radio-nuclides can transport from the underground to the biosphere, rock types and geological conditions where groundwater flow is very slow (e.g., very low permeability) should be considered for construction of a repository.

Continuous radiation produces heat and high temperature affects the properties of rock. Therefore, the study of thermal behaviour of rock becomes indispensable for designing an underground space, where surrounding rock mass is subjected to high temperature. The highest temperature of surrounding rock mass due to radiation of heat by HLW is expected to be 160^{o}C. In view of this, BARC Mumbai entrusted CSIR-CIMFR to study various thermo-mechanical properties of Indian granites and charnockites at high temperatures in the range of 30-160^{o}C, keeping in view the highest temperature expected in underground nuclear waste repositories.

Studied physico-mechanical properties (porosity, permeability, coefficient of thermal expansion, uniaxial compressive strength, and indirect Brazilian tensile strength) of granite and charnockite rocks at high temperatures in the range, 30^{o}C-200^{o}C.The study was carried out in view of looking for a potential rock to store high-level nuclear waste.

CIMFR designed and developed an indigenous environmental chamber for heating rock specimens before testing. The heating chamber is fitted under the UTM to test the rock specimen at desried temperature without bringing out the specimen from the chamber for the testing. Also a dummy rock specimen has been prepared to ensure that the core of the core has achieved the desired testing temperature. Thermo-mechanical properties of granites were studied to determine Young's modulus, uniaxial compressive strength, tensile strength, Poisson's ratio, coefficient of linear thermal expansion, creep behaviour and the development of micro-cracks on heating using scanning electron microscope (SEM), whereas porosity, permeability, P-wave velocity and micro-cracks' behaviour were tested at high temperatures for charnockites (Dwivedi et al. 2008 and Lokajicek et al., 2012). The study is has helped in providing important data used for the design of underground repository for high-level nuclear waste (HLW).

The study of thermal behaviour of micro-cracks of Charnokite by SEM analysis at different high temperature levels in the range, 30^{o}C – 160^{o}C, revealed that width of preexisting micro-cracks increase with rise in temperature leading to increase in porosity and permeability of the rock (Dwivedi et al., 2018). Further, this behaviour of micro-cracks has been supported by the acoustic emission, porosity, permeability and ultrasonic tests conducted at desired temperature levels. Permeability of rock is an important parameter to be considered when going for designing an underground HLW repository because rock with high permeability provides a preferential pathway allowing radionuclides to travel directly from the repository to the biosphere.

Permeability (K_g) of Charnokite rock was determined using nitrogen (N_2) gas. Kg-values were observed to be increased with increase in temperature up to the highest tested temperature, 160^{o}C. These values increased from 265% to 324% at 160^{o}C in comparison of the values at 30^{o}C (room temperature). No practical change was observed at 65^{o}C. Porosity was also observed to be increased with increase in temperature from 100^{o}C onwards up to 160^{o}C. P-wave velocity (V_p) decreased with increase in temperature from 100^{o}C onwards up to the highest tested temperature, 200^{o}C. No practical change in V_p-values was observed at 65^{o}C. In addition to this, V_p-values measured in the axial direction of the rock sample were observed to be higher in comparison of lateral direction. Thermal conductivity was found to be decreasing with increase in temperature like V_p-values. Figures 4 to 9 show the testing apparatus including the environmental chamber and the rock specimens. Figure 10 depicts variation in micro-cracks' width with temperature increase.

The research work has been published in Indian and international journals.

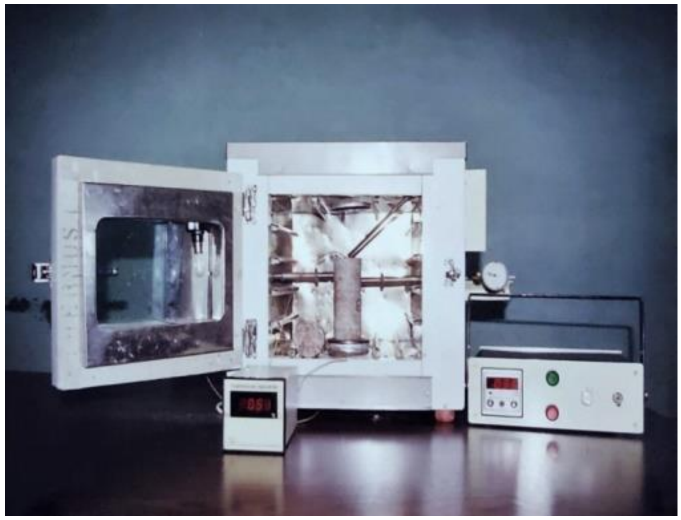

Fig.4 - Inside view of Environmental chamber for heating during rock testing

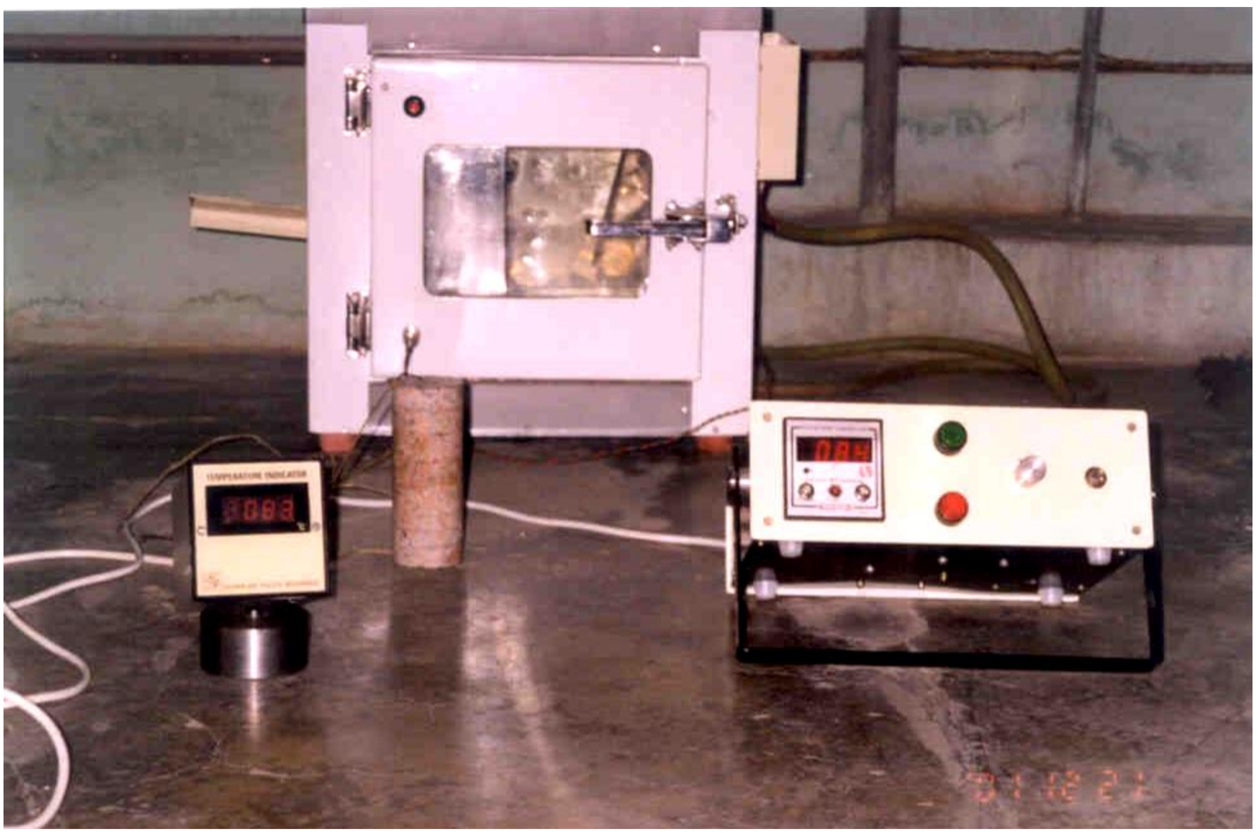

Fig.5 - Environmental chamber with digital display for controlled heating of rock specimens

Fig.6 - Acoustic emission testing of hot charnockite specimen

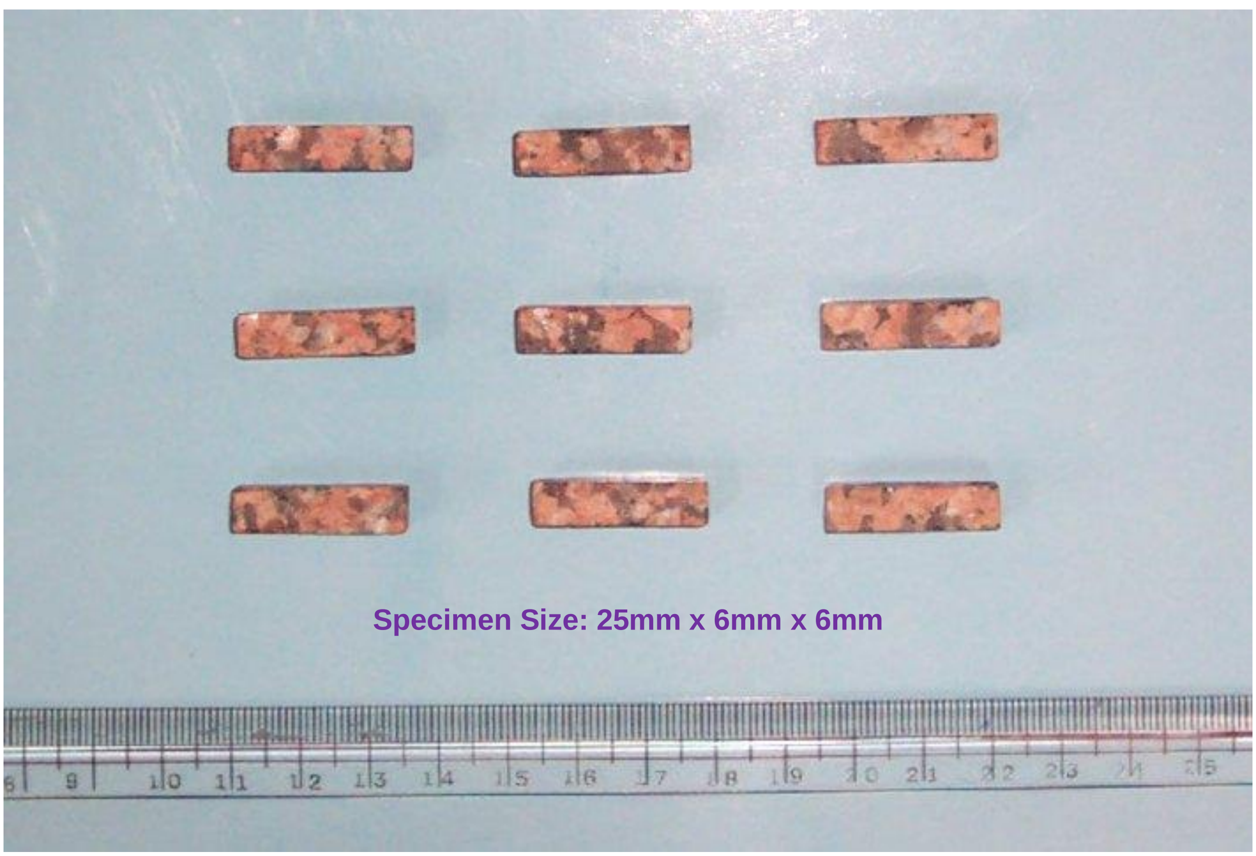

Fig.7 - Granite specimens for testing coefficient of linear thermal expansion

Fig. 8 - Granite specimens ready for testing under high temperature

Fig. 9 - Fracture pattern in charnockite rock specimens after UCS test

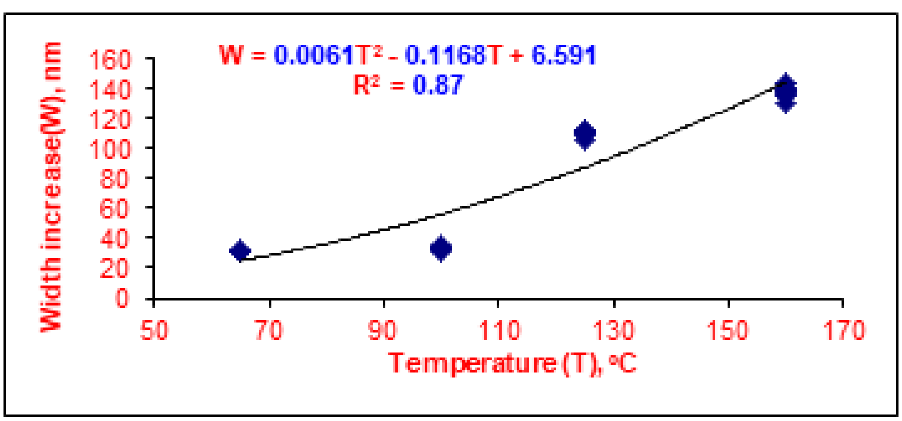

Fig. 10 – Variation in width of pre-existing micro-cracks with rise in temperature

The research work has been published in Indian and international journals.

2.3 Strategic Underground Facility for Storage of Crude Oil

Indian Strategic Petroleum Reserves Ltd. (ISPRL) has created a strategic underground facility to store 1.33 million metric tonnes crude oil in Visakhapatnam, India. For this strategic facility of national importance, expertize provided by CIMFR are (i) identification of critical slope, (ii) stability analysis of critical slope sections cut in soil and rock mass of very poor to fair quality along the 2.0 km long boundary wall, entry road and permanent surface facilities of cavern project site near Visakhapatnam sea port; (iii) Design of optimum support to make the critical slopes stable; (iv) Design of support system for the casing guide frame of shaft for holding the crude and other pipe lines entering in the cavern from the shaft; and (v) Design optimization of spillway. The facility has the largest underground storage compartments in the country and is expected to give a boost to the nation's energy security. It was inaugurated on 10 Feb. 2019 by Hon’ble Prime Minister Shri Narendra Modi.

Fig.11 - Slope stabilization above rock cavern in Vishakhapatnam

Fig.12 - Inside view of rock cavern for oil storage in Vishakhapatnam

2.4 Design of Tunnels in Challenging Geotechnical Conditions

Himalayan region is highly tectonically active and give rise to excessive horizontal in situ stresses, which usually pose problems in tunnelling with regard to support system. Most of the tunnels constructed in hydro projects for water transportation, roadway and railway projects for passenger and goods transportation are located in Himalayan region only. Due to this fact, the Himalaya has been laboratory for tunnel engineers and geologist from all around the world. CSIR-CIMFR studied effect of tunnel diameter on the support pressure and tunnel deformation especially in squeezing ground behaviour and hence developed empirical correlations to predict ground behaviour, tunnel deformation and support pressures for squeezing and rock burst conditions, which have been great challenges while construction of tunnels (Dwivedi et al., 2013, 2014 and 2019). The correlations are being used as handy tools in tunnelling sites to get benefitted in terms of framing the strategy (excavation methods, type and quantum of tunnel supports, shape of tunnel cross-section) to tackle the foreseen geological challenges.

CIMFR has contributed by technical expertise to various tunnelling projects of national importance. Some of these are-

2.4.1 Highway Tunnels

(i) <u>Dr. Shyama Prasad Mukherjee Tunnel (Formerly known as Chenani-Nashri Tunnel)</u>

It is 9.2km long bidirectional highway tunnel constructed between villages Chenani (Udhampur) and Nashri (Ramban) on national highway (NH-44) near Patnitop in the state of Jammu and Kashmir. It was inaugurated by Hon'ble Prime Minister Shri Narendra Modi on 2 April 2017. ***He said to the Kashmiri Youths during his inaugural address:*** *"Kashmiri youths have two options: tourism and terrorism. For 40 years terrorism gave you nothing but bloodshed, deaths and destruction. Had you chosen tourism, the benefits today would have been phenomenal." And "Want to tell the Kashmiri youth what actually is the power of stones. On one side, youth in*

Kashmir throwing stone. On other side, people giving their blood and sweat, cutting rocks for Kashmir's development."

Fig.13 - Highway blocked due to snowfall near Patnitop in winter season

Fig.14 - Main tunnel view during excavation

Fig.15 - Hon’ble Prime Minister during inauguration of Dr. Shyama Prasad Mukherjee tunnel

CSIR-CIMFR provided very vital technical and R&D support for construction of the tunnels. CIMFR was associated in this project throughout the construction period for continuous evaluation and design of tunnel supports and monitoring of the tunnel construction quality. During construction of this tunnel, many challenges such as encountering mixed geological formation comprising bands of siltstone, claystone, sandstone and intermixed of all these three rocks under high in situ stresses due to high rock cover upto 1km and tectonic activity of the region leading to squeezing ground conditions observed during construction. CSIR-CIMFR provided timely techno-economical practical solutions for trouble shooting such construction challenges by modifying the support systems with the help of continuous load-deformation behaviour analysis (Dwivedi and Goel, 2017). Developed empirical correlations as handy tools for site personnel to predict ground behaviour, tunnel deformation and support pressure especially for squeezing ground conditions (Dwivedi et al., 2013, 2014, 2014 a).

Socioeconomic benefits from this high way tunnel are as follows:

- The tunnels provide safe, all-weather road protected from snowfall, avalanches, and landslides for civilian and army movement.
- Travel route of 41km along the previous highway route between Chenani and Nashri villages has been reduced to 9.0 km through the route of newly constructed tunnel.
- Travel time has been reduced from 2 hour to approximately 11min.
- The tunnel saves fuel of about Rs. 27lac every day and carbon emission is also minimized. Thus, it contributes to Government’s campaign “Clean India and Healthy India”.
- Lithology of the ground surface is intact and hence, it also preserves the ecological balance all along the tunnel route.
- It will boost economy and tourism in J&K.

(ii) Z-Morh Tunnel (6.5km)

The tunnel is located on strategically important NH-1 in Jammu and Kashmir state, India at altitude of about 2637m between Rezan and Shetkari villages in Srinagar (J&K). The tunnel will provide safe, all-weather road protected from snowfall, avalanches and landslides to civilians and Indian army in reaching Kargil. The existing highway is usually closed in winter for about 6 month due to high snowfall. Thus, the tunnel when constructed will save revenue which is spent yearly on maintenance of open road getting damaged every year in winter and rainy season. In addition to this, it will also increase traffic in Ladakh region and hence will help in development of the region and at the same time easy access of terrorists will also be restricted.

CSIR-CIMFR was entrusted by ITNL (IL&FS) for (i) monitoring of support adequacy and redesign of supports, if found inadequate, (ii) guiding and revising the instrumentation scheme to face the challenges of difficult geology encountered during excavation of tunnel, and (iii) design of east tunnel portal in highly challenging rock mass comprised of riverine material (Dwivedi et al. 2019a).

Fig.16 - Western portals of tunnels

Fig.17 - Eastern portal of main tunnel

Fig.18 Eastern portals of Z-Morh tunnels

2.4.2 Railway Tunnels

(i) ***<u>Rishikesh-Karnprayag Rail Link Tunnels for Char Dham Yatra</u>***

This rail link between Rishikesh and Karnprayag will be quite helpful for the pilgrims of Char Dham Yatra in Uttarakhand state, India. The rail route will be 125km long, which involves 17 tunnels measuring total length of 105km. It includes a 15.1km long tunnel between Devprayag and Lachmoli, which would be one of the longest tunnels in country. The project is of national strategic importance and it is being tracked on the Central Government's PRAGATI (Pro Active Governance and Timely Implementation) portal. On completion, it will improve connectivity to the Char Dham pilgrimages of Yamunotri, Gangotri, Badrinath and Kedarnath in the Garhwal region of the Himalayas.

All the rail tunnels of the Rishikesh-Karnprayag rail link project are being constructed in difficult geology of tectonically active Himalayan region. The tunnel-adits are traversed through challenging geology comprising of highly weathered rock mass and watery strata. RVNL entrusted CSIR-CIMFR to provide its expertise with regard to design evaluation, stability analysis during construction of Tunnel Adits 1, 2 3, 6, 6A and 7 for main rail tunnel Nos. T-1, T-2, T-3, T-11, T-12 and T-13 respectively. CIMFR also provided techno feasible solutions for seepage control in Adit-2, chimney control in Adit-3 and portal design for Adit-7, which had to be constructed in a dump material comprised of small sized rock fragments below highway. With the technical advice of CSIR-CIMFR support comprising of reinforced rib of shotcrete (RRS) has been used for the first time in the country in Adit 2.

The socio-economic benefits of these tunnels on the rail route would be as follows:

- Construction of tunnels on this rail route will shorten the travel time between Rishikesh and Karnprayag from 7 hour to 2 hour.
- The Char Dham pilgrims will be highly facilitated by this rail link with number of tunnels as this will provide all-weather shorter-route avoiding landslides in hills especially in rainy season.
- Twelve new railway stations will be constructed which will provide new dimensions of employment to the youth of Uttarakhand.
- Due to shortening of the route, consumption of fuel will also be reduced hence reduced carbon emission also to contribute in Government’s campaign “Clean India and Healthy India”.

Fig.19 - Shotcrete application in Adit 3

Fig.20 Blasthole drilling operation in Adit 3

(ii) ***Bhanupali-Bilaspur-Beri (BBB) Rail Tunnels (Punjab-Himachal Pradesh)***

This is the first broad gauge rail line project started in Himachal Pradesh. This rail link will connect Bhanupali (Punjab) via Bilaspur (Himachal Pradesh) to Beri (Himachal Pradesh). Total length of the rail track between Bhanupali and Beri would be 108.1km. There are many tunnels proposed in the route. Northern railway has given the project work to RVNL and RVNL has entrusted CSIR-CMFR for its expertise in construction of 16 main tunnel Nos. T1-T16 and one escape tunnel. CIMFR is providing its expertise with regard to evaluation of support design prior to start of the construction, stability analysis to check adequacy of supports, optimize support design for tunnels and cut slopes at portals during construction of the tunnels.

Fig.21 - Slope cutting preparation to start construction of T1 tunnel of BBB railway project


Fig.22 - Excavated heading of a tunnel in BBB railway project


Fig.23 - Face geology of tunnel 1 in BBB railway project

Socioeconomic benefits of the rail link would be as follows:

- On completion of 108.1km long rail link with tunnels, the travel time of the route shall be reduced from 3 hour 10 in to 40 minute only.
- Due to shortening of the route consumption of fuel will also be reduced hence carbon

emission shall also be reduced to help in making clean India and healthy India.

- Central government has a plan to connect it to Leh via Kullu-Manali. ***Thus, the rail link would be of national importance from strategic point of view***.
- The rail route will reduce traffic on the respective highway leading to less maintenance expenditure on highway and less number of possible accidents due to landslides near hills.
- Tourists going to Nainadevi, Kullu and Manali will reach faster using the rail link. Education centre Mandi would also be reached quickly by this route.
- New railway stations on the new rail route will not only facilitate the travellers but also will develop new opportunity of employment to the youths of the concerned region.
- Transportation of product of the cement factory situated near Beri will be easier by the new rail route.

2.5 Safe Rock Excavation

CSIR-CIMFR has been contributing the tunnelling industry by giving its expertise with regard to using the controlled and smooth blasting technique during tunnel excavation. Tunnels are usually located in hills but metro tunnels are constructed below the city ground, where the ground surface has got numerous infrastructure like residential buildings, historical monuments, roads and large crowd open markets etc. These places are highly sensitive with respect to any kind of rock blasting done for tunnel excavation. In such areas, controlled blasting is carried out. CIMFR optimizes blasting parameters to restrict the ground vibrations and air-over pressure within the permissible limits. The Mumbai metro line works was such type of site where blasting was carried out under constrained construction environment due to large number of the housing structures along the alignment. Some of the structures are high-rise and in dilapidated conditions too. The cover along the alignment of the underground works is less than 18 m. Moreover, there are sensitive structures like Wadia ji Atash Behram. Hon’ble Supreme Court of India have also restricted permissible level of the ground vibration to 2.544 mm/s peak particle velocity at the Wadia ji Atash Behram. Due to poor progress of the works, HCC requested CSIR-CIMFR Roorkee to explore and provide technical assistance for use of drill and blast method to expedite the underground excavation works. In light of the above, CSIR-CIMFR Roorkee Research Centre have conducted trial blasts in two adits of Mumbai Metro Line 3, UGC package 02 in order to study the response of rock to the blasting parameters and suggested safe optimized and controlled rock blasting so that the blast induced ground vibrations could restrict within the safe limits.

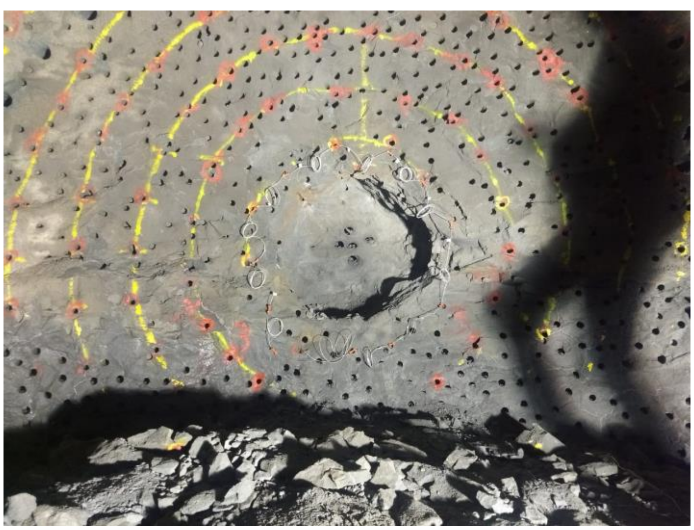

Fig.24 - Drill patterns for controlled blasting in Adit-1 (massive basalts)

Fig.25 - View of excavated inner blast rings during controlled blasting in Adit-1 of Mumbai metro

3. TRAINING AND KNOWLEDGE DISSEMINATION

CSIR-CIMFR has been disseminating knowledge to the executives, site engineers, geologists and other site personnel engaged in tunnelling and other underground constructional activities by organizing short-term training courses and workshops. These training courses not only increase and refine the knowledge of attending site personnel but also develop confidence level in them, which enables them in construction of safe and stable tunnels.

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