Chapter

Ecofriendly Hill Mining by Tunneling Method

Rama Dhar Dwivedi and Abhay Kumar Soni

Abstract

Mostly, hills are mined by 'Strip mining' i.e. removing the hills from top. This conventional approach destroys the landscape and defaces the beauty of the hill. Besides, a large amount of dust generated at source disturbs the villagers and nearby human settlements during the excavation operation or related activities. To eliminate this, and remove the 'out yard dumping of material', except at initial stage i.e. during developmental phase, if tunneling methods of civil construction work is applied, 'the conventional hill mining' can be turned into an eco-friendly hill mining with very little planning efforts. This chapter highlights the abovementioned aspects of 'hill mining' covering overviews about the 'hill mining by tunneling method'. In this technique, the extraction of mineral deposits is done by driving tunnels at the bottom (or other accessible higher level of the hills) and combining it with cross-cuts and adits, to protect the green cover and the serene hill environment. A case study of limestone mining in hilly Meghalaya region of India forms a part of the description where its feasibility exists.

Keywords: hill mining, strip mining, tunneling in hills, mining of minerals in India

1. Introduction

Hills are being mined since long, ever since man discovered the use of metals and valuable stones. The mineral resources (called mineral deposits) do exist both above ground level and below ground level. The hills have been mainly targeted because the winning of minerals above the ground is easier as compared to the mineral deposits found at depth. For instance, a broken hill lode in South Australia, one of the largest lead-zinc lode, ever discovered, is being mined for its mineral content in hills. Similarly, mining in hills is carried out for commercial minerals like iron ore (*Kudremukh, Karnataka*, India); bauxite (*Kollimalai hill deposits of Nilgiris* in Tamil Nadu India); base metal (*Arravallis in Rajasthan*, India); Magnesite of Indian Himalayas; useful stones such as granites, slates, marble, sandstone, etc. Thus, ubiquitous 'hill mining' was existing in the past, present and will continue to remain in future as well, wherever these deposits are made available by nature for mankind.

In the context of 'hill mining', two aspects matter significantly, and they are - 'scientific extraction' and 'environmental protection'. With judicious planning and serious efforts, *the conventional approach* of mineral extraction (mining) in hills can be turned into an eco-friendly hill mining. Fragile/serene hill environment can be protected by adopting 'best practices' as applied in mining.

The characteristic features of hilly topography and the typical conditions encountered in such terrain have to be taken into account for achieving the desired results. Because favorable conditions do exist, a combination and integration of civil and mining engineering knowledge have been done and 'tunneling method' is evolved as an engineering field application. Various key aspects of hill mining covering overviews on the environment are also highlighted and described in the chapter. A selective case record of limestone mining in the Meghalaya state of India forms the part of the description for such type areas, the reason being its feasibility.

Conceptualization of tunneling method, though not new, came into our mind around the la*te* nineties *(≈ 1996 to 1998) when* limestone mining by underground methods was tried in an experimental adit in Himachal Pradesh, India**.** This site was located in the hilly Himalayas and the framed experimentation was found quite effective to protect the sensitive and fragile Himalayan environment [1]. In this way, integration of our knowledge about conventional 'underground method of mining 'and tunnel excavation work, prominent in hydel power projects of Himalaya, have to lead to the development of, *ecofriendly tunneling method*, considering the hill topography (or hill areas) as our concentration point.

2. Hill mining by tunneling method

Mostly, hills are excavated by 'stripping method', which consists of removing the top hill cover and moving downward (chopping down) in steps. When hills are mined for mineral extraction, the methodology of mining is termed as **'Strip Mining'**. This method is a conventional method and the extraction is carried out by construction of berms (or benches) to reach the deposit, and excavating mineral by digging either manually or mechanically. The conventional approach destroys the landscape and defaces beauty of the hill (**Figure 1**). Also, a large amount of dust generated at the source disturbs the surroundings, villagers and nearby human settlements during ongoing excavation operation or related ancillary activities.

Figure 1.
Defacing of hills due to illegal quarrying is a typical sight in many hilly areas (severe environmental impacts to natural hill landforms).

To eliminate and overcome this, 'tunneling methods', as used in civil construction work, maybe the alternative that can be applied.

Tunneling method involves number of tunnels driven either in the country rocks and/or in the ore/mineral formation itself. The size of tunnels is chosen based on the thickness and compressive strength of the orebody and host rocks encountered.

It is well known that the economics of mineral extraction depends on the adopted mining method and its market value. Location, orientation, size and strength of ore deposit are the prime influential parameters to choose a mining method. However, nowadays environmental conditions are forcing the decision-makers to indulge in the activities which are ecofriendly or at least it should not harm the flora and fauna of the landscape. In this context, going underground without disturbing the natural surface features is appreciated for mining the minerals from the ground. In addition to this, the excavated *underground space* is preferred to be re-utilized either as a waste material refill or as a valuable space for miscellaneous purposes, to avoid subsidence at the ground surface above the mined-out area. Thus, rehabilitation of the excavated space is a value addition by public or industry. In such condition, the underground mined out areas need to be well supported so that these can stand for several coming years and thus accrues to the cost of mining.

If the mineral deposit in a hill is found feasible for mining, it shall be mined using 'tunneling method ', which would involve the following steps.

A. Geological and geotechnical investigations for planning

To extract mineral, location, thickness and alignment of mineral/orebody should be known as it influences the preparation of actual excavation plan (mining plan), to be implemented into practice. Overburden or rock cover should be known because it gives an idea about induced stresses around excavation built underground. Here, the size and diameter of the underground opening play an important role in the stability. Further, rock mass properties, information of water condition and physico-mechanical properties of rock mass decide the requirement of support needed for the excavated area (i.e.tunnel walls) for the required life span.

Both, geological and geotechnical investigations help in the planning of mine and execution of various unit operations that lead to the extraction of mineral from the earth. These investigations reveal the following information about the mineral deposit/ore body and their properties.

i. Thickness and alignment:

Thickness indicates the volume of the orebody and determines the economy for mining activity and alignment or orientation is a deciding parameter for mining methodology. It is estimated with the help of core-log details obtained from various boreholes.

ii. Overburden or rock cover above the orebody:

This is the rock cover thickness above the orebody. It helps in the estimation of vertical in-situ stress, if any, at an underground place of workings.

iii. Rock joint properties:

Number and properties of rock joints together with the strength of rock mass helps to know its behavior when subjected to induced stresses during excavation activities below ground. Rock joints present also helps in knowing the water permeability of the strata.

iv.Location of the water table, if present:

Depth of water table provides information about water head to be considered while designing supports for roof or walls of the excavated area. In addition to this, it also gives an idea about the expected quantum of water inside the workings below ground.

v. Physico-mechanical properties:

Physical properties, like permeability (K) and specific gravity (γ) help the support designer in the estimation of the rate of water inrush and value of vertical in-situ stress respectively. Whereas, mechanical properties like Uniaxial compressive strength (σc), modulus of elasticity (E), Poisson's ratio (ν), cohesive strength (c), and angle of internal friction (ϕ) play a vital role in determining deformational behavior of rock mass (country rock and orebody) while excavation goes below ground during actual mining.

B. Preparation of a mining plan.

It includes preparation of geotechnical baseline reports, structural design report and drawings, for the approach roads, excavation sequence of tunnels and cross-cuts, applicable supports and drainage plan. As the reports and drawings are prepared based on geological and geotechnical data explored from the surface, the reports and drawings are revised when actual geology and rock types are encountered i.e. during going underground.

C. Design of tunnels and cross-cuts.

Size of tunnels is decided based on the rock mass quality, thickness of the orebody and rock cover. The rock mass is characterized and its quality is assessed using Barton's Q-system, rock mass rating (RMR) system or geological strength index (GSI) system. Rock mass with RMR value greater than or equal to 80 has high *standup time*. For example, 10 m of unsupported tunnel span can withstand up to about 70 months in a rock mass with RMR of 80 (Q = 55). Due to this reason, tunnel excavated in such quality rock mass does not require any artificial supports except spot bolting. On the other hand, the requirement of supports increases with a decrease in the quality of rock mass. Based on rock quality (Q-value), the quantum of supports required for tunnels of 5 m and 10 m diameter have been listed in **Table 1,** which have been obtained from the Barton's Q-chart as given in **Figure 2** [2].

Excavation support ratio (ESR) is the weightage assigned to the type of structure based on their importance. The more important structure is assigned with a lower value of ESR (**Table 2**). Value of ESR for temporary mining opening has been assigned as 3–5. Average ESR value (3) has been considered for calculation of supports in **Table 1** for the tunnels or cross-cuts, which are temporary and shall be backfilled after mining of the mineral/ore. On the other hand, the tunnels or cross-cuts, which shall be retained as rehabilitated underground space are permanent and have been assigned with ESR value of 1.6.

This is significant to note that an arched crown of the tunnel distributes the induced stresses around the tunnel boundary in a better way. Required supports

Rock quality (Q)	Tunnel span (D) =5 m				Tunnel span (D) =10 m			
	ESR = 1.6		ESR = 4		ESR = 1.6		ESR = 4	
	D/ESR	Supports	D/ESR	Supports	D/ESR	Supports	D/ESR	Supports
0.4	3.125	Nil	1.25	Nil	6.25	L = 2.5 m, S = 1.5 m, Sc = 9 cm	2.5	Nil
1	3.125	Nil	1.25	Nil	6.25	L = 2.5 m, S = 1.7 m, Sc = 8 cm	2.5	Nil
4	3.125	Nil	1.25	Nil	6.25	L = 2.5 m, S = 2.1 m, Sc = 6 cm	2.5	Nil
10	3.125	Nil	1.25	Nil	6.25	L = 2.5 m, S = 2 m	2.5	Nil
40	3.125	Nil	1.25	Nil	6.25	Nil	2.5	Nil
50	3.125	Nil	1.25	Nil	6.25	Nil	2.5	Nil

Notations: ESR-Excavation support ratio; L-Bolt length; S-spacing of bolt length; Sc-Reinforced shotcrete.

Table 1.
Requirement of supports according to rock mass quality and span or diameter of the tunnel.

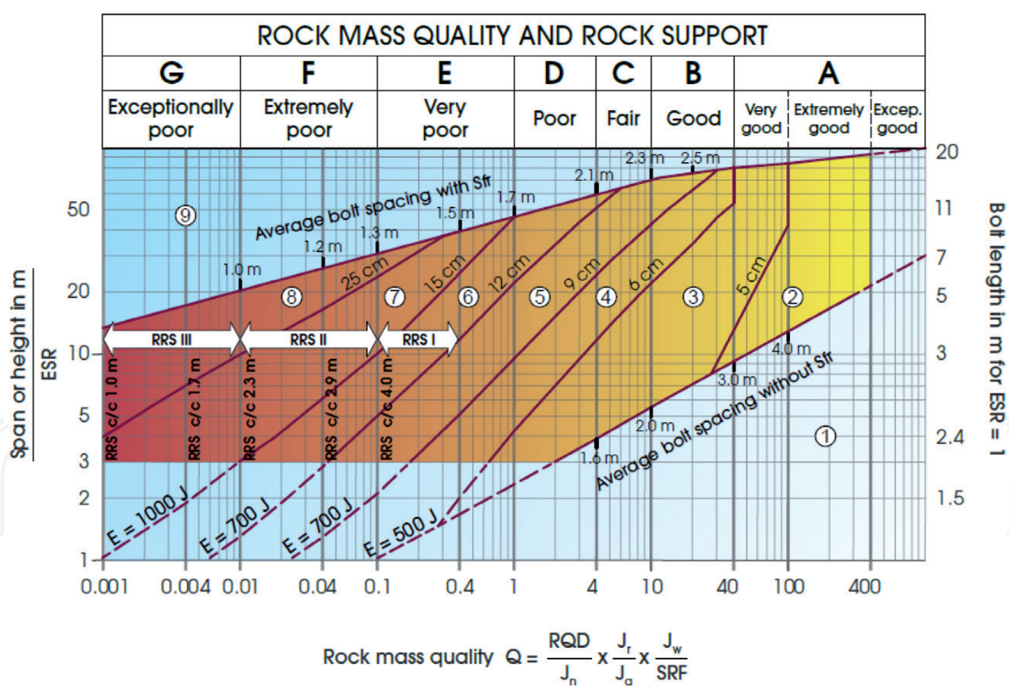

Figure 2.
Tunnel support chart based on Q-system [2].

for tunnels of diameter 5 m and 10 m have been given in **Table 1** for construction in various quality of rock mass with Q-values greater than 0.4. Construction of tunnels in rock mass less than Q-value of 0.4 would attract the large quantum of supports and hence the mining cost may not be feasible for the ores of an average value. For the ores containing the high mineral value (silver, gold, zinc etc.), hill mining using tunnels would be economical even in the rock mass of very poor quality which requires more stiff supports to stabilize the tunnel (s).

Category	Type of structure	ESR
A	Temporary mine openings, etc.	3–5
B	Vertical shafts*: i) circular sections ii) rectangular/square section * Depends on purpose and may be lower than given values.	2.5 2.0
C	Permanent mine openings, water tunnels for hydropower (exclude high-pressure penstocks), water supply tunnels, pilot tunnels, drifts and headings for large openings	1.6
D	Minor road and railway tunnels, surge chambers, access tunnels, sewage tunnels, etc.	1.3
E	Powerhouses, storage rooms, water treatment plants, major road and railway tunnels, civil defense chambers, portals, intersections, etc.	1.0
F	Underground nuclear power stations, railways stations, sports and public facilitates, factories, etc.	0.8
G	Very important caverns and underground openings with a long lifetime,≈ 100 years, or without access for maintenance.	0.5

Table 2.
ESR values assigned to various type of structures [2].

Tunnels or cross-cuts of 5 m diameter are very safe without any additional supports (except some spot bolting) for the suggested range of rock mass quality, i.e. $Q \geq 0.4$ (**Table 1**). Rate of mineral/ore production shall be low using tunnels/cross-cuts of 5 m diameter as compared to 10 m diameter tunnels because of deployment of smaller size machines in the former case. Similarly, mining with large tunnels of 10 m diameter shall also not require any additional supports, if excavation is carried out using controlled blasting technique i.e. causing minimum disturbance to the surrounding rock mass and the mined-out area is temporary and planned to be back-filled. Further, permanent openings of diameter 10 m created in a rock mass with quality index Q = 0.4–4 would need supports in form of 2.5 m long steel rock bolts at the spacing of 1.5–2.1 m with 6-9 cm steel fiber-reinforced shotcrete (SFRS). The same large openings in the rock mass with quality Q = 4–10 would need only rock 2.5 m long rock bolts at a spacing of 2 m as supports, whereas supports would not be required for the permanent 10 m diameter openings in a rock mass with $Q > 10$ (**Table 1**).

In mines, size of underground roadway i.e. roadway height and its dimension, as per the statute, is one point which needs due consideration while planning hill mining by tunneling method. In India, the dimensions of the pillars are regulated by Regulation 111 to 115 of Coal Mines Regulations (CMR), 2017 [4]. The regulation stipulates that the width of galleries shall not exceed 4.8 m and height of galleries shall not exceed 3 m. In this view, it is suggested to design the tunnels with width ≤ 4.8 m and height ≤ 3 m for coal deposits. Tunnels of larger dimensions may be designed for hill mining of non-coal minerals i.e. metallic minerals, which occur in narrow forms. However, smaller dimensions of excavation are always desirable from stability viewpoint because lager dimension gives rise to deformation and attracts requirement of stiffer supports. Thus, the smaller the opening better will be stability. If the value of the ore is high, the extraction by underground means, remain economical even after provision of stiffer support, mine planner can go for a larger dimension of underground openings.

For coal deposits having 30 x 30 m^2 pillar dimension, the strength of pillar lies in the range of 5.4 MPa to 7.4 MPa at various depths. The pillar width shall be according

For coal strength in a laboratory, σ_c = 5.4 MPa				
σ_s (MPa)	**W/h**	**σ_p (MPa)**	**H (m)**	**Factor of safety = (σ_s/ σ_p)**
9.68	3.2	6.08	100	1.59
11.85	4.32	7.61	150	1.56
13.72	5.28	9.17	200	1.50
15.90	6.4	10.55	250	1.51
18.07	7.52	11.91	300	1.52
20.25	8.64	13.27	350	1.53
22.12	9.6	14.70	400	1.50
24.30	10.72	16.05	450	1.51
26.16	11.68	17.45	500	1.50
For coal strength in the laboratory, σ_c = 7.4 MPa				
11.56	2.56	7.13	100	1.62
13.69	3.36	8.83	150	1.55
15.82	4.16	10.35	200	1.53
17.95	4.96	11.81	250	1.52
20.08	5.76	13.23	300	1.52
22.21	6.56	14.62	350	1.52
24.34	7.36	16.01	400	1.52
26.47	8.16	17.38	450	1.52
28.61	8.96	18.75	500	1.53

Note: All notations i.e. W, h, H, σs and σp has the same meaning as explained in Eq. 1 and 2 above.

Table 3.
Width of square shape coal pillars at various depths.

to the values given in **Table 3**. The gallery width and height are 4.8 m and 3 m respectively. Strength of pillar has been determined using the formula suggested by Bieniawski and Van [5] for square-shaped coal pillars (Eq.1).

$$\sigma_s = \sigma_c \left[0.64 + 0.36 \frac{W}{h} \right] \quad (1)$$

where,
σ_s = strength of pillar (MPa).
σ_c = unconfined compressive strength (MPa).
W = width of coal pillar (m).
h = height of pillar (m) or gallery.

Stress on the pillar as shown in **Figure 3**, is computed according to the following Eq.2:

$$\sigma_p = \frac{\gamma H.(W + D)^2}{(W)^2} \quad (2)$$

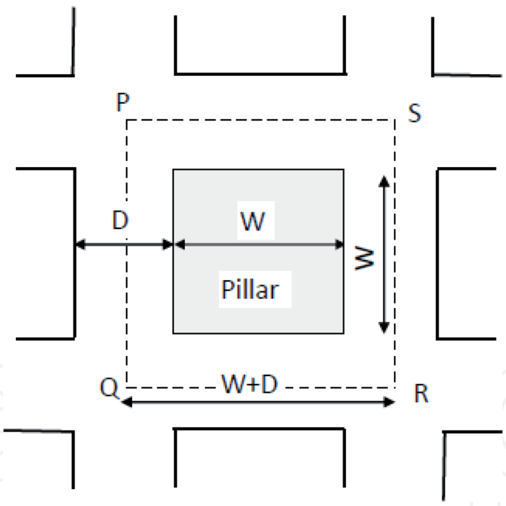

Figure 3.
Plan view of a coal pillar.

where,
σ_p = strength on the pillar (MPa).
γ = unit weight of rock mass above the pillar in MPa/m.
H = rock cover above the pillar.
W = width of the pillar (m).
D = width of the gallery (m).

D. Limitations and other issues

While dealing with hill mining by tunneling method, two important issues arise. Firstly, the 'shape of the underground openings' and secondly the mining methodology that includes both development and depillaring operation of mineral extraction. Due consideration should be given on both these points and its explanation has been given in the following paragraphs.

In general, tunnels are either D shaped (horseshoe shaped) or circular, having 'arched roof' whereas underground mine galleries have nearly flat roofs. Tunnels with an arched roof are more stable and hence safer compared with the underground galleries. This is scientifically established that *flat roofs* having corners have more chances of failure due to higher stress concentration at the corners. The mine planner can select rectangular openings, if depillaring and backfilling are the parts of the mining plan and method of mining because backfilling, after the depillaring operation is over, takes care of stress concentration at the corners which are the likely point of initiation or propagation of failure/crushing in the underground openings. Furthermore, in case of depillaring with backfilling, additional land area (on the surface) is not required for rock/waste storage generated from excavation underground. Therefore, dump creation and its management are eliminated, thereby economizing the overall cost of mineral production. Waste rocks which are huge in quantity destroy the landscape of the surface area completely and cause water and land pollution. Saving of the landscape of the mining area is priceless in terms of environmental benefits. In this way, the suggested tunneling method, which is an improved form of *underground mining method* would be both economically viable and environmentally friendly. Following are some limitations of 'tunneling methods' which shall be mentioned here.

- To make the 'tunneling method of mining' most feasible, the mined-out area shall be backfilled with rock waste, fly ash, sand or combination of more than one stowing material. Thus, 'depillaring with backfilling' is the best tunneling option, for safe exploitation of minerals by underground means.

- The method shall not be useful if entire rock cover is comprised of riverine material or soil having flowing tendency when destabilized.

- According to a rough estimate the cost of underground mining is more compared to the open -cast or surface mining [1] hence, cost analysis is essential for 'tunneling method of mining'. If found appropriate, this limitation can be easily overcome, particularly for high value and strategic minerals (gold, uranium ore, nickel ore, base metals i.e. Cu, lead, silver, zinc etc.).

When the tunneling method is practised, the value addition of the 'developed underground space' is suggestive. With such practices, the cost of production can be minimized and both revenues, as well as employment for locals, can be generated. Such value addition of the underground space/areas, if planned for the future, tunnels with an arched roof are advised. Research by the authors shows that the development roadways (areas developed during mine development, in particularly) has other civic uses too e.g. development as an underground storage space, place for a miscellaneous purpose, place of tourist extraction etc. [6].

3. Construction of approach road

Approach roads are vital at hill sites. The paucity of land and constrained space in hills are some well-known problems of hill mining. For open surface mines, larger length of approach roads is needed, If the tunneling method is the choice of mineral winning, road length is reduced and dust hazard is kept contained. **Figures 4** and **5** show various approach roads to tunnels excavated in hills. The approach roads, only means of hill transportation, shall remain functional round the year to keep geared the mining activities in the hills and also for transportation of man, material and machinery. Their construction and design should be rugged enough as per the load they have to handle because heavy machinery of big size will often use the roads.

Figure 4.
A view of the construction of approach road in the left for the tunnel shown on the right.

Figure 5.
View of approaches to the tunnel constructed in the hill.

3.1 Layout of tunnels and cross-cuts for mining

In a normal underground mine, the position of working face and its layout has close linkage as these facilitate the overall development of mine workings. Dimension and layout of tunnels and cross-cuts should be decided based on the thickness of the ore body. Thus, for the massive thickness of mineral bed, larger dimensions may be permitted. In case of metallic ore deposits which is found in narrow veins, lodes and pockets smaller dimensions suffice the purpose. For an ore-body having a thickness in the range of 5 m or more, development of mine working shall be through tunnels and cross-cuts of diameter 'D' diameter (**Figure 6**).

The tunnels are constructed within the orebody or in host rocks. Construction of underground openings in host rocks is a non-productive exercise and shall be kept limited. This methodology starts giving production right from the beginning when underground excavations are made in mineral instead of host or country rocks. The tunnels are interconnected with cross-cuts of the same or different cross-section perpendicular to the tunnel direction/alignment at a fixed interval. Thus, pillars

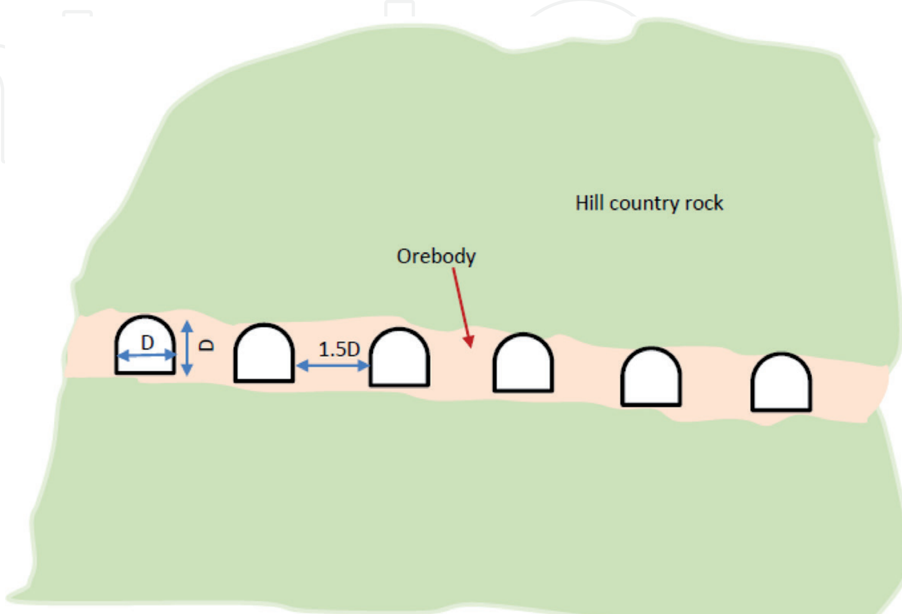

Figure 6.
Layout of tunnels for hill mining.

are formed which are extracted in the extraction phase of the mining operation. To get the mineral finally, these developed mine-workings are either fully or partially excavated.

The development of underground space, through tunneling and cross-cuts, for mining of minerals, has yet another dimension of multi-level mineralization in different horizons with host rocks in between, called 'parting'. All such levels, if not connected through tunnels from outside the hill, the dugout mineral or rocks can be poured down to the lower level and transportation underground can be done by gravity using shafts or chutes. Inter connectivity of levels at different points is required for the full development of the deposit which contains the mineral. If the mined-out area has to be backfilled then the pillar width should be reduced to a minimum with due consideration of roof stability. As such, the maximum quantity of ore should be dug out for mineral conservation purposes. At the decommissioning phase of 'eco-friendly hill mining by tunneling method', the underground space created during mining can create a value too and shall be maintained till the end. If done so, the underground space may be developed as a tourist place, underground market and other utilities like hotels/shops in future which has value.

Thus, two aspects of the discussed method are quite apparent, firstly, 'clean mining and green environment' and secondly, 'value addition' after mining is over. Revenue generation and socio-economic gains are therefore well connected to the method at once the rehabilitation of the created underground space is sought.

3.2 Productivity, risk and safety

In general, productivity is a measure of performance or output. It is a measure of how effectively the business targets of mining companies are being met [7]. In hill mining by underground approach, productivity is a ratio of input Vs output and implies how much mineral/ore is produced through various inputs. Obviously, hill mining, done by any method, has limited productivity and high risk. Its principal reasons are terrain condition. Another risks associated with the hill, particularly the Himalaya region, are the extreme weather conditions and environmental fragility, which should be attended scientifically.

Tunneling methods of mineral extraction has environmental and safety advantages over conventional mining. Safety in mines and mining industry (from accident angle) is prime and has to be maintained and accrued through constant efforts. At ground level, the safety can be enhanced or dealt effectively with knowledge of "Safety Management and Safety Engineering", as they are the modern and newly emerged tools to achieve the road to zero harm [8]. Undoubtedly, safety is a major concern for lofty hills and for this mining professionals are required to keep an eye on the stability of underground openings and slopes near the underground entry points i.e. portals. For this, scientific tools of numerical modeling, field measurement etc. pave the way as described in the following two paragraphs.

Deformation monitoring of excavated underground stretches: For safe underground working, the stability of the tunnel/cross-cuts is highly recommended to monitor so that counter measures can be taken in time to strengthen the rock mass around the excavated opening i.e. tunnel periphery wherever needed. For this, bi reflex targets are fixed at various cross-sections, especially near the cross-cuts because there are large spans of excavated space at such places, which need special care. After all, large excavations attract high induced stresses around the boundary of the openings. The targets are suggested to fix as given in **Figures 7** and **8**. One target at each TP1 (crown), TP2 & TP3 at the springing level and TP4 & TP5 at the upper bottom.

Frequency of such measurement depends on the trend of change in the radial deformation. If deformation shows an increasing trend, the frequency of

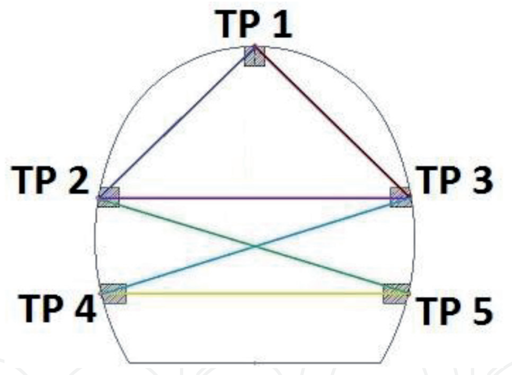

Figure 7.
Position of bi-reflex targets required to fix for monitoring radial tunnel deformation.

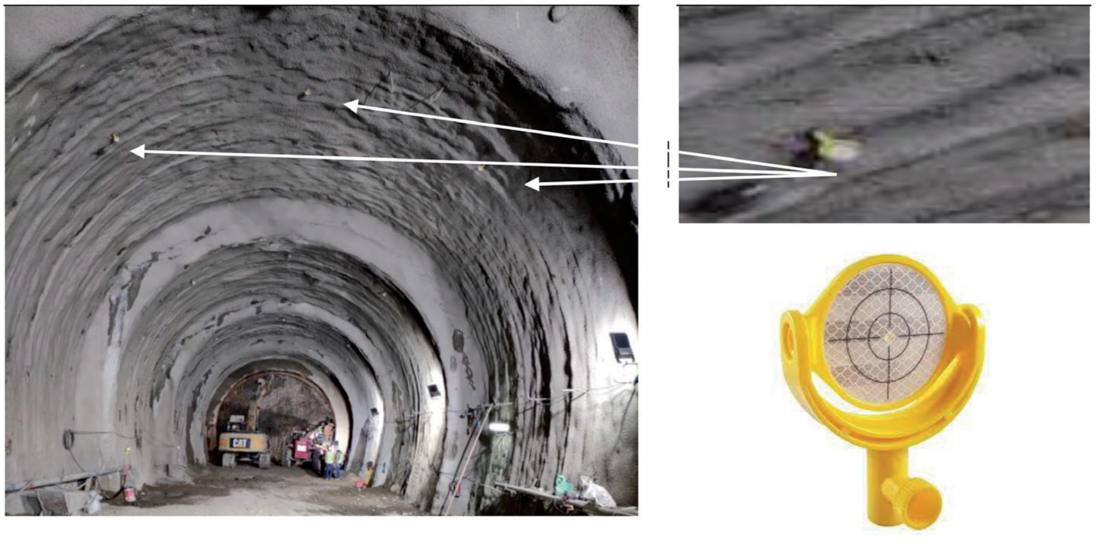

Figure 8.
Bi-reflex targets fixed to monitor radial tunnel deformation.

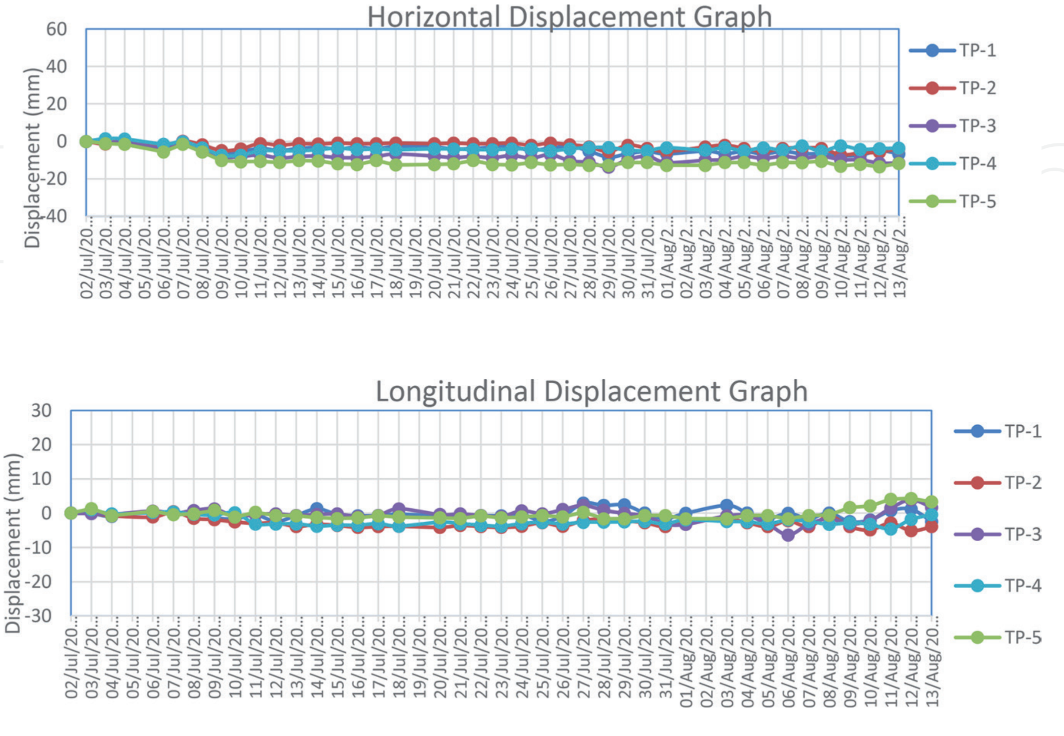

Figure 9.
Tunnel deformation recorded at all bi reflex targets of a tunnel section.

measurement needs to be increased. The readings obtained from such monitoring should be religiously analyzed so that action can be taken in advance before any untoward incidence (accident) takes place. **Figure 9** shows tunnel deformation in vertical, horizontal and longitudinal directions at TP1, TP2, TP3, TP4 and TP5 target points of a tunnel section. Alarming deformation level should be fixed at 80% of the allowable limit as per the design.

Slope monitoring near facade/tunnel portals: The purpose of a slope monitoring is to plan and maintain safe operating practises for the protection of personnel, equipment, and facilities. It provides warning of instability, so that action can be taken to minimize the impact of slope displacement and analyze the slope failure mechanism. The crucial geotechnical information provides help in designing the appropriate corrective measures [9]. Sufficient and suitable monitoring must be done to detect instability at an early, non-critical stage, to initiate the safety measures.

Opening of the mine i.e. portals of the tunnels is of prime importance as these serve as escape routes. Therefore, it is highly recommended to keep them intact and stable throughout the life of their existence and for a longer period, particularly when the mined-out areas have to be utilized for civic purposes in future. From this viewpoint, the portals are strongly supported with sufficient stretches (up to 15 m from the portals) and support density (1.25 times). To monitor the slope stability, bi-reflex targets are fixed at portal slopes as shown in **Figure 10**. Inclinometer and slope monitoring electronic gazettes such as 'terrestrial laser scanner (TSL)' and 'slope stability radar' (SSR) are some available equipment that may be used to assess the movement of hill slopes [10]. Depending on the requirement and feasibility on cost economics basis, they may be deployed. Piezometers can be installed to monitor the water head.

Precisely, the tunneling method for hills is an eco-friendly method that adopts similar basic principles as that of 'underground mining' in general and follows similar safety routes. To get a speedy and fast return on investment, the tunneling method of mining is best suited for the high-value minerals however, coal and other low-value minerals namely limestone, dolomite etc. can also be mined by this method taking into account the cost–benefit analysis. To make the method more cost-effective for mineral extraction, another dimension that may be added to this method is the 'eco-friendly transportation in hills' [11] and 'best practice mining' [1].

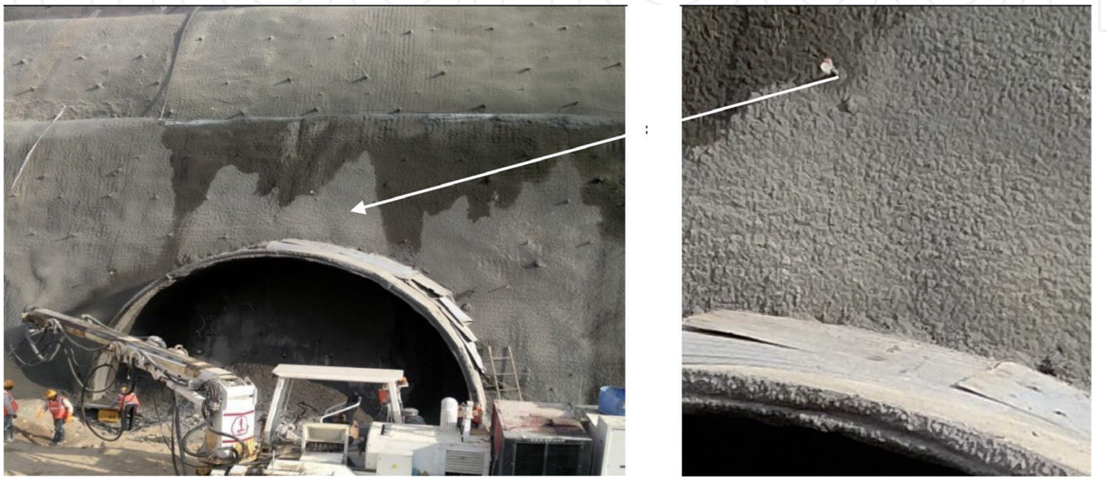

Figure 10.
Bireflex targets fixed at a tunnel portal to monitor the movement of the slope.

4. Case study: limestone mining in Meghalaya

Meghalaya, a high rain intensity state of India, in the North-Eastern part is mostly a hilly state (West, South and East Garo Hills; West and East Khasi Hills and Jaintia Hills) where sky seldom remains free of clouds. Meghalaya is rich in minerals and blessed with about 9% of the total limestone reserve of India [12]. The hills containing limestone minerals are being mined by open cast mining method in Meghalaya. Conventional 'Strip mining' is the method adopted in hill mining at Meghalaya.

Geologically, limestone in Meghalaya falls under the rocks formations namely Cretaceous-Tertiary sedimentary rock, which is further divided into three groups i.e., the Khasi group, the Jaintia Group and the Garo group. The Jaintia Group is further sub-divided into three formations, which include the *Longpar (lower), the Shella (middle)* and the *Kopili (upper)* formations.

The limestone deposited in Jaintia Hills, possesses limestone with alternating bands of sandstone. However, the limestone deposit in Cherrapunjee area of Meghalaya consists of limestone layers in the upper part of hills and dolomite in the lower portion. The limestone rocks found in Meghalaya belong to the Shella formations of the Jaintia Group of Cretaceous-Tertiary sedimentary rocks of Eocene geological age [3, 13].

As described above, in hill districts of Meghalaya, limestone is being extracted by open cast method of mining at both large scale and small scale levels. Jaintia Hills is being extracted in large scale for cement, whereas East Khasi hills are being extracted in small and large scale for manufacturing of quick lime, edible lime and cement. Most of the mines are owned by small private entrepreneurs. Some of the landowners are organized, and some make use of crude methods and adopt unscientific practices of mining on an individual basis to extract limestone. The captive mines of the cement industries are efficient, being mechanized, make use of heavy machinery for excavation. On the other hand, extraction by individual landowners is manual or semi-mechanical only and thus slow.

It is noticed and revealed periodically, that the local environment around the mines or in mining regions has been affected by creating hullabaloo. Engaged mining companies of the concerned area of the state faces its consequences both financially and socially (**Figure 11**). In general, extraction of limestone involves mechanical removal of overburden (using bulldozers), drilling of the blast holes, blasting of rocks (shattering), sizing, loading and then finally transportation of limestone to the consumer or industry cement plants.

In many hilly areas of Meghalaya, quarrying, for limestone, building stone/material such as slate, granite, clay etc., is a typical sight. Most of them are unscientific and cause disastrous and irreversible changes to natural habitats. At the

Figure 11.
View of various opencast mines in Meghalaya.

developmental phase, to reach the deposit, the mineral winning process shall be through driving of tunnel and approaching underground instead of the surface.

With adequate planning, 'the tunneling method' can be implemented into practices at Meghalaya as its tremendous feasibility exist. In this way, agricultural land and the landscape, nearby rivers and other water bodies, are not polluted. Air, water and land environment of the area can be protected with underground hill mining approach (tunneling).

5. Conclusions

Our experience of working in Indian mines and the analysis described in this technical communication concludes that 'the conventional hill mining can be turned into eco-friendly mining with small efforts, according to the hill topography, when the tunneling method is selected for implementation into practice. Many hill areas, including The Himalayas, will be the direct beneficiary and by doing so land degradation could be reduced to a minimum. The ill-effects of surface mining e.g. possibility of deforestation/denudation of forest, creation of scars on hill slopes (defacing) due to dumping on slopes, destabilization of natural hill slopes, landslides (destabilization) of hills, water pollution and disturbance to natural drainage pattern of the hills are either eliminated or curbed substantially. In this way, mining and environment can go hand-in-hand and the greenery of a hill and the surrounded environment is preserved. The less disturbed land surface, on one hand, protect the serene hill environment and on other hand allows the production of mineral deposits in hills irrespective of the scale of mining.

Author details

Rama Dhar Dwivedi[1] and Abhay Kumar Soni[2*]

1 CSIR-Central Institute of Mining and Fuel Research (CIMFR), Roorkee, (Uttarakhand), India

2 CSIR-Central Institute of Mining and Fuel Research (CIMFR), Nagpur, (Maharashtra), India

*Address all correspondence to: abhayksoni@gmail.com

References

[1] Soni A.K. (2017), Mining in the Himalayas - An Integrated Strategy, Book Published by CRC Press / Taylor & Francis, p. 225 (ISBN - 9781498762342).

[2] NGI (2015). Using the Q-system: Rock mass classification and support design, Norwegian Geotechnical Institute (NGI) Publication, 54p.

[3] DMR (2016), Directorate of Mineral Resources (DMR) Profile, Government of Meghalaya (http://megdmg.gov.in/), Shillong, Meghalaya.

[4] GOI (2017), Coal Mines Regulations, 2017, Government of India (GOI), Amended and modified from Coal Mines Regulation (CMR), 1957(from the web; last accessed 0n 17/09/2020).

[5] Bieniawski ZT, Van HWL (1975). The significance of in situ tests on large rock specimens. Int. J. Rock Mech. Min. Sci. Geomech. Abstr. 12(4): 101-113.

[6] Soni A.K., (1995), Environmental Study of a Limestone Mining in the Himalayas, Journal of Mining Research, Vol. 3, Nos. 3 &4, January–March, pp.1-8.

[7] Jairo Ndhlovuand Peter R K Chileshe (2020), Global Mine Productivity Issues: A Review, Int. J. of Engineering Research & Technology (IJERT), Vol. 9 Issue 05, May (ISSN: 2278-0181; http://www.ijert.org), pp. 319-329.

[8] Soni A.K. and Suman Kiran (2012), The Road to Zero Harm: Safety Management and Safety Engineering in Context to Underground Mines, Workshop on Safety Management in Mines. Nagpur, pp. 01-10.

[9] Call R.D., J.P. Savely (1990). Open-pit rock mechanics. Surface Mining, 2nd Edition. Society for Mining, Metallurgy and Exploration, Inc., pp. 860-882. B.A. Kennedy ed.

[10] Prakash Amar, Kumar A., Singh K. B. (2016). Highwall mining: A critical appraisal, MineTech, Vol. 36 No. 3, pp. 17-30.

[11] Soni A.K. (1999), Environmentally - Friendly Transportation of Limestone for Cement Production, International Journal of Bulk Solid Handling - Germany, ISSN: 01739980 Vol.19. N0.3, July–September, pp. 329-336.

[12] Lamare R. E., Singh O. P. (2016). Limestone mining and its environmental implications in Meghalaya, India. ENVIS Bulletin Himalayan Ecology, 24:87-100.

[13] Sarma S. (2003). Meghalaya: The Land and Forest - A Remote Sensing Based Study, Geophil Publishing House, Guwahati, India, 5-16.