"Cut and Cover Tunnel on Mumbai Nagpur Expressway "

Abhishek Sanyal
abhishek.sanyal@force-se.com
Force Structural Engineers Pvt. Ltd.
Mumbai, India

Yash Shah
yash.shah@force-se.com
Force Structural Engineers Pvt. Ltd.
Mumbai, India

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1 ABSTRACT

This paper explores the design and construction innovation for the Cut and Cover Tunnel segment within the Mumbai Nagpur Expressway project in Maharashtra, India. With a meticulous emphasis on design principles and construction techniques, the paper outlines the innovative utilization of specific backfill materials to achieve ideal soil structure interaction and cost-effectiveness. By classifying chosen backfill materials according to their characteristics and performance, the paper illustrates a systematic approach to enhance load distribution and stability while mitigating environmental impact. Through thorough analysis and innovative engineering solutions, the paper offers valuable insights into the successful implementation of the Cut and Cover Tunnel within demanding geological conditions.

2 INTRODUCTION

The Government of Maharashtra, in collaboration with its executing body, the Maharashtra State Road Development Corporation (MSRDC), oversaw the construction of the Nagpur-Mumbai Super Communication Expressway, also known as Mumbai Nagpur Expressway, which followed a Greenfield alignment.

The Mumbai Nagpur Expressway was a meticulously planned Greenfield project, encompassing a six-lane access-controlled corridor spanning 706 km between Mumbai (Thane) and Nagpur, with an estimated cost of 6 billion US Dollar. The project was segmented into 16 packages, with this paper focusing on the design aspects of viaduct 2 package no. 14. Package-14 stretched from Taranganpada-Pimpri Sadroddin village to Vashala bk. village in Maharashtra, traversing through greenfield areas. The designated length of this section was 13.100 km.

3 DESCRIPTION OF CUT AND COVER TUNNEL

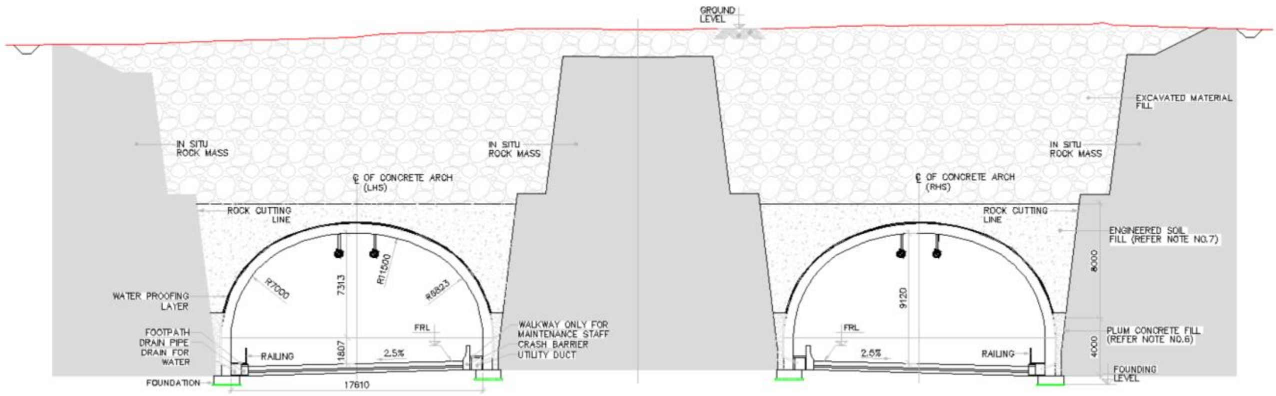
The cut and cover tunnel comprised a D-shaped concrete arch, achieved by providing three different radii to the arch. The span of the arch measured 17.61m, accommodating a clear carriageway of 16m, a 1.2m drain cum footpath, a 0.5m crash barrier, and a 0.91m drain. The rise of the arch was 10.27m, determined based on the required clear height for vehicles to travel.

The height of backfill for the cut and cover tunnel varied from 3.90m to 12.80m above the crown of the arch. The cut and cover tunnel were divided into four groups based on the amount of backfill they carried over the crown. The thickness of the arch for all groups remained constant at 675mm. Each group, comprising 60m in length, strategically placed expansion joints at intervals of 36m, followed by another expansion joint at 24m.

During the geotechnical investigation, basalt rock was encountered at a very shallow depth. With a bearing capacity of approximately 300t/m2, open foundations were utilized as footings for the cut and cover tunnel. Given the high bearing capacity of the subsoil, the traditional rectangular padded open foundation method was opted for. The overall dimensions of the open foundation were 1.80m in width and 0.6m in depth.

The tunnel fell in a hilly area, with hilly terrain consisting of basalt rock with exceptionally high bearing capacity. Consequently, no temporary structures were required to support the slope during or after excavation. Due to the high-quality rock, a very stiff slope of 1H:8V was utilized during excavation.

In the approach to backfilling, a different strategy was chosen and various backfill materials were utilized to achieve remarkable cost-effectiveness without compromising structural performance. Three different types of materials with varying filling heights were employed: plum concrete fill, engineered soil fill, and excavated soil fill.



4 BACKFILL MATERIAL

In the project, the methods and materials employed for backfilling played a critical role, particularly due to the chosen "arch" geometries for the cut and cover tunnels, significantly influencing the static performance of the structure. The backfilling material above the arch imposed a lithostatic load solely on the structure, while the lateral backfilling material (up to the arch level) acted as an integral part of the structural system, providing essential horizontal confinement for static effectiveness.

As previously noted, the lateral backfill material played a crucial role as it behaved as an integral component of the structural system. Therefore, it was imperative to enhance its performance for load distribution. To achieve this, the backfill material was categorized into three distinct categories based on their properties and behavior. This differentiation allowed for the optimization of the selection of backfill material for improved soil structure interaction and performance.

For the initial layer, extending up to 4 meters from the ground, plum concrete was chosen due to its exceptional ability to provide essential horizontal confinement. Plum concrete was specifically selected for its unique properties that made it ideal for this purpose. Its dense composition and coarse aggregate content offered significant resistance to lateral pressure, effectively confining the surrounding arch structure and increasing stability. By utilizing plum concrete in this layer, robust support was ensured for the structural system, laying a strong foundation for the subsequent backfill stages.

For the second layer, strategically positioned 8 meters above the plum concrete fill, an innovative approach was implemented by utilizing engineered soil fill. This specially formulated soil with improved properties, such as a higher angle of internal friction, increased modulus of elasticity, and elevated unit weight, was chosen. These enhancements were meticulously selected to offer substantial support in terms of horizontal confinement, contributing significantly to the soil structure interaction of the structure.

The selection of these enhanced soil properties reflected a commitment to pushing the boundaries of traditional construction methods. By integrating advanced engineering principles and materials science, a second layer was developed that went beyond conventional practices, offering unparalleled performance in terms of load distribution and stability. This innovative approach not only ensured the structural robustness of the project but also set a new standard for excellence in geotechnical engineering.

In selecting the third layer, the decision leaned towards excavated material, recognizing its limited contribution to horizontal confinement. This deliberate choice was motivated by dual objectives: minimizing environmental impact and optimizing cost-effectiveness. By utilizing locally sourced excavated material, the project aimed to reduce the carbon footprint associated with material transportation and extraction, aligning with sustainable construction practices. Furthermore, this approach resonated with a commitment to cost-efficient strategies, as it mitigated expenses linked to procuring specialized backfill materials, ultimately promoting financial prudence without compromising structural integrity.

Since the backfill material significantly influenced the effectiveness of the structure, static calculations were conducted considering not only the strength properties but also the deformability parameters of the backfilling materials. This allowed for the evaluation of the level of confinement offered by the backfilling as it was placed in subsequent layers. The geotechnical parameters of the backfilling soils were dependent on the construction method used and the level of compaction achieved. Therefore, during construction, the geotechnical hypotheses utilized were thoroughly verified.

Table. Properties of Backfill Material

Material	Unit Weight (kN/m^3)	Height of Fill (m)	Angle of Internal Friction	Modulus of Elasticity (N/mm2)
Plum Concrete	25	4	40°	27000
Engineered Soil Fill	20	8	35°	50
Excavated Soil Fill	18	Varies	30°	20

5 CONSTRUCTION STAGES

During the first construction phase, open-air excavation was conducted to reach the base levels of the foundation. Excavations were adjusted based on the geotechnical properties of the ground, primarily following slopes of 1H:8V.

Upon completing the excavation to the required levels, PCC was laid to create an even surface for the foundation. Over the PCC layer, the foundation was cast, followed by the construction of the arch. Once the arch construction was completed, a proper waterproofing system was installed along the periphery of the arch. After laying the waterproofing system, the first fill of plum concrete was laid up to 4m.

Before proceeding with the remaining backfill material, the face portal was constructed at the beginning of the tunnel to retain the backfill in the traffic direction. After completing the construction of the face portal wall, the engineered soil fill was laid in the form of 1m lifts. Before moving on to the next lift, each lift was compacted to match the assumed geotechnical properties. The same procedure was followed for laying the excavated fill.

6 ANALYSIS

For the structural analysis, the finite element model in the SOFiSTiK software was utilized. The methodology involved modelling a detailed global model specifically designed for analysis. Within this framework, beam elements depicted the arch, while shell elements simulated both the backfill material and the in-situ rock. Recognizing that tunnel-like structures fall under the category of plain strain structures, this essential categorization was carefully integrated into the model to guarantee the utmost precision and accuracy of the findings. Additionally, recognizing the significant role of the backfill material in load distribution, soil-structure interaction was duly considered in the analysis process.

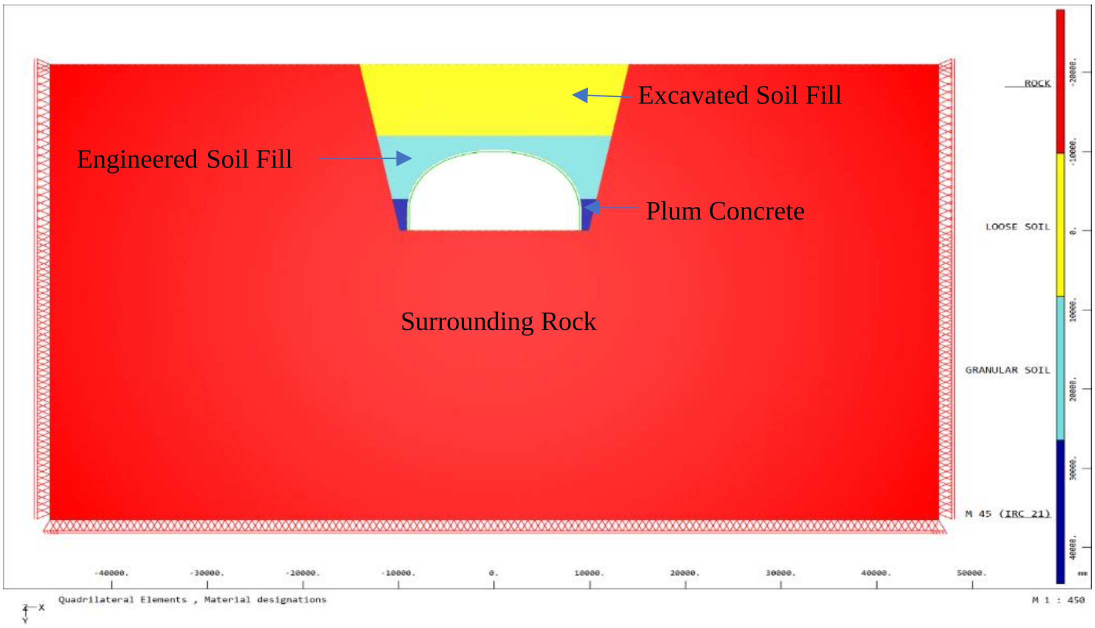


Fig. Finite element model in the SOFiSTiK software

6.1 Static Analysis

Static analysis was employed as a method to assess the behavior of the structure under constant or non-changing loads. This analysis was conducted within the software for various load cases such as SIDL, live load surcharge, and backfill load.

6.2 Construction Stage Analysis

Different phases of construction were analysed using the software. Construction stages corresponding to the construction scheme were integrated into the analysis model to ensure accurate results. These stages were modelled along with a time frame to precisely calculate creep and shrinkage effects on the structure. A typical construction stage considered included:

a. Construction of Arch
b. Laying of Plum concrete fill
c. Laying of Engineered fill in the form of 1m lift.
d. Laying of Excavated fill in the form of 1m lift.

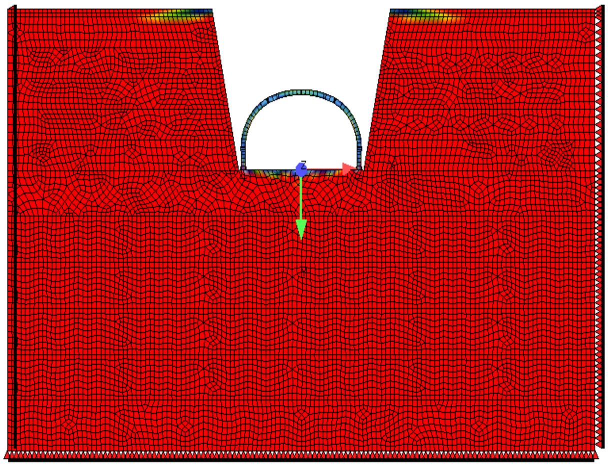


Fig. Construction of Arch

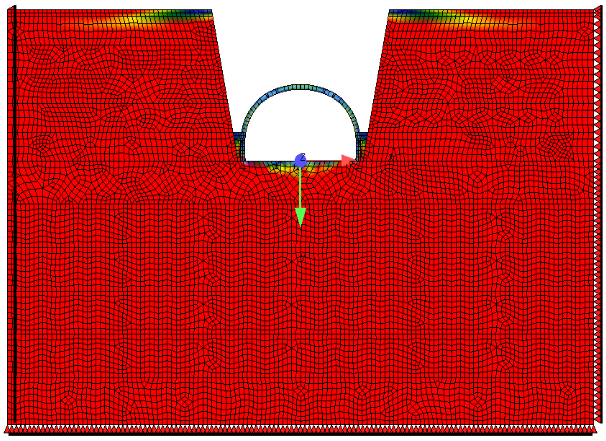


Fig. Laying of Plum concrete fill

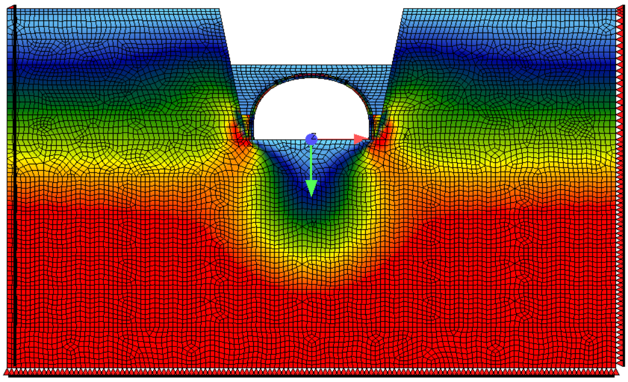


Fig. Laying of Engineered fill.

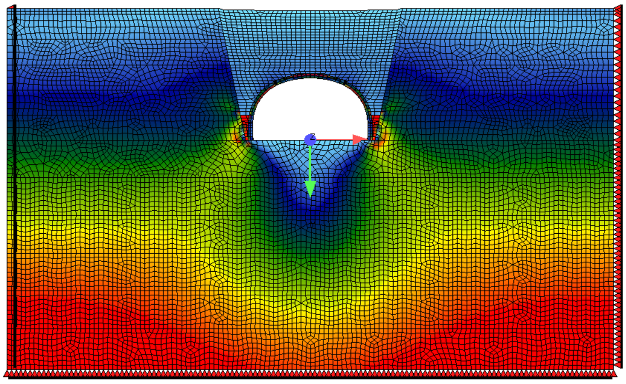


Fig. Laying of Excavated fill

6.3 Seismic Analysis

Since the structure was of the plain strain type, longitudinal seismic analysis was not considered. The seismic analysis of the cut and cover tunnel was conducted using the SOFiSTiK software. Additionally, the soil-structure interaction for seismic loads was checked, providing a comprehensive understanding of the entire structure's behavior during a seismic event.

7 STREAMLINED ARCH CONSTRUCTION: PRECISION PLANNING AND COLLABORATION

With meticulous attention to design considerations, detailed drawings, and a method statement were prepared for the construction phase. These documents played a crucial role in guiding the erection process, ensuring strict adherence to the analysis assumptions at each stage. This level of planning and documentation proved particularly vital for a complex arch structure, where precise analysis assumptions were essential for project success.

The seamless collaboration between designers and contractors facilitated the project's successful implementation. By meticulously following the provided drawings and construction plans, the erection of the structure proceeded smoothly without encountering any significant incidents. This effective coordination emphasized the importance of thorough planning and adherence to design specifications in achieving project objectives.

In line with this meticulous planning, the application of construction stage loading was strategically executed to achieve the desired results. Detailed calculations and simulations guided the application of construction loads, ensuring the equilibrium of internal forces and sustained structural stability during the erection process. This methodical approach to construction stage loading complemented the overarching emphasis on meticulous planning and adherence to design specifications, significantly contributing to the successful completion of the project.

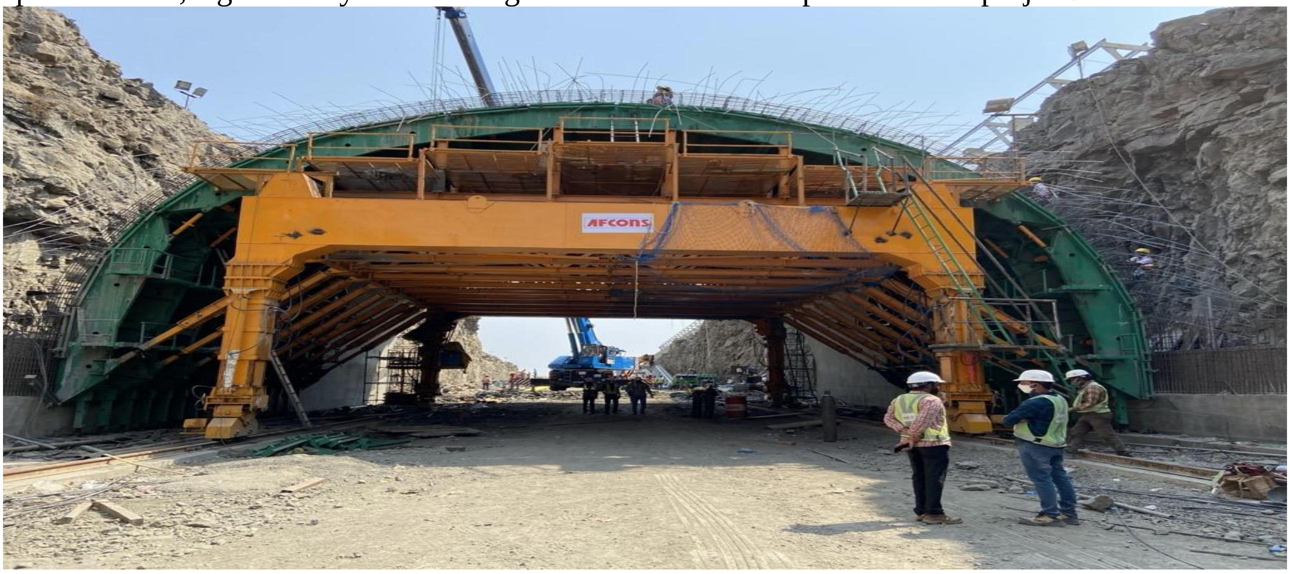


Fig. Finised pictures of Cut and Cover Tunnel

8 CONCLUSION

This paper analyses the construction strategies employed to mitigate challenges encountered during the cut-and-cover tunnel project. The primary focus was on achieving cost-effectiveness, optimizing soil-structure interaction, and minimizing environmental impact. Through meticulous geotechnical investigations, structural design optimization, and rigorous construction planning, the complexities inherent to cut-and-cover construction were successfully addressed. Furthermore, the project prioritized environmental sustainability by incorporating utilizing locally available materials whenever feasible. This approach not only reduced transportation costs and emissions but also fostered positive community relations by minimizing reliance on external resources. The successful completion of the cut-and-cover tunnel serves as a testament to the effectiveness of innovative engineering solutions in overcoming construction hurdles.