International Journal of Innovative Research in Engineering and Management (IJIREM)
ISSN (Online): 2350-0557, Volume-11, Issue-6, December 2024
https://doi.org/10.55524/ijirem.2024.11.6.14
Article ID IJIR3051, Pages 128-137
www.ijirem.org

The Hidden Costs of Geological Overbreak (GOB) in EPC Tunnel Projects: Assessing the Economic Impact

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Received: 25 November 2024 Revised: 9 December 2024 Accepted: 22 December 2024

ABSTRACT- Overbreak, defined as the excavation of excess material beyond the required tunnel profile, is a common issue in tunnel construction, particularly in tunnels constructed using New Austrian Tunnelling Method (NATM). In the context of Jammu and Kashmir, India, five tunnels are currently being constructed along National Highway-44 (NH-44) under the National Highways Authority of India (NHAI). Given the region's complex and varied geology, NATM has been adopted for these tunnel projects. This study focuses on one such under-construction twin-tube tunnel, measuring 4.3 km in length. Notably, the contract agreements for these tunnels do not account for geological overbreak (GOB), with no provisions for compensating contractors for additional excavation costs. The study involved a detailed analysis comparing the theoretical and actual quantities of shotcrete applied, along with the calculation of rebound quantities. Using Amberg Software, tunnel sections were modelled to better understand the extent of overbreak. The research quantified the additional costs incurred by the contractor due to GOB and proposed recommendations for addressing such issues in future projects.

KEYWORDS- Tunnelling, Himalayas, Overbreak, GOB, Cost Overrun. J&K.

I. INTRODUCTION

Tunnels have played a pivotal role in shaping human civilization, serving diverse functions ranging from transportation and water management to military defense and resource extraction. The history of tunnelling dates back to ancient times. As per the Oxford English Dictionary the oldest record when the word tunnel was used is around 1150 to 1500.Early examples of tunnelling has been found in Mesopotamia and Egypt, where tunnels were constructed for irrigation and flood control[3]. In the medieval period, tunnels were used strategically in warfare, notably during sieges, and for religious purposes, such as the construction of catacombs in Rome [2]. The Industrial Revolution marked a significant advancement in tunnelling, with innovations in mining and the construction of canals and railways, laying the groundwork for modern infrastructure projects [1]. The 20th and 21st centuries saw remarkable progress, with the development of subway systems, underwater tunnels, and large-scale transportation networks, such as the Channel Tunnel and Gotthard Base Tunnel [4]. Modern tunnelling techniques, including Tunnel Boring Machines (TBMs), have enabled the construction of ambitious projects that connect cities, power economies, and facilitate global trade[5].

Tunnelling in India has a long history, evolving from ancient water management systems and religious structures to modern engineering feats. During the British colonial period, India saw its first significant tunnelling projects, primarily for the construction of railways, such as the Kalka-Shimla Railway Tunnel (1903) and the Arrah Railway Tunnel (1899). Post-independence, India expanded its tunnelling efforts to support infrastructure development, including railways, highways, and hydropower projects. Notable projects include the Jawahar Tunnel (1956) in Jammu & Kashmir and the Bhakra Nangal Dam Tunnel (1950s).

With the advent of Science and Technology different methods have been devised for the carrying out the tunnelling. In today's era The New Austrian Tunnelling Method (NATM) which is a flexible, ground-support-based tunnelling technique, developed in the 1950s by Austrian engineer Dr. Robert Maidl. It relies on the natural properties of the surrounding rock or soil for support and applies incremental support as excavation progresses. The method is highly adaptable, continuously monitoring and adjusting construction methods to suit varying geological conditions. NATM is particularly effective in areas with soft to moderately hard rock and weak soil conditions. The method was first employed in Austria, where complex mountain tunnels for railways and highways required adaptable and safe tunnelling methods. Its use quickly spread across Europe, particularly in the Alps, and later to other parts of the world, including Asia and the Middle East.

However more recently a new method of tunnelling has emerged which is done by the Tunnel Boring Machines (TBMs) which are mechanized, rotary-driven machines used for excavating tunnels with minimal disruption to the surrounding environment. The TBM method uses a large rotating cutter head to break rock or soil, with the machine's body supporting the tunnel's lining as excavation progresses. TBMs are particularly suited for long, straight tunnels through hard rock or stable ground, offering fast excavation with a high level of precision. While TBMs are ideal for homogenous geological conditions, they face challenges when the ground is unstable or heterogeneous, such as in soft soils or mixed rock conditions. The first

TBM was developed in the mid-19th century, with the first successful application in the London Underground tunnels. Over the next century, TBM technology evolved, with significant advancements in the 1950s and 1960s. Modern TBMs, like the Earth Pressure Balance (EPB) and Slurry Shield TBMs, became more sophisticated, allowing them to handle various geological conditions.

Overbreak refers to the excavation of more material than required during tunnel boring, which leads to inefficiencies, increased costs, and potential structural instability. Both NATM and TBM methods experience overbreak, though the causes and impacts differ. Overbreak in NATM typically occurs when the surrounding ground is weaker than expected, leading to the excavation of additional material beyond the intended tunnel profile. Since NATM relies heavily on monitoring and adjusting construction methods to the ground's response, overbreak in this method can be mitigated with real-time adjustments to support systems. Excessive overbreak can lead to higher costs due to additional support requirements (e.g., more shotcrete, steel reinforcement) and longer construction time. Furthermore, poor ground support may compromise the tunnel's stability, leading to delays or safety risks. Overbreak in TBM is less common but can still happen, especially when the TBM encounters mixed or unexpected ground conditions that are harder or softer than anticipated. In stable rock, TBMs tend to maintain a precise tunnel profile, but in soft or heterogeneous soils, overbreak can result from an overcutting effect or incorrect pressure applied by the machine. Overbreak in TBM tunnels can result in cost overruns due to additional excavation, time delays, and the need for more extensive tunnel lining. Moreover, improper TBM operation in unstable or poorly characterized ground can lead to tunnel deformation, reduced structural integrity, and increased maintenance costs.

II. RESEARCH OBJECTIVES

- To quantify the overbreak in tunnel excavation and its effect on material requirements.
- To assess the additional costs incurred due to overbreak and excessive shotcrete use, especially when these costs are not reimbursed by the client.
- To compare theoretical quantities of excavation and shotcrete with actual quantities, considering the design mix.
- To analyse the impact of overbreak on the overall project cost, including labour, materials, and time delays.

III. RESEARCH METHODOLOGY

This research employs a quantitative approach based on field measurements, theoretical calculations, and software analysis to quantify and assess the impact of overbreak and shotcrete on project costs. The following steps outline the methodology that we had deployed and is summed as follows:

A. Data Collection

- **Profiles and Measurements:**

Profiles were taken at four key stages using the Leica TS-16:

- Theoretical profile
- After excavation (actual excavation profile).
- Before shotcrete application (pre-shotcrete profile).
- After shotcrete application (final profile).

The TS-16 system provided accurate 3D profiles of the tunnel, which were crucial for calculating the overbreak and its variations at different sections of the tunnel.

- **Theoretical Quantities**
  - The theoretical excavation volume was calculated based on the original design of the tunnel.
  - Shotcrete requirements were also estimated based on the theoretical quantities, considering standard thickness and application factors as mentioned in the design.

B. Analysis

- **Using Amberg Tunnel Software**
  - The raw data of the sections (pre-excavation, post-excavation, pre-shotcrete, and post-shotcrete) were inputted into the Amberg Tunnel Software. This software is designed for making the high precise sections of the tunnel and has multiple functions to:
  - Compare the theoretical and actual excavation volumes.
  - Quantify the overbreak (difference between theoretical and actual excavation).
- **Overbreak Quantification**
  - Overbreak was calculated as the difference between the theoretical tunnel volume and the actual excavation volume, considering variations in tunnel geometry.
  - Shotcrete Volume Calculation: The volume of shotcrete applied was calculated based on the tunnel profile before and after shotcrete application, factoring in the overbreak.

C. Cost Impact Assessment

The cost analysis focused on the following:

- **Additional Excavation Costs:** Overbreak increases the amount of excavation required, resulting in higher labor and equipment costs. The additional excavation volume was calculated, and its cost was derived based on unit rates for excavation activities.
- **Excessive Shotcrete Costs:** Excessive shotcrete usage was quantified by comparing the required shotcrete based on theoretical excavation volumes with the actual shotcrete used (accounting for overbreak). The cost of shotcrete was calculated based on material cost per cubic meter, application labor, and equipment.
- **Time Delays:** The additional excavation and shotcrete application time were estimated, and the corresponding labor and equipment costs were factored in.
- **Client Reimbursement Issues:** Since the client does not pay for overbreak, the impact of non-reimbursed costs on the overall project budget was analyzed. This includes the indirect costs resulting from overbreak that the contractor has to absorb.

IV. FIELD WORK

As mentioned in the Research Methodology, first of all the sections of the tunnel were taken. Although the tunnel is 4000 m in length but since only 1000 m + 1000 m in both the tunnel have been excavated. So, sections of the said 2

Km were taken. The Twin tube tunnels have been designated as North Bound Tunnel (NBT) and South Bound Tunnel (SBT). The Starting Chainage of the NBT is 154+608 from one end and 158+608 from the other end. Similarly, SBT's starting chainage is 155+267.5 from one end and 159+267.5 from the other end. The main point that is worth to mention is that the study area of 2000 m encountered all the Rock Classes viz Rock Class 5, 4,3 and even Rock Class-2 as below in Table 1.

Table 1: Rock Class encountered in Twin Tunnels

S No.	Item	Rock Class			
		5	4	3	2
01	North Bound	150	250	500	100
02	South Bound	150	250	500	100

Note: Since both the tunnels run parallel to each other therefore nothing significant change was in the Rock Class.

A. Quantitative Analysis

Since the tunnelling process was divided into Heading and Benching portions, the data was also bifurcated accordingly into these two categories. This approach allowed for a more detailed analysis and provided greater clarity regarding the excavation and overbreak conditions in both the Heading and Benching sections of the tunnel. By separating the data in this manner, we were able to gain a clearer understanding of the specific challenges and variances that may exist between the two portions of the tunnel, aiding in more precise assessment. After the theoretical data was calculated, the results were organized and tabulated as follows.

Table 2: Details of Theoretical Excavation Volume in NBT Heading

S No.	Tunnel	Chainage From - To	Volume as per Drawing in "cum"	Total Length in "m"	Theoretical Volume in "cum"	Rock Class
1.	North Bound Tunnel Heading	158+608 to 158+458	73.08	150	10,962	5
2.		158+458 to 158+369	70.66	89	6,288	4
3.		158+369 to 158+093	69.18	276	19,094	3
4.		158+093 to 157+943	70.66	150	10,599	4
5.		157+943 to 157+768	69.18	175	12,106	3
6.		157+768 to 157+668	66.9	100	6,690	2
7.		157+668 to 157+619	69.18	49	3,390	3
8.		157+619 to 157+608	70.66	11	778	4

The above Table 2 shows Theoretical Excavation Volume in NBT Heading. Same was calculated by simple volume formula.

Table 3: Details of Theoretical Excavation Volume in SBT Heading

S No.	Tunnel	Chainage From - To	Volume as per Drawing in "cum"	Total Length in "m"	Theoretical Volume in "cum"	Rock Class
1.	South Bound Tunnel Heading	159+267.5 to 159+117.5	73.08	150	10,962	5
2.		159+117.5 to 159+187	70.66	89	6,288	4
3.		159+187 to 158+911	69.18	276	19,094	3
4.		158+911 to 158+761	70.66	150	10,599	4
5.		158+761 to 158+586	69.18	175	12,106	3
6.		158+586 to 158+486	66.9	100	6,690	2
7.		158+486 to 158+437	69.18	49	3,390	3
8.		158+437 to 158+426	70.66	11	778	4

The above Table 3 shows Theoretical Excavation Volume in SBT Heading.

Table 4: Details of Theoretical Excavation Volume in NBT Benching

S No.	Tunnel	Chainage From - To	Volume as per Drawing in "cum"	Total Length in "m"	Theoretical Volume in "cum"	Rock Class
1.	North Bound Tunnel Benching	158+608 to 158+458	62.76	150	9414	5
2.		158+458 to 158+369	61.65	89	5487	4
3.		158+369 to 158+093	63.23	276	17452	3
4.		158+093 to 157+943	61.65	150	9248	4

5.		157+943 to 157+768	63.23	175	10891	3
6.		157+768 to 157+668	59.91	100	5991	2
7.		157+668 to 157+619	63.23	49	3099	3
8.		157+619 to 157+608	61.65	11	679	4

Table 5: Details of Theoretical Excavation Volume in SBT Benching

S No.	Tunnel	Chainage From - To	Volume as per Drawing in "cum"	Total Length in "m"	Theoretical Volume in "cum"	Rock Class
1.	South Bound Tunnel Benching	159+267.5 to 159+117.5	62.76	150	9414	5
2.		159+117.5 to 159+187	61.65	89	5487	4
3.		159+187 to 158+911	63.23	276	17452	3
4.		158+911 to 158+761	61.65	150	9248	4
5.		158+761 to 158+586	63.23	175	10891	3
6.		158+586 to 158+486	59.91	100	5991	2
7.		158+486 to 158+437	63.23	49	3099	3
8.		158+437 to 158+426	61.65	11	679	4

The above Table 5 shows Theoretical Excavation Volume in SBT Benching.

After calculating the theoretical quantities of muck, the actual excavation sections were measured using a Total Station. Excavation sections were surveyed using a Total Station, and the raw data collected was processed using Amberg Software for detailed analysis. The processed data was then compared with the theoretical sections, focusing on key parameters such as volume, shape, and alignment. The actual data, processed and tabulated through Amberg Software, is presented as follows.

Table 6: Details of Actual Excavation Volume in NBT Heading

S No.	Tunnel	Chainage	Total Length in "m"	Actual Calculated Volume in "cum"	Rock Class
1	North Bound Heading	158+608 to 158+458	150	14799	5
2		158+458 to 158+369	89	8174	4
3		158+369 to 158+093	276	23868	3
4		158+093 to 157+943	150	13779	4
5		157+943 to 157+768	175	15133	3
6		157+768 to 157+668	100	7493	2
7		157+668 to 157+619	49	4238	3
8		157+619 to 157+608	11	1011	4

The above Table 6 shows Actual Excavation Volume in NBT Heading. Theoretical and after excavation profiles were compared and the data was obtained.

Table 7: Details of Actual Excavation Volume in SBT Heading

S No.	Tunnel	Chainage	Total Length in "m"	Actual Calculated Volume in "cum"	Rock Class
1	South Bound Heading	159+267.5 to 159+117.5	150	19978	5
2		159+117.5 to 159+187	89	10627	4
3		159+187 to 158+911	276	29835	3
4		158+911 to 158+761	150	17913	4
5		158+761 to 158+586	175	18916	3
6		158+586 to 158+486	100	8393	2
7		158+486 to 158+437	49	5298	3
8		158+437 to 158+426	11	1315	4

The above Table 7 shows Actual Excavation Volume in NBT Heading. Theoretical and after excavation profiles were compared and the data was obtained.

Table 8: Details of Actual Excavation Volume in NBT Benching

S No.	Tunnel	Chainage	Total Length in "m"	Actual Calculated Volume in "cum"	Rock Class
1	North Bound Benching	158+608 to 158+458	150	12716	5
2		158+458 to 158+369	89	7134	4
3		158+369 to 158+093	276	21815	3
4		158+093 to 157+943	150	12023	4
5		157+943 to 157+768	175	13614	3
6		157+768 to 157+668	100	6710	2
7		157+668 to 157+619	49	3873	3
8		157+619 to 157+608	11	883	4

The above Table 8 shows Actual Excavation Volume in NBT Benching. Theoretical and after excavation profiles were compared and the data was obtained.

Table 9: Details of Actual Excavation Volume in SBT Benching

S No.	Tunnel	Chainage	Total Length in "m"	Actual Calculated Volume in "cum"	Rock Class
1	South Bound Benching	159+267.5 to 159+117.5	150	13000	5
2		159+117.5 to 159+187	89	7200	4
3		159+187 to 158+911	276	22000	3
4		158+911 to 158+761	150	12520	4
5		158+761 to 158+586	175	14216	3
6		158+586 to 158+486	100	6789	2
7		158+486 to 158+437	49	4125	3
8		158+437 to 158+426	11	916	4

The above Table 9 shows Actual Excavation Volume in SBT Benching. Theoretical and after excavation profiles were compared and the data was obtained.

After the calculation of both theoretical and actual excavation volumes, a comparison was made, and some remarkable results were revealed. It was found that in various rock classes, up to 38% excessive overbreak occurred. This means that the actual excavation exceeded the theoretical requirements by a significant margin.

Table 10: Details of Actual vs Theoretical Heading Excavation in Both the tunnels

S No.	Tunnel	Chainages	Actual Excavation in "cum"	Theoretical Excavation in "cum"	Excess Percentage	Rock Class
1	North Tunnel Heading	158+608 to 158+458	14799	10,962	35%	5
2		158+458 to 158+369	8174	6,288	29%	4
3		158+369 to 158+093	23868	19,094	25%	3
4		158+093 to 157+943	13779	10,599	30%	4
5		157+943 to 157+768	15133	12,106	25%	3
6		157+768 to 157+668	7493	6,690	12%	2
7		157+668 to 157+619	4238	3,390	25%	3
8		157+619 to 157+608	1011	778	28%	4
9	South Tunnel Heading	159+267.5 to 159+117.5	19978	10,962	35%	5
10		159+117.5 to 159+187	10627	6,288	29%	4
11		159+187 to 158+911	29835	19,094	25%	3
12		158+911 to 158+761	17913	10,599	30%	4
13		158+761 to 158+586	18916	12,106	25%	3
14		158+586 to 158+486	8393	6,690	13%	2
15		158+486 to 158+437	5298	3,390	25%	3
16		158+437 to 158+426	1315	778	27%	4

The above Table 10 shows Actual Excavation vs Theoretical Volume in Headings of twin tunnels. Theoretical and after excavation profiles were compared and the data was obtained.

Table 11: Details of Actual vs Theoretical Benching Excavation in Both the tunnels

S No.	Tunnel	Chainages	Actual Excavation in "cum"	Theoretical Excavation in "cum"	Excess Percentage	Rock Class
1	North Tunnel Benching	158+608 to 158+458	12716	9414	35%	5
2		158+458 to 158+369	7134	5487	30%	4
3		158+369 to 158+093	21815	17452	25%	3
4		158+093 to 157+943	12023	9248	30%	4
5		157+943 to 157+768	13614	10891	25%	3

6		157+768 to 157+668	6710	5991	12%	2
7		157+668 to 157+619	3873	3099	25%	3
8		157+619 to 157+608	883	679	30%	4
9	South Tunnel Benching	159+267.5 to 159+117.5	13000	9414	38%	5
10		159+117.5 to 159+187	7200	5487	32%	4
11		159+187 to 158+911	22000	17452	26%	3
12		158+911 to 158+761	12520	9248	35%	4
13		158+761 to 158+586	14216	10891	30%	3
14		158+586 to 158+486	6789	5991	13%	2
15		158+486 to 158+437	4125	3099	33%	3
16		158+437 to 158+426	916	679 c	34%	4

The above Table 11 shows Actual Excavation vs Theoretical Volume in Benching of twin tunnels. Theoretical and after excavation profiles were compared and the data was obtained.

After comparing the theoretical excavation volumes with the actual excavation quantities, another critical parameter was analysed: the comparison of actual versus theoretical shotcrete quantities. As per the tunnel design, the primary shotcrete thicknesses specified were 350 mm, 300 mm, 250 mm, and 150 mm for Rock Class 5,4,3 and 2 respectively.

The shotcrete quantities were calculated based on the theoretical design thicknesses and compared with the actual quantities sprayed. The procedure for calculating the shotcrete quantities followed a similar methodology to the excavation comparison. For each section, measurements were taken before and after the shotcrete application using a total station. These measurements were then analysed using Amberg software to calculate the actual shotcrete quantities. The use of advanced software provided reliable data to assess the consistency of shotcrete application across the tunnel sections.

Table 12: Details of Actual vs Theoretical Heading Shotcrete in Both the tunnels

Item	Chainage	Theoretical Shotcrete in "cum"	Actual Shotcrete in "cum"	Excess %	Rock Class	Remarks
North Bound Heading	158+608 to 158+458	1044	2100	101%	5	300 mm Thickness
	158+458 to 158+369	600	1100	84%	4	300 mm Thickness
	158+369 to 158+093	1502	3000	99%	3	250 mm Thickness
	158+093 to 157+943	1012	2100	107%	4	300 mm Thickness
	157+943 to 157+768	952	1960	106%	3	250 mm Thickness
	157+768 to 157+668	473	700	48%	2	150 mm thickness
	157+668 to 157+619	266	562	112%	3	250 mm Thickness
	157+619 to 157+608	74.25	220	196%	4	300 mm Thickness
South Bound Heading	159+267.5 to 159+117.5	1044	2000	91%	5	Perimeter = 23.2 m
	159+117.5 to 159+187	600	1020	70%	4	Perimeter = 22.5 m
	159+187 to 158+911	1502	2925	94%	3	Perimeter = 21.78 m
	158+911 to 158+761	1012	1950	92%	4	Perimeter = 22.5 m
	158+761 to 158+586	952	1860	95%	3	Perimeter = 21.78 m
	158+586 to 158+486	473	725	53%	2	Perimeter = 21.2 m

	158+486 to 158+437	266	520	95%	3	Perimeter = 21.78 m
	158+437 to 158+426	1044	1952	87%	4	Perimeter = 22.5 m

The above Table 12 shows Actual vs Theoretical Heading Shotcrete in Both the tunnels Theoretical and after Shotcrete profiles were compared and the data was obtained.

Table 13: Details of Actual vs Theoretical Benching Shotcrete in Both the tunnels

Item	Chainage	Theoretical Shotcrete in "cum"	Actual Shotcrete in "cum"	Excess %	Rock Class	Remarks
North Bound Benching	158+608 to 158+458	431	920	113%	5	300 mm Thickness
	158+458 to 158+369	225	421	87%	4	300 mm Thickness
	158+369 to 158+093	660	1200	81%	3	250 mm Thickness
	158+093 to 157+943	430	962	123%	4	300 mm Thickness
	157+943 to 157+768	419	825	96%	3	250 mm Thickness
	157+768 to 157+668	142	250	75%	2	150 mm thickness
	157+668 to 157+619	117	290	147%	3	250 mm Thickness
	157+619 to 157+608	32	65	103%	4	300 mm Thickness
South Bound Benching	159+267.5 to 159+117.5	431	890	106%	5	Perimeter = 23.2 m
	159+117.5 to 159+187	255	428	68%	4	Perimeter = 22.5 m
	159+187 to 158+911	660	1031	56%	3	Perimeter = 21.78 m
	158+911 to 158+761	430	820	91%	4	Perimeter = 22.5 m
	158+761 to 158+586	419	725	73%	3	Perimeter = 21.78 m
	158+586 to 158+486	142	190	34%	2	Perimeter = 21.2 m
	158+486 to 158+437	117	214	82%	3	Perimeter = 21.78 m
	158+437 to 158+426	32	68	113%	4	Perimeter = 22.5 m

The above Table 13 shows Actual vs Theoretical Benching Shotcrete in Both the tunnels Theoretical and after Shotcrete profiles were compared and the data was obtained.

V. RESULTS

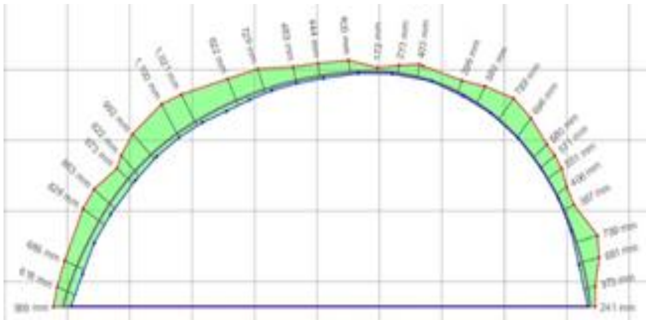

Figure 1: Excessive Shotcrete in Heading

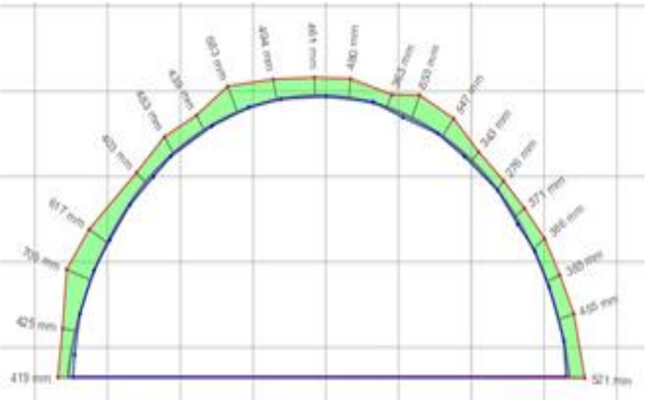

Figure 2: Excessive Shotcrete in Heading

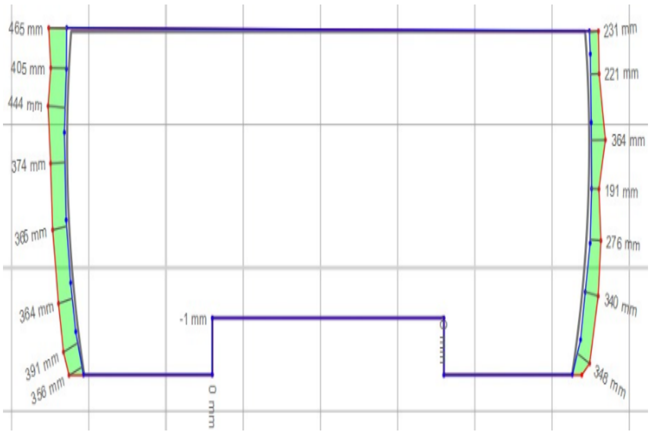

Figure 3: Excessive Shotcrete in Benching

Figure 4: Excessive Shotcrete in Benching

The above clearly shows how excessive shotcrete was used. In Figure 1 & Figure 2 heading sections have been shown while as, Figure 3 and Figure 4 show excessive shotcrete in Benching. Same have been plotted by using Amberg Tunnel.

During the research significant thing was observed between the theoretical and actual quantities of shotcrete applied. The theoretical amount of shotcrete, based on the design and calculated requirements, was approximately 96% extra in Heading and 91% in Benching.

This resulted in nearly 90% excess shotcrete, an alarming and unexpected variance.

A. Cost Impact Analysis

- **Excavation**

  In the analysis of tunnelling excavation, it was found that approximately 35% excessive excavation occurred, significantly surpassing the theoretical volume. While the standards allow for a permissible over-excavation limit of 10%, the actual excavation exceeded this threshold by 25%. For example, assuming the theoretical excavation volume is 1,000 cubic meters (Y), the permissible excess excavation would be 10% of 1,000, or 100 cubic meters. However, the actual excavation performed was 35% of 1,000, which equals 350 cubic meters. This resulted in an excess of 250 cubic meters (350 - 100). If Z is the rate of excavation per cubic meter (e.g., Z = 50 units of currency per cubic meter), the contractor incurred an additional cost of 250Z units due to the excess excavation. Since the contractor was not compensated for this over-excavation commonly known as GOB, the contractor suffered a loss of 250Z units. For instance, if Z = 50, the loss would amount to 250 × 50 = 12,500 units. This emphasizes the financial impact of non-payment for excess excavation beyond the permissible GOB limit, highlighting the need for more accurate excavation techniques and clearer payment terms in tunnelling contracts to avoid such losses.

- **Shotcrete**

  In addition to the excessive excavation observed, significant over-application of shotcrete was also noted during the tunnelling process. It was found that approximately 90% more shotcrete was sprayed than originally planned, primarily due to overbreaks in the tunnel. The overbreak was particularly severe in the crown area, but it also extended to the benching section of the tunnel. This increased shotcrete application was necessary to stabilize the tunnel and ensure safety, but it led to a significant deviation from the theoretical shotcrete requirements. For example, assuming the theoretical shotcrete volume required for the project was S cubic meters, the actual shotcrete sprayed amounted to 1.9S cubic meters, representing a 90% excess. If Z is the cost of shotcrete per cubic meter, the contractor incurred an additional cost of 0.9S × Z units due to the over-application. If we assume S = 1,000 cubic meters and Z = 100 units of currency per cubic meter, the contractor faced an additional cost of 0.9 × 1,000 × 100 = 90,000 units. This illustrates the financial impact of overbreak-related shotcrete over-application and highlights the importance of improving tunnel design, excavation precision, and monitoring to minimize such excesses in future tunnelling projects.

- **Labour and Machinery**

  Due to excessive excavation and over-application of shotcrete, the contractor faced significant increases in machinery and labor costs. The excavation overrun of 35% and shotcrete overrun of 90% required additional machinery and labor. For machinery, the extra cost amounted to 15,750 units (considering an additional 35% for excavation and 90% for shotcrete, with machinery costing 500 units/day over 30 days). Labor costs increased by 4,200 units (with additional labor needed for the excess excavation and shotcrete over 20 extra days at 200 units/day). Combining these costs, the contractor incurred an additional 19,950 units for machinery and labor. Including the losses from over-excavation (12,500 units) and shotcrete over-application (70,000 units), the total loss to the contractor was 102,450 units, highlighting the severe financial impact of the inefficiencies in the project.

In short we can say "Overbreak eats the profit of EPC Projects in case same in not compensated"

VI. FUTURE SCOPE AND RECOMMENDATIONS

The findings of this research highlight several critical areas where improvements can be made to prevent inefficiencies and financial losses in tunnelling projects.

A. Strict Adherence to Allowed Pull Lengths per Blast:

Contractors must ensure that the work is executed in strict accordance with the specified pull lengths per blast for each rock class. For instance, if the design for **Class 3 rock** allows for a pull length of only **1.5 meters**, it is imperative that this limit be adhered to without deviation. Exceeding this limit can lead to significant overbreak, which in turn increases excavation volume, shotcrete requirements, and overall project costs. Future research should focus on optimizing blast designs and techniques to minimize overbreak and ensure better control of excavation volumes.

B. Inclusion of GOB Clause in Contracts:

To address the issue of excessive excavation and shotcrete, the **Geological Overbreak (GOB)** clause must be formally included in government contracts and agencies like NHAI should add the same to the contract agreement. Contractors should be compensated for any excess excavation or shotcrete application within the approved GOB limits, based on the actual work performed. Future studies could explore models to quantify fair compensation for over-excavation and shotcrete overuse, ensuring that contractors are not unduly penalized for operational challenges beyond their control.

C. Improved Blast Monitoring and Control Systems:

Advanced monitoring techniques, such as real-time blast performance tracking, should be adopted to better predict and control the impact of blasting on excavation quality. This would include the use of geophysical surveys, laser profiling, and 3D mapping technologies to assess overbreak and adjust blasting parameters accordingly. Future research can explore the effectiveness of these technologies in reducing overbreak and optimizing shotcrete application.

D. Material and Process Optimization:

The research suggests that excess shotcrete application, especially in the crown and benching areas, contributes to significant financial loss. Therefore, future studies could focus on developing more precise shotcrete placement techniques and investigating alternative materials that may reduce the amount of shotcrete required for stabilization. Additionally, investigating more efficient ways to distribute shotcrete in high-risk areas could reduce waste and improve project cost-efficiency.

E. Training and Best Practices for Contractors:

Contractors should undergo specialized training in blast design, excavation control, and material application. This would ensure better adherence to design specifications, minimize errors, and enhance efficiency on-site. Future research could explore the effectiveness of contractor training programs in reducing over-excavation and shotcrete over-application, ultimately improving the financial health of tunnelling projects.

F. Regulatory Framework and Standardization:

Governments and regulatory bodies must work towards standardizing tunnelling practices, including clear guidelines on acceptable overbreak limits, shotcrete application standards, and appropriate compensation mechanisms. Future research could focus on developing a more robust regulatory framework to standardize best practices across the industry, ensuring that contractors, clients, and governments are aligned in their expectations and responsibilities.

By addressing these areas, future tunnelling projects can become more cost-effective, efficient, and sustainable. Additionally, ensuring that contractors are fairly compensated for unavoidable over-excavation and over-application of shotcrete will help foster a healthier working environment and mitigate financial risks for all stakeholders involved.

ACKNOWLEDGMENT

I would like to begin by expressing my sincere gratitude to (Prof) Dr. Sandeep Singla**,** presently the Dean at Chitkara University, Punjab, whose guidance and mentorship during my P.G program instilled in me a strong research mindset. His constant encouragement and valuable insights have been instrumental in shaping my academic journey.

I am also deeply thankful **to** Mr. Gaurav Singh for his continuous support and for always sharing new knowledge and ideas. His initiative in collaborating with me on writing this paper has been invaluable, and I have learned a great deal through his guidance.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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