Kochi Chapter

Indian Geotechnical Conference
IGC 2022
15th – 17th December, 2022, Kochi

# Tunnel Lining – Soil Interaction Study Through Finite Element Modelling of Tunnels in Deltaic Belt of Kolkata

Sagarika Mallik[1] and Soumya Roy

[1] M.Tech Scholar, Department of Civil Engineering, Meghnad Saha Institute of Technology, Kolkata, West Bengal 700150
[2] Assistant Professor, Department of Civil Engineering, Meghnad Saha Institute of Technology, Kolkata, West Bengal 700150
sagarika0307@gmail.com, soumya.roy@msit.edu.in

**Abstract.** The populous city of Kolkata, located beside the River Ganges in India, lies in one of the largest deltaic regions. Underground metro tunnels are getting constructed across the city predominantly in the north-south direction. Another underground metro tunnel is being built in the east-west direction connecting the heart of the city to the railway stations and the airport. As a part of the project, twin tunnels of a diameter of 6.1 m and 15 m apart are being constructed below the most congested part of the city. The tunnels are at a depth between 17 m and 24 m below the surface. The soil layers in Kolkata essentially consist of soft clays with layers of dense sand at much greater depth. Both static and dynamic finite element analyses have been performed to estimate the settlement and response of the tunnel lining and its interaction with the surrounding soils. The results of the analyses are compared with the reported previous literature on tunnel constructions worldwide on soft soils and with the available empirical methods. The results are also verified by drawing the moment and shear capacity curves for the tunnel linings.

***Keywords:*** metro tunnels; twin tunnels; finite element analysis; tunnel lining

## 1 Introduction

The over populous city of Kolkata, located besides the river Ganges in India, lies in one the largest deltaic regions. The city is located in the boundaries of seismic zone 3 and 4 which indicates moderate to high seismic hazards according to Indian standards. The soil of the city is essentially of alluvial nature consisting of soft clays with layers of dense sand at much greater depth. The ever-moving nature of the city demands for smooth and efficient traffic flow and the underground metro tunnels are one of the most efficient solutions for the same. These underground metro tunnels are getting constructed across the city predominantly in the north-south direction. Another underground metro tunnel is being built in the east-west direction connecting the heart of the city to the railway stations and the airport. Many studies have been made to determine the effect of the east-west metro twin tunnel construction on the nearby heritage buildings and to determine the settlement of the ground surface due to the construction of the structures. This paper focuses on the tunnel lining-soil interface interaction through finite element modeling tool and the results are then compared with the previous pieces of literature reported on the same. For reference, the route of the east-west metro tunnel is shown in figure 1.

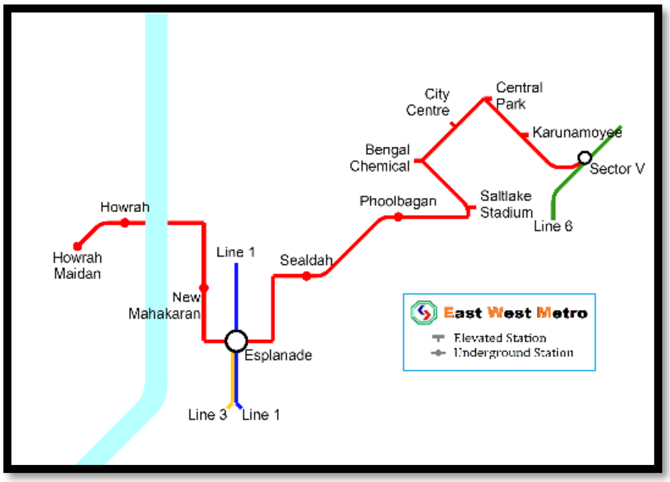



**Fig. 1.** Route of Kolkata east-west metro tunnel advancement

## 2 Subsoil Layers and Their Properties

The subsoil layers in the area of the east-west metro twin tunnel continuation in Kolkata are obtained from previous pieces of literature and borehole logs; the subsoil layer is essentially alluvial in nature having soft clay deposits and dense sand layers at much greater depth. As per recorded data the top 2 meters are majorly fill material. From 2 meters to 15.4 meters the layer is essentially silty clay or clayey silt. From 15.4meters to 19.5 meters the soil is medium silty clay. The groundwater table is present 1 meter below the ground surface during the rainy season. All of the data obtained about the subsoil characteristics are summarized in table 1 under the soil properties of each layer.

**Table 1.** soil properties.

| Soil Type | Permea-bility | Unit Wt. (kN/m3) | Undrained Strength Cu (kPa) | Cohe-sion (kPa) | Friction Angle (Deg.) | Deformation Modulus Es (kPa) |
|---|---|---|---|---|---|---|
| Fill | $5 \times 10^{-5}$ | - | - | - | - | - |
| Silty Clay | $10^{-7}$ | 18 | 31 | 1 | 25 | 18600 |
| Medium Silty Clay | $10^{-9}$ | 20 | 70 | 0 | 31 | 31500 |
| Silty Clay | $10^{-6}$ | 21 | 55 | 0 | 29 | 27500 |

The values of permeability and other parameters are taken from previous pieces of literature and recorded data, where the soil is conservatively assumed to be normally consolidated (i.e., OCR=1). The properties of the fill layer are assumed to be similar to the properties of silty clay in the second layer. Figure 2 below shows the graph for the assumption of $K_c$ on the basis of OCR.

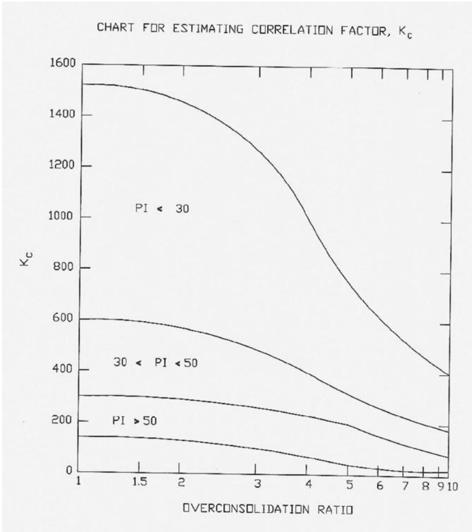



**Fig.2.** Estimation of KC on the basis of OCR and PI of soil (ref. USACE 1990)

## 3 Twin Tunnel lining and its properties

The centers of the twin tunnels are 15 meters apart from each other having 6.1 meters in diameter. The thickness of the lining is considered 350 millimeters. The deformation modulus of the concrete lining is taken as 31620000-kilo pascal and the poison's ratio is taken as 0.15; these values are obtained from previous literature and recorded data for the east-west metro twin tunnels in Kolkata.

## 4 Twin Tunnel geometry and settlement analysis

The soil interface and the tunnel geometry are constructed in Autodesk AutoCAD2021 and the geometry is then imported to GTS NX for numerical analysis.

The analysis is based on the assumption that the soil is non-linear and elastoplastic in nature and follows Mohr-Coulomb yield criteria.

The tunnels are also assumed to be impervious and elastic in nature with negligible seepage loss during construction.

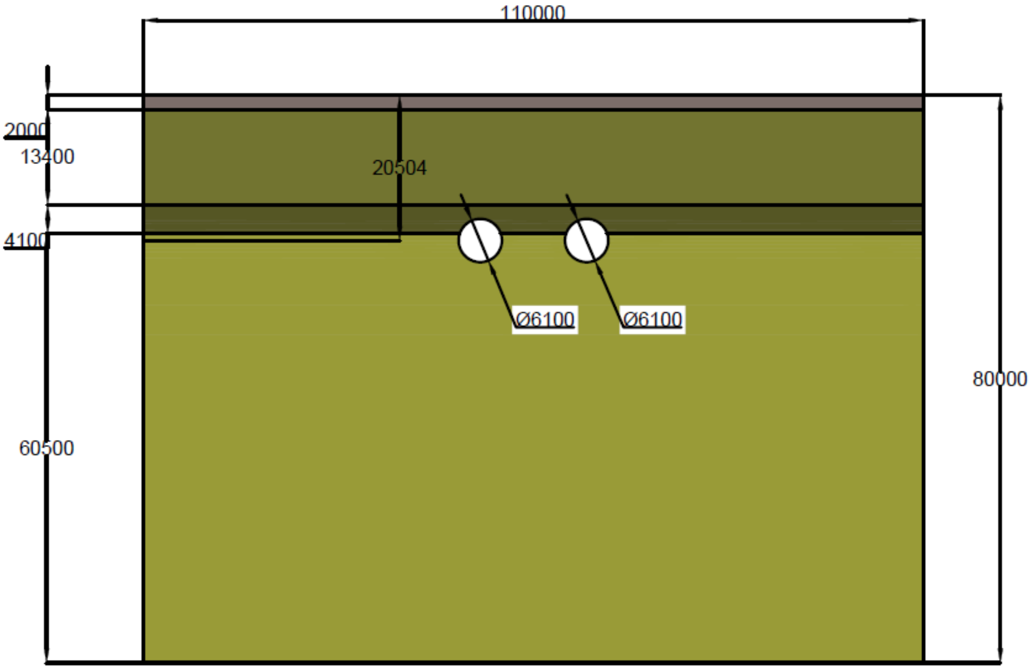



**Fig. 3.** Geometry of the soil profile and the placement of the east-west metro twin tunnels (all the dimensions provided are in millimeters)

The geometry as shown above in figure 3 assumed for the analysis extends up to 110 meters horizontally and 80 meters in depth. The top 2 meters are the fill layer, and the depths of 2 meters to 15.4 meters are of silty clay material from 15.4 meters of depth to 19.5 meters of depth the soil is medium silty clay, and below the depth of 19.5 meters, the soil is seen to be silty clay with some sand. All the dimensions mentioned in the diagram in figure 3 are in millimeters.

Settlement analysis of the twin tunnels are done in GTS NX; the settlement of the crown and the bottom part is calculated. Figure 4 shows the same geometry model redrawn in the GTS NX software and the generation of mesh for the entire system.

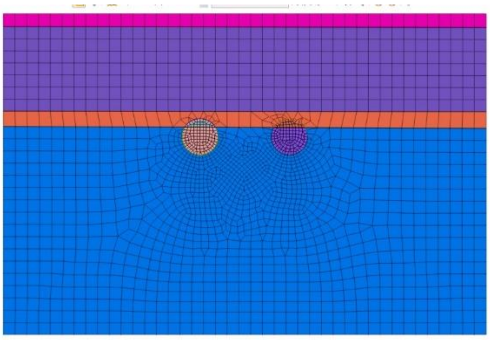


**Fig. 4.** Discretization of the ground and tunnels

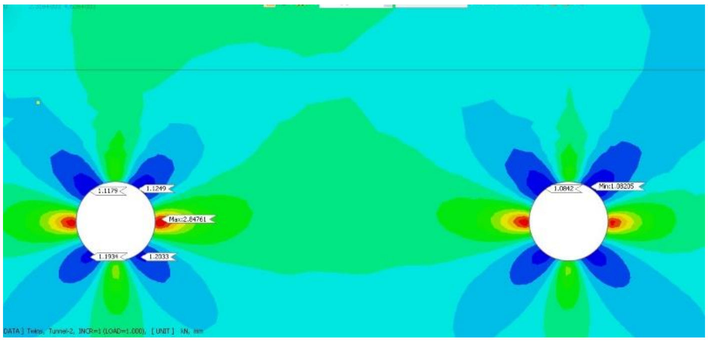



**Fig.5.** Analysis of tunnels in progress

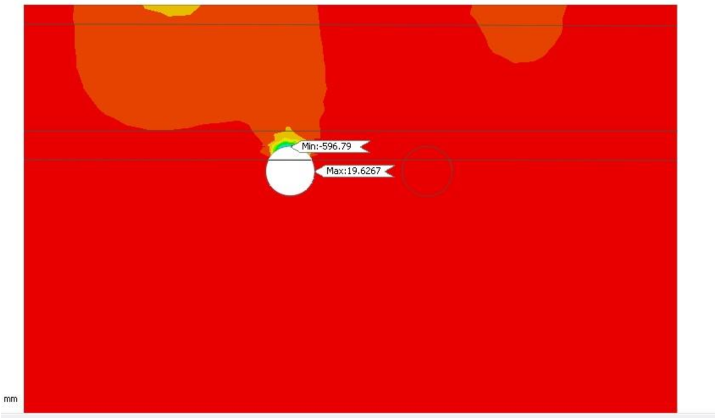



**Fig. 6.** maximum settlement achieved

Figure 5 and figure 6 show the result of analysis the east west metro twin tunnel and the maximum settlements achieved through the finite element analysis.
The maximum settlements were taken at the crown of both the tunnels and the results showed the tunnels collapse.

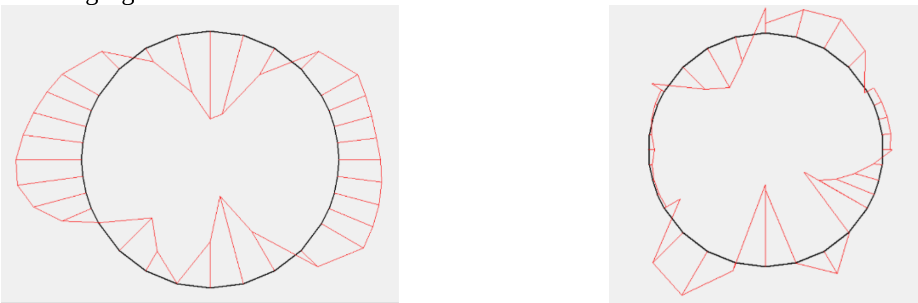
## 5 Result of analysis

The axial forces obtained by the analysis for tunnel 1 and tunnel 2 are shown in the following figures, the following images and data in figure 7 and figure 8 are obtained from the analysis of the tunnels in PLAXIS 2D.

The extreme axial force experienced by tunnel 1 is 62.58* $10^{-3}$ kN/m and that of tunnel 2 is 73.57*$10^{-3}$ kN/m.

**Fig.7.** Axial forces on tunnel 1 and tunnel 2

The bending forces obtained by the analysis for tunnel 1 and tunnel 2 are shown in the following figures



The extreme bending force experienced by tunnel 2 is 19.04* $10^{-3}$ kNm/m and the shear force of tunnel 2 is -30.18*$10^{-3}$ kN/m.

**Fig.8.** Bending forces and shear force of tunnel 2

## Conclusion

The analysis shows a huge settlement of the tunnel lining which differs drastically from the actual data and previous literature. The tunnels at the given depth and with the given soil and lining properties collapse. The settlement of the tunnels also varies with the modeling tools used.

## References


- Aniruddha Sengupta**,** Estimation of Settlement and Vibration on the Surface Due to the Construction of East-West Metro Tunnels in Kolkata, India, (July 2018)

- FHWA: Technical Manual for Design and Construction of Road Tunnels –Civil Elements,
- FHWA-NH1-10-034, U.S. Department of Transportation, Federal Highway Administration,
- Washington DC, pp. 7–20, December 2009
- Gouw, T.-L.: Tunneling Induced Ground Movement and Soil Structure Interactions. Seminar on
- Tunnel Technology in Civil Engineering, Peninsula Hotel, Jakarta, Indonesia, pp. 1–13, 22
- March 2005
- KMRC: Application for Permission for Construction Work of Mahakaran Underground Station
- and Tunnel near the Protected Monument of Currency Building along with Assessment Study
- Report. Kolkata Metro Rail Corporation, June 2015