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RESEARCH ARTICLE

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# ANALYSIS OF CHAWRI BAZAR SECTION OF DELHI METRO TUNNEL

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**ABSTRACT**

Present paper deals with the analysis of the Delhi Metro Tunnels of Chawri bazar area. The design and construction of metro tunnels and their linings require the knowledge of displacements and stresses in the surrounding rocks due to excavation. With the use of Finite Element Method (FEM), the analysis of the tunnels has been done under various loading conditions for Hauz Khazi tunnel near Amar Cinema. A comparative study was made with various loading cases, in this study elastic solutions were considered. Hauz Khazi section has two tunnels of diameter 3m and center to center distances between the tunnels are 6.26 m. Study suggest that loading of a assumed surcharge and water pressure acting all along the periphery of the tunnels with assumed lining thickness was found to be critical for this section.



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# INTRODUCTION

Large diameter tunnels are commonly used for metro tunnels, they were linear underground structures in which the length was much larger than the cross sectional dimension. Settlement control and surface movement is a critical phase of any tunnel construction before commencing any construction of tunnel (Dindarloo and Siami-Irdemoosa, 2015). Principal stress orientation also have an effect on the tunnel stability (Zhu et al. 2015) Due to seepage, rise in pore water pressure causes reduction in effective stresses all-around the tunnel this poses stability problems (Hashash et al. 2015). Tunnels located below the ground water table undergone following pressures and displacement.

- Increased lateral pressure
- A loss of lateral passive resistance
- Flotation or sinking in the liquefied soil.
- Lateral displacements if the ground experiences lateral spreading.
- Permanent settlement, compression and tension failure after the dissipation of pore pressure and consolidation of the soil.
- Based on these experiences three deformation modes were considered namely, compression extension, longitudinal bending and ovalling/racking of the tunnel(Hashash et al. 2015). These deformation modes were studied through elastic analysis of Delhi Metro Tunnel by Finite Element Method (FEM) for Hauz Khazi tunnel near Amar Cinema of the Chawri bazar area station of the Delhi Metro Rail Corporation (DMRC). The tunnel stability was studied based on the deformations of the tunnel (Bhardwaj, 2001).

Geology of the Study Area: The geology of the Chawri Bazar Area and Hauz Khazi tunnel near Amar Cinema for Delhi Metro project were mainly alluvial deposits generally loose/soft, becoming medium dense to firm, clay/clayey silts. Rock heads is 5-8 m below ground level. Bedrock comprises highly weathered Quartzite (Grade III), Orthoquartzite and Schist locally reduced to a Saprolite. Recoveries generally very poor, suggesting rock to be weak and /or highly fractured. Ground water table is at 2m below ground. The characterization and mechanical properties of the bed rock were given in Table 1.

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**Table 1. Mechanical properties of Geological Materials**

| | |
|---|---|
| For Rocks | |
| Elastic Modulus of the rock ($E_{t(50)}$) | 9550 MPa |
| Poisson's Ratio (ν) | 0.20 |
| Unit weight of Rock mass(γ) | 25.55 kN/m$^3$ |
| Insitu stress ratio($K_0$) | 1 |
| For Soil | |
| Elastic Modulus of the soil ($E_{t(50)}$) | 26.62 MPa |
| Poisson's Ratio (ν) | 0.25 |
| Unit weight of soil(γ) | 25.55 kN/m$^3$ |
| Insitu stress ratio($K_0$) | 1 |
| For Concrete | |
| Elastic Modulus of the concrete ($E_{t(50)}$) | 31622.77 MPa |
| Poisson's Ratio (ν) | 0.17 |
| Unit weight of soil(γ) | 24 kN/m$^3$ |

**Geometry of the Study Area Tunnel:** The diameters of the tunnel were 3 meters (approximately) and center to center distances between the tunnels were 6.26 m. The ground water table was 2 meters below ground level. Cover above the crown level was 20 meters (approximately) as shown in [Fig 1.0].

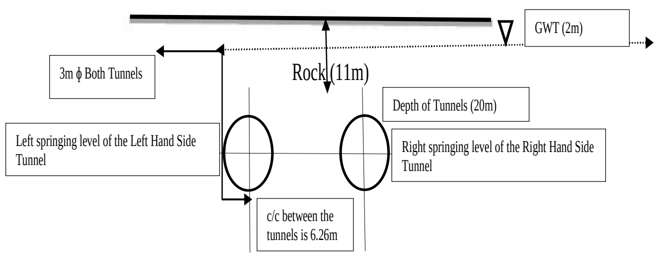


**Fig. 1 Geometry of the Hauz Khazi Tunnel near Amar Cinema (Before revision in year 2001).**

# METHODOLOGY AND ANALYSIS

The formulation of finite element method to determine the displacement and stress around underground opening have been implemented through a computer program FEMINF, which is provided by IITDelhi, in year 2001. These programs were for linear elastic analysis of underground openings. These consist of following provisions for analysis namely.

- Applied forces ( Point load, surface loads, body forces and pressure forces)
- Insitu stresses
- Simulation of sequential excavation
- Mesh change option
- Boundary conditions.

The pre-processing of the problem was done manually through plotting on a graph paper; Elements considered in this analysis were 8 noded quadrilateral elements. Post processing was done through the NISA software which was available at IITDelhi during the analysis.

**Analysis Cases: Two loading cases were considered when no surcharge was acting on the tunnel and when surcharge of 35 kN/m$^2$ were acting on the tunnel. These cases further divided into following categories:**

**Case 1(a):** Excavation of tunnel when no surcharge was acting above the tunnel.

**Case 1(b):** Excavation of tunnel takes place when lining of 300 mm is put on the tunnel and water pressure was acting all along the periphery of the tunnel. And no surcharge was acting above the tunnel.

**Case 2(a):** Excavation of tunnel when 35kN/m$^2$ surcharge was acting above the tunnel.

**Case 2(b):** Excavation of tunnel when 35kN/m$^2$ surcharge was acting above the tunnel when 300 mm lining is in place. Water pressure was acting all along the periphery of the tunnel.

The discretization scheme used for the analysis of Hauz Khazi tunnel section is using eight noded finite elements. In all 512 elements and 1607 nodes have been used. Plain strain condition has been assumed for analysis. In simulation of excavation, equivalent nodal loads due to insitu stress, were calculated along the excavation boundary and were applied in opposite direction to have stress free boundary. The displacement and stresses were calculated from the analysis. The resultant stress condition in the rock mass surrounding the tunnel was obtained by adding the insitu stress to induced stress due to excavation. [Fig 2.0]

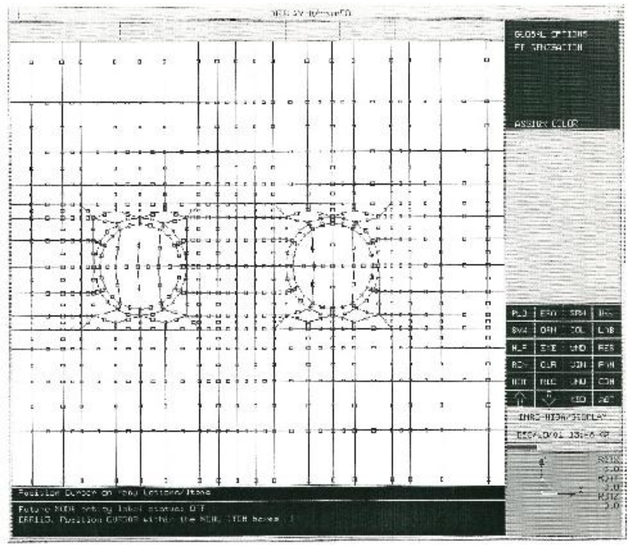

**Fig 2.0. Discretized mesh of Hauz Khazi Tunnel before excavation. (Post processing was done through NISA software).**

## RESULTS

**Case1** (a): Excavation of tunnel when no surcharge was acting above the tunnel. Displacements obtained along horizontal direction for left side of tunnel section were positive where as in case of right side of tunnel were negative displacement values. Maximum horizontal displacements for left hand side tunnel was 0.104 mm, obtained at the left springing level of the tunnel and for right hand side tunnel were 0.113 mm obtained at right springing level of the tunnel. Similarly maximum vertical displacement for left hand side and right hand side tunnel was obtained at the crown with a magnitude of 0.129 mm. The maximum major principal stress was obtained at springing level of the tunnel i.e. right springing level for the left hand side tunnel and left springing level for the right hand side tunnel. Both have the same magnitude of 1.23 MPa. Similarly the maximum minor principal stress was obtained at bottom of the both tunnels with a magnitude of 0.154 MPa.

**Case 1(b):** Excavation of tunnel takes place when lining of 300 mm is put on the tunnel and water pressure was acting all along the periphery of the tunnel. And no surcharge was acting above the tunnel.

Maximum Displacements along the horizontal direction for left hand side was obtained at left springing level of the left hand side tunnel with a magnitude of 0.122 mm and right springing level of the right hand side tunnel with a magnitude of 0.124 mm. The maximum vertical displacement for both the tunnels was occurred at the crown of the tunnel, with a same magnitude of 0.141 mm. The maximum major principal stress was obtained at right springing level of the left hand side tunnel and left springing level of right hand side tunnel and both have same magnitude of 1.31 MPa. The maximum minor principal stress was obtained at bottom of the tunnel with a magnitude of 0.0831 MPa.

**Case 2(a): Excavation of tunnel when 35kN/m$^2$ surcharge was acting above the tunnel.**

The maximum horizontal displacement for left hand side tunnel was at the left springing level of the tunnel with a magnitude of 0.102 mm and for right hand side tunnel was at the right springing level with a magnitude of 0.111 mm. The maximum vertical displacement of both the tunnel was obtained at the crown with a magnitude of 0.218 mm. The maximum major principal stress was obtained at right springing level of the left hand side tunnel and left springing level of right hand side tunnel with a magnitude of 1.32 MPa. The maximum minor principal stress was obtained at the bottom of both the tunnels with a magnitude of 0.157 MPa.

**Case 2(b): Excavation of tunnel when 35kN/m$^2$ surcharge was acting above the tunnel when 300 mm lining is in place. Water pressure was acting all along the periphery of the tunnel.**

The maximum horizontal displacement for left hand side tunnel was occur at the left springing level and right springing level of the right hand side tunnel, both having the same magnitude of 0.122 mm. The maximum vertical displacements for both the tunnels were at the crown, both having the same magnitude of 0.23 mm. The maximum major principal stress was at the right springing level of the left hand side tunnel and left springing level of the right hand side tunnel, both having the same magnitude of 1.40 MPa. The maximum minor principal stress was at the bottom of both the tunnel with a same magnitude of 0.878 MPa. [Fig.3.0 (b) and (c)]

**Conclusions and Discussion**

- In all loading cases maximum horizontal displacements were occur at the left springing level of the left hand side tunnel and right springing level of the right hand side tunnel.
- In all loading cases maximum vertical displacements were occur at the crown.
- In all loading cases maximum major principal stresses was found at the right springing level of the left hand side tunnel and left springing level of the right hand side tunnel.
- In all loading cases maximum minor principal stresses was found at the bottom of the tunnel.
- Loading case with excavation of tunnel when 35kN/m$^2$ surcharge was acting above the tunnel when 300 mm lining is in place, water pressure was acting all along the periphery of the tunnel was found to be critical.

For any single loading cases, maximum horizontal displacements for both the tunnels have same magnitude; similarly, maximum vertical displacements for both the tunnels have same magnitude. Also maximum major and minor principal stresses have same magnitude for both the tunnel

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